An analysis of embodied carbon considerations in a Building Information Modelling (BIM)-enabled building design process through structuration theory

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Abstract

In recent decades there is a worldwide effort to reduce carbon emissions from buildings. However, carbon emission reduction efforts have predominantly focused on the reduction of operational carbon emissions. This has resulted in Embodied Carbon (EC) emissions to have a more significant proportion of the whole-life carbon of buildings. Despite its growing significance, tackling EC remains a challenge for the construction industry. Building Information Modelling (BIM) has been advocated to address some of the challenges in tackling EC. However, literature that considers both EC and BIM has predominantly focused on the technical aspects of EC assessment facilitation through the use of the BIM model and has failed to address the social aspects of EC inclusion in the BIM-enabled building design process. This research addresses this gap by taking a socio-technical approach to investigate how EC considerations are set and addressed in BIM-enabled building design process.

The research follows a critical realist philosophy to reveal the conditions and mechanisms that affect the inclusion of EC considerations in the design process and the potential (and barriers) of BIM to facilitate EC considerations to be communicated and addressed in a building project. The research was conducted in two phases; the first phase was exploratory and aimed to provide a rich description of the way EC considerations are set and addressed in a BIM-enabled project. The first phase informed subsequent data collection and the development of an analytical framework for the second phase of the research. The developed framework drew from theoretical concepts of Structuration Theory and phase 1 empirical findings and was used in the second phase of the research to analyse the conditions and mechanisms that affect EC-target setting and the use of BIM for communicating and addressing EC considerations. The second phase of the research also investigated the impact of context through cross-case comparison analysis.

The main findings of the research highlighted the importance of people in setting and addressing EC in BIM-enabled projects. The clients were found to be either a barrier or an enabler for EC consideration inclusions depending on their aspirations. Whereas, the importance of the professional team to act as middle agents to tackle EC was highlighted. Tackling EC was found to relate to position-practice relations, a mechanism that was expressed either through the introduction of new expert roles or the expansion of the role of principal design team members. Industry as well as project-level conditions and their impact on the capabilities of professionals for setting and addressing EC considerations were considered in relation to the dialectic of control mechanism. The dependence of the professionals on industry-wide conditions was found to be higher when they had a low dialectic of control over project-level resources, particularly when professionals were novice to incorporating EC considerations to the building design. The EC information management requirement through BIM was found to relate to the dialectic of control of the professional performing the EC calculations over the BIM model data input. Informed by the research findings, two pathways to facilitate EC considerations in BIM-enabled projects were proposed. The pathways considered the enabling conditions and the position-practice and dialectic of control mechanisms for two BIM-enabled project outcomes: *How EC considerations are set and communicated* and *How EC considerations are addressed*. For *How EC considerations are set and communicated* the pathways relate to the project stakeholder who drives EC considerations for the project and can be either client or design team driven. For *How EC considerations are addressed* the pathways relate to the way that required professional skills are brought to the project, which can be either through the appointment of consultants or through the principal design team professionals.

This study extends the use of Structuration Theory through the integration of two of its basic concepts into one analytical framework and expands its operationalisation through the use of social network mapping to visualise the framework elements. The empirical contributions stem from the socio-technical approach of the thesis that revealed position-practices and dialectic of control as mechanisms that affect setting and addressing EC considerations in BIM-enabled projects. The research provided novel insights into the interplay of these mechanisms with power relations between the client and the design team, as well as their relation to industry and project-level structures.

Further research recommendations were based on the research findings that indicated that further exploration is required on aspects such as the impact of EC reduction on the capital cost of projects, project contracts with a focus on the stage of novation, EC optimisation incorporation to project design stage timetables. Further research recommendations also related to the newly revealed relations of dialectic of control to industry and project-level structures which could be used as hypotheses in subsequent qualitative and quantitative research.

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List of Acronyms and Abbreviations

AECOM	Architecture Engineering Construction and Management
ARCH	Architect
BEP	BIM Execution Plan
BIM	Building Information Modelling
BREEAM	Building Research Establishment Environmental Assessment Method
BS	British Standards
BSI	British Standards Institute
CAD	Computer Aided/Assisted Design
CADQAS	Computer-aided Qualitative Data Analysis Software
CCC	Committee on Climate Change
CDE	Common Data Environment
CIC	Construction Industry Council
CMO	Condition Mechanism Outcome
CO_2	Carbon Dioxide
CO_2e	CO_2 equivalent
COBie	Construction Operations Building information exchange
CR	Critical Realism
CS	Case study
DTM	Design Team Meeting
EC	Embodied Carbon
ECC	Embodied Carbon Coefficient
EIR	Employer's Information Requirements
EPC	Energy Performance Certificate
EPD	Environmental Product Declarations
GG	Green Guide
GHG	Greenhouse Gas
GWP	Global Warming Potential
ICE	Inventory of Carbon Energy
IFC	Industry Foundation Classes
IHP	Innovative Housing Programme
IS	Information System
ISO	International Organisation for Standardisation
ISTRUCTE	Institute of Structural Engineers
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LEED	Leadership in Energy and Environmental Design
LETI	London Energy Transformation Initiative
LOD	Level of Detail
MEP	Mechanical Electrical and Plumbing engineers
MPDT	Model Production and Delivery Table
NBS	National Building Specification
OC	Operational Carbon
PAS	Publicly Available Specification

PCSA	Pre-Construction Services Agreement
PoW	Plan of Work
PTM	Progress Team Meeting
QS	Quantity Surveyor
RIBA	Royal Institute of British Architects
RICS	Royal Institute of Chartered Surveyors
SAP	Standard Assessment Procedure
SME	Small Medium Enterprise
SNA	Social Network Analysis
SNM	Social Network Map
ST	Structuration theory
STR	Structural engineers
STS	Socio-technical Systems
STST	Socio-technical Systems Theory
UK	United Kingdom
UKGBC	UK Green Building Council
WFGA	Well-being of Future Generation
WGBC	World Green Building Council

List of publications

Banteli, A., Stevenson, E., Patel, H. 2020. Embodied energy considerations in a BIM-enabled building design process: an ethnographic case study. *ARCOM 36th Annual Conference.* Virtual, 7-8 September 2020. Published in: Scott, L. and Neilson, C.J. eds. Proceedings of the 36th Annual ARCOM Conference. Leeds, U.K.: ARCOM, pp. 376-385. Available at: https://arcom.ac.uk/-docs/archive/2020-Indexed-Papers.pdf. Accessed: 15 May 2023.

Banteli, Amalia, Stevenson, V., Zapata-Lancaster, G. 2018. Building Information Modelling (BIM) application in relation to embodied energy and carbon (EEC) considerations during design: A practitioner perspective. *Second International Conference for Sustainable Design of the Built Environment: Research in Practice.* London, UK, 12-13 September 2018. Published in: Elsharkawy, H., Zahiri, S. and Clough, J. eds. International Conference for Sustainable Design of the Built Environment SDBE 2018: Proceedings. pp. Available at: https://orca.cardiff.ac.uk/id/eprint/115088/. Accessed: 15 May 2023

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Chapter 1 Introduction

1.1 Introduction

This chapter presents the background of the thesis with an aim to position the research in the topic area and justify the purpose of the thesis. It outlines the research aims and objectives and provides information on the focus, scope and structure of the research. The thesis structure is presented at the end of this chapter along with the thesis phases and objectives.

1.2 Background

In recent years there is a worldwide effort to reduce carbon emissions. As buildings significantly contribute to carbon emissions, regulations are enforcing the reduction of carbon emissions from buildings. The building industry, in order to meet these targets, has included energy efficiency and carbon emission reduction in their building design aspirations. Carbon in buildings can be categorised as either operational or embodied carbon; the former relates to energy consumed during the building use and the latter to energy associated to the building construction (Yohanis and Norton 2006).

Operational Carbon (OC) reduction has been the main focus of the building industry as (historically) it accounted for a greater proportion of carbon emissions throughout the building life and is easier to predict than embodied energy. However, as buildings become more energy efficient and their operational carbon is reduced, Embodied Carbon (EC) has a more significant proportion of the whole-life carbon of buildings (Capper et al. 2012).To address this, decisions made during the design stage are crucial as they determine a significant portion of a building’s life-cycle impacts and can’t be amended later in the life of a building (Basbagill et al. 2013). However, in the United Kingdom (UK) there is no legislation in place relating to embodied carbon in buildings and at the outset of this research there was lack of relevant guidance to the industry (Iddon and Firth 2013). The lack of legislation and relevant guidance have been stated as barriers to the inclusion of EC considerations as part of the carbon reduction efforts of the building sector (Oluwole Akadiri and Olaniran Fadiya 2013). Although guidance has become available during the course of this research, EC has mostly been addressed in literature as a technical problem, with studies focusing on estimation methodologies, databases and tools (Azari and Abbasabadi 2018) and EC remains a low or non-existent consideration in the construction sector (Orr et al. 2019). Another important barrier to EC inclusion to building design is the UK construction industry fragmentation and silo working (Egan 1998; Farmer 2016) that hinders the spreading of good and collaborative practices required to tackle EC in buildings.

Building Information Modelling has been advocated as a process tool that enhances collaboration through information management and enables information to be collated into one single digital model accessible to all professionals throughout the building life cycle (Succar 2009; Isikdag and Underwood 2010; Eastman 2011; Singh et al. 2011). As such, BIM has been considered to have the potential to facilitate EC information management amongst the design team and EC calculations through the use of the BIM model (Capper et al. 2012; Ariyaratne and Moncaster 2014; Bueno and Fabricio 2018). This research started in 2015, when BIM was about to be mandated by the UK government in 2016 for all centrally procured public projects as an effort to enhance BIM uptake and with an aim to drive sustainability and improve the efficiency of the construction sector (HM Government 2012). Since this mandate in 2016 and during the course of this research, BIM has been increasingly adopted by the UK construction industry and has become part of the work practice across the industry (NBS 2020).

Literature relating to both EC and BIM has predominantly focused on the technical aspects of EC assessment facilitation through the use of the BIM model (as is presented in detail in Chapter 2). However, tackling EC in a BIM-enabled building design does not only relate to EC assessment but the entire design development, which is a social process. As such, a socio-technical approach is required to investigate the way EC considerations are integrated in BIM-enabled building design. To reveal the actual potential of BIM to facilitate EC information management and EC assessment, an understanding of how EC considerations are set and addressed in BIM-enabled building projects by professionals in practice is required.

Considering all the above, this work aimed to address this gap by adopting a socio-technical perspective to investigate how EC considerations are set and addressed in BIM-enabled building design process. The work focused on UK-based practice to analyse the conditions and mechanisms that affect the inclusion of EC considerations in the design process and the potential (and barriers) of BIM to facilitate EC considerations to be communicated and addressed in a building project.

1.3 Research overview

1.3.1 Research aim and objectives

The overarching question of this research is: *How are Embodied Carbon (EC) considerations set and addressed in a Building Information Modelling (BIM)-enabled building design process?*

This research aims to investigate EC target setting in building design and the factors that influence EC to be included as a design consideration in BIM-enabled new building projects. To achieve this overarching aim the following objectives have been set:

1. Explore how EC considerations are set and addressed in a BIM-enabled project
2. Analyse the conditions and mechanisms that affect EC target setting and their communication through BIM
3. Analyse the conditions and mechanisms that affect BIM use for addressing EC considerations
4. Analyse the impact of context on setting and addressing EC considerations in a BIM-enabled project
5. Propose recommendations to facilitate EC considerations in a BIM-enabled project

1.3.2 Research focus and scope

This research focuses on embodied carbon, its inclusion to the building design process, and how EC considerations are communicated and addressed through BIM application. It looks at practice in order to investigate the implementation of EC considerations in a BIM-enabled building design, and to analyse the conditions and mechanisms that influence EC inclusion to design considerations and how they are communicated and addressed through BIM. This research focuses on the UK context, as such the UK forms the geographical boundary of the research. As the aim is to investigate the implementation of EC considerations in a BIM-enabled building design process, the research considers the design stage of new building projects.

1.3.3 Research structure

The research was conducted in two phases; Phase 1 was an exploratory phase that included Industry perspective interviews and an Exploratory Case study. This phase aimed to explore how EC considerations are set and addressed in a BIM-enabled building design process and corresponds to objective 1. Phase 1 findings were used to inform subsequent data collection and the development of an analytical framework for Phase 2. Phase 2 was an explanatory phase during which an analytical framework was developed for the analysis of three case studies. The analytical framework was both theoretically and empirically informed as it drew from main concepts of structuration theory and the Phase 1 findings. Phase 2 included the analysis of three case studies using the developed analytical framework. Phase 2 also included a cross-case comparison to analyse the impact of context on EC target-setting and assessment in BIM-enable projects with an aim to propose recommendations to facilitate the inclusion of EC considerations in BIM-enabled projects. Phase 2 corresponds to objectives 2-5.

1.4 Thesis structure

The thesis is structured into nine chapters; Figure 1.1 presents the chapter structure of the thesis along with the thesis phases and objectives. A brief description of each chapter is included below:

Chapter 1: Provides the background and context of the research. It presents the research aim and objectives and how the thesis is structured in relation to chapters and corresponding research phases and objectives.

Chapter 2: Presents literature that relates to the topic to identify the research gap and the approach of the thesis to address the identified gap. The chapter gives an overview of the building design process, Building Information Modelling (BIM) and Embodied Carbon (EC) and then reviews literature that considered the use of BIM in addressing EC considerations. Finally, BIM and EC literature adopting a socio-technical approach is discussed. The identified research gaps are presented in the conclusion of the chapter.

Chapter 3: Outlines the research philosophy and approaches adopted by the thesis along with the research methods applied to address the research aim and objectives. Following the establishment of the theoretical background of the thesis, the research design is described in detail highlighting the approaches used for data collection and analysis and the data collected during each phase of the thesis.

Chapter 4: Presents the results and analysis from the Phase 1 data collection. Phase 1 included Industry perspective interviews and an Exploratory Case study for which data collection included meeting observation, interviews with key project stakeholders and project document analysis. The data collected in Phase 1 were analysed, and informed data collection and analysis of Phase 2.

Chapter 5: Presents the Phase 2 analytical framework development. It starts with an overview of socio-technical systems and the identification of the most appropriate theory to inform the framework for Phase 2 analyses. The chapter continues with an overview of Structuration Theory analytical concepts and how these were used alongside Phase 1 findings for the development of the Phase 2 analytical framework.

Chapter 6: Presents the results and analysis from the Phase 2 data collection. Phase 2 included the theoretical re-description of Case study 1 (Exploratory case study used in Phase 1) through the use of the Phase 2 analytical framework and data collection and analysis for two additional case studies: Case study 2 and Case study 3.

Chapter 7: Presents a cross-case comparison analysis of the three case studies considered in Phase 2. The cross-case comparison includes the identification of contextual similarities and differences amongst the three cases and an analysis of the impact of context on outcomes that relate to how EC considerations are set and addressed in a BIM-enabled design process. This analysis provides deeper explanatory accounts of the conditions and mechanisms that affect EC considerations in BIM-enabled projects and led to the proposal of two pathways to facilitate EC consideration inclusion in BIM-enabled projects. These pathways are presented in this chapter.

Chapter 8: This chapter discusses the main findings of this research and considers how they relate to relevant literature. This discussion reveals the thesis contribution to the body of knowledge. The chapter concludes with a presentation of the theoretical, methodological, and empirical contributions of this research.

Chapter 9: Presents a summary of the conducted research to address the research objectives and ultimately respond to the main research question. The chapter also presents a summary of the thesis contributions and their implications. Limitations of the research and further research recommendations are also included in this chapter.

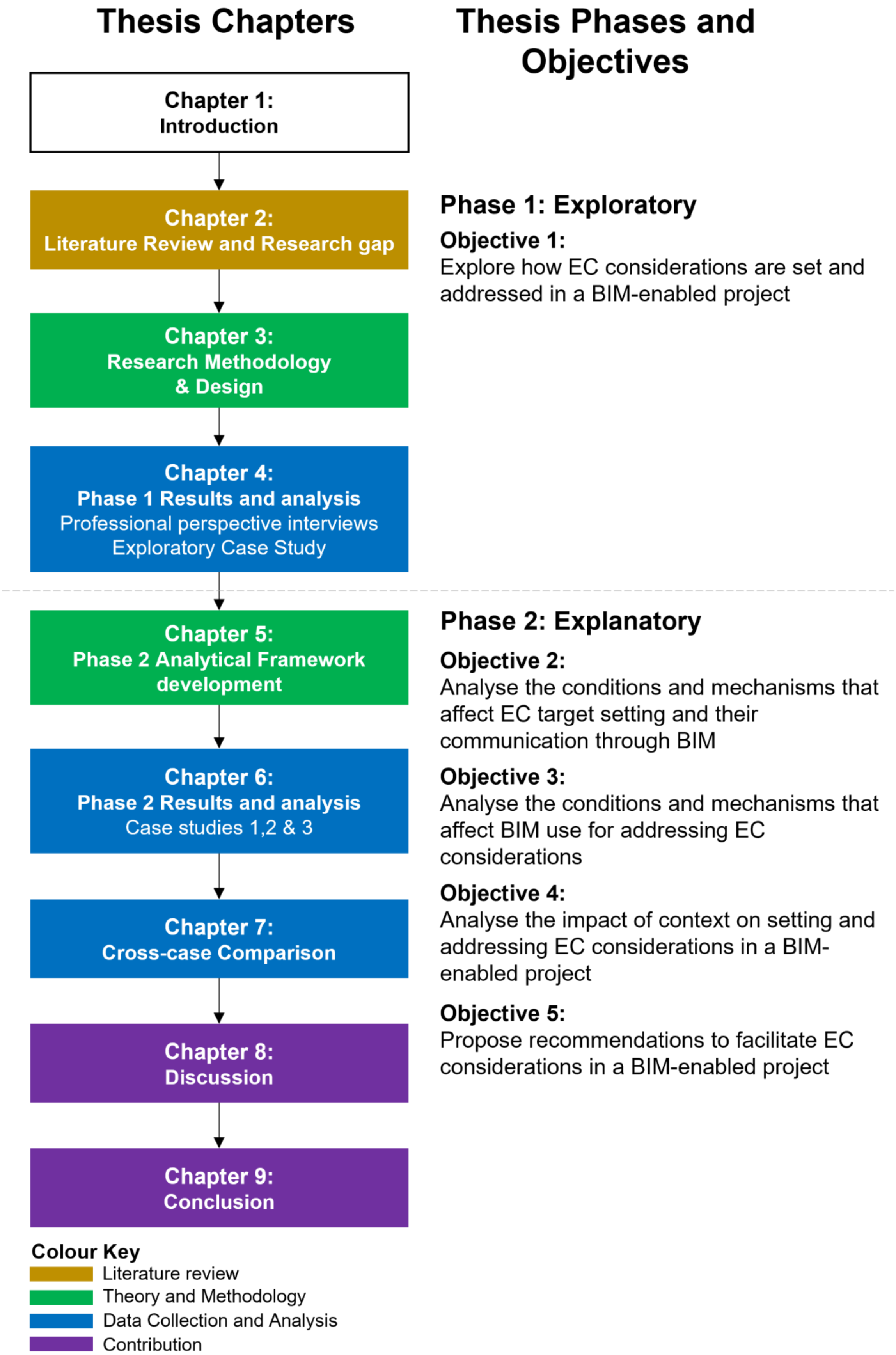

Figure 1.1 Thesis chapter structure and corresponding research phases and objectives

Chapter 2 BIM and Embodied Carbon in building design

2.1 Introduction

This chapter reviews relevant literature in order to identify the research gap and the investigation approach. It starts with an overview of the building design process, Building Information Modelling (BIM) and Embodied Carbon (EC) and then reviews literature that considered the use of BIM in addressing EC considerations. Finally, BIM and EC literature adopting a socio-technical approach is discussed. The identified research gaps are presented in the conclusion of the chapter.

2.2 Building design process overview

This research aims to analyse how Embodied Carbon (EC) considerations are set and addressed in a Building Information Modelling (BIM)-enabled building design process and considers the social aspects that affect EC inclusion and the use of BIM to address them. As such, an overview of the building design process is presented where the social aspects of building design are considered. The design process management within the geographical context of the research (UK) is also presented as the design stages defined by it are used in the thesis for the analysis of the design process.

2.2.1 Design as a social process

Building design has been defined by Hassan (1996) as:

'a process which maps an explicit set of Client's and end user's requirements to produce, based on knowledge and experience, a set of documents that describe and justify a project which would satisfy these requirements plus other statutory and implicit requirements imposed by the domain and/or the environment'.

The definition shows the situatedness of building design and the influence of contextual factors on the design process and its outcomes. According to Laseau (2001), architectural practice refers to an organisational design process that consists of defined steps: (i) building programme, (ii) schematic design, (iii) preliminary design, (iv) design development, (v) contract documents, (vi) drawings, and (vii) construction. Within each step, Laseau (2001) described a linear process of problem definition, developing alternatives, evaluation, selection and communication. This linear process however does not capture the iterative nature of design that includes framing and reframing of problem interpretations by designers (Schön 1984). Building design development however does not only include designers; the building design process includes various professionals, including architects, engineers and specialists that each contribute through their respective expertise and skills during each design stage. As such, design has been considered as a complex social process that necessitates the notion of teamwork (Alexiou and Zamenopoulos 2008). For the efficient interdisciplinary teamwork, coordination amongst the different professionals is required through a design process structure (Peng 1999). This can facilitate the required information flows during the respective design stages which is crucial for effective design process management (Newton 1995; Hassan 1996; Zanni et al. 2017).

2.2.2 Design process management in the UK

In the UK, the Royal Institute of British Architects (RIBA) provides a standard for building design management, the ‘RIBA Plan of Work (PoW)’, which divides the design process into stages. It was first published in 1964 as a matrix that defined professional roles during the design and construction process. The PoW had a major review in 2013 which aimed to address the increasing complexity of building projects by considering multiple procurement routes and acknowledging multi-disciplinarity in design teams (RIBA 2013). Other RIBA publications became available as supplements to the 2013 Plan of Work, such as the BIM Overlay and the Green Overlay to the RIBA PoW (RIBA 2011,2012). In 2020, the latest version of the RIBA PoW highlights the requirement of focusing sustainable project outcomes from the outset of the project (RIBA 2020). This version also provides improved guidance on information requirements at each design stage. As the case studies considered started their design stage based on the 2013 version, this version has been considered throughout this thesis when referring to project stages. However, the design stages considered by the two versions are very similar, with very small naming alterations between the two versions. Table 2.1 presents the two latest versions of the RIBA plan of work and core design aspects considered by each version.

Table 2.1 RIBA Plan of Works versions 2013 and 2020.

	RIBA Plan of Work 2013	RIBA Plan of Work 2020
Design Stages	0: Strategic Definition 1: Preparation and Brief 2: Concept Design 3: Developed Design 4: Technical Design 5: Construction 6: Handover and Close Out 7: In Use	0: Strategic Definition 1: Preparation and Brief 2: Concept Design 3: Spatial Coordination 4: Technical Design 5: Manufacturing and Construction 6: Handover 7: Use
Stage Outcome	n/a	Considered at the end of each stage
Core Objectives	Of each design stage	Replaced by ‘Core tasks’ during each stage
Procurement	• Traditional • Design & Build 1 Stage • Design & Build 2 Stage • Management Contract • Contractor-led • ‘To be determined’ option where the programme and (town) planning strategies are agreed but further flexibility is required in terms of procurement.	• Traditional • Design & Build 1 Stage • Design & Build 2 Stage • Management Contract • Construction Management • Contractor-led
Sustainability	Sustainability checkpoints included for each design stage	Detailed tasks outlined in Sustainability Strategy
Information Exchanges	Considered at the end of each stage	Considered at the end of each stage

2.3 Building Information Modelling (BIM) overview

As this research considers the use of BIM as an information management and software tool for tackling embodied carbon in building projects, a BIM overview is included that aims to create an understanding of the shift from traditional drafting to modelling and the way BIM is defined in this thesis. The standards and governance of BIM in the geographical context of this research (UK) is presented and the benefits and challenges of BIM adoption are discussed.

2.3.1 From traditional drafting to modelling

Traditionally, building design has been illustrated have been hand drawn and paper-based through the use of instruments such as pen, T-square, drawing board, paper, and irregular curves (Henderson 1994). Technological innovation contributed to the evolution of building design and representation from paper based to Computer Aided Drafting/ Design (CAD). At the early stages of CAD adoption, CAD was primarily focused on two-dimensional (2D) representation of building geometry (Choi et al. 1984). In the 1990s 2D CAD was widely adopted across the construction industry and within the following decade advances in the CAD system enabled the representation of building designs in three-dimensional (3D) CAD models (Sackey 2014). Further developments incorporated the parametric representation of graphical and non-graphical data through 3D object-oriented CAD which enabled the embeddedness of information within the 3D CAD models. As such the building representation through CAD evolved from an abstract graphical representation to an embedded database of information and relationships which presents a paradigm shift for the construction industry (Denzer and Hedges 2008).

BIM as a concept was first introduced by Eastman (1975) with the term ‘Building Description System’ (BDS) in a study that presented the main principles underpinning the digital and parametric representation of buildings and their elements. The term ‘Building Information Model’ appeared in 1992 by van Nederveen and Tolman (1992). Since the emergence of the term, various definitions of BIM have emerged, with a shift of the term to ‘Building Information Modelling’, that present BIM as a process rather than an object (Azhar 2011; Sacks et al. 2018).

2.3.2 BIM Definitions

The United States (US) National BIM Standards define BIM as:

> *'A digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its lifecycle, from earliest conception to demolition'* (NBIMS 2007).

In the UK, the UK Government has defined BIM as:

> *'A collaborative way of working, underpinned by the digital technologies which unlock more efficient methods of designing, creating and maintaining our assets. BIM embeds key product and asset data and a three-dimensional computer model that can be used for effective management of information throughout a project lifecycle – from earliest concept through to operation'* (HM Government 2012)

The application of BIM involves not only the utilization of technology and a BIM model, but also brings about a change in procedures within the construction industry by enabling the management of data throughout the entire project life cycle (Succar 2009; Shrivastava and Chini 2012). As such, BIM is multifaceted and involves technology and processes that are used and enacted by various stakeholders engaged in the development of buildings. Various authors have considered the fields that BIM incorporates as: people, process and technology/ tools (Rekola et al. 2010; Chen and Luo 2014) whereas others considered policy, process and technology, and incorporated 'people' as part of the 'process' field (Succar 2009; Succar et al. 2012; Succar and Kassem 2015).

This research defines BIM as a collaborative way of working with enhanced information management throughout the building life cycle that promotes a holistic view of the project's objectives. However, there can be different levels of BIM adoption, which reflect the dimensions and the level of collaboration that are aimed for a construction project.

BIM Maturity levels

To provide clearer definition for the extent to which BIM can be adopted, BIM maturity levels were introduced by Bew and Richards in 2008 through a BIM maturity diagram. This was adopted by the UK Government as the main definition for co-ordinated graphical and non-graphical project information (Richards 2010). The BIM maturity levels refer to the level of Computer Aided Design (CAD) use and collaboration through the use of BIM. According to the Bew-Richards maturity model, there are four levels that are associated with relevant tools used for information delivery:

- Level 0 Unmanaged process with 2D CAD with no collaboration using paper-based tools.
- Level 1 Managed CAD with increased spatial coordination that may include 2D and 3D information. Level 1 is often described as 'Lonely BIM' as models are not shared between project team members and collaboration is file based.
- Level 2 is distinguished by a 3D managed BIM environment where project team models are federated through the use of a Common library management, or else a Common Data Environment (CDE).
- Level 3 aims for fully integrated and interoperable data in a single, shared project model.

The different levels of BIM are also aligned with dimensions which have evolved from the differentiation of modelling geometry in two or three dimensions to the embeddedness of different information in the BIM model. Past the third dimension (3D), the fourth dimension (4D) refers to the incorporation of scheduling information to model construction sequences, the fifth dimension (5D) to the incorporation of cost information, the sixth dimension (6D) to facility management information, the seventh dimension (7D) to sustainability information and the eighth dimension (8D) to health and safety information (Hamil 2021). The BIM levels along with the associated tools and dimensions are presented in Figure 2.1. As this research analyses EC information management through BIM and the use of the BIM model in addressing EC considerations, the BIM levels are used in the thesis to refer to the BIM-level maturity of the case studies considered. The also reflects on the BIM maturity level implications on the use of BIM to tackle EC considerations.

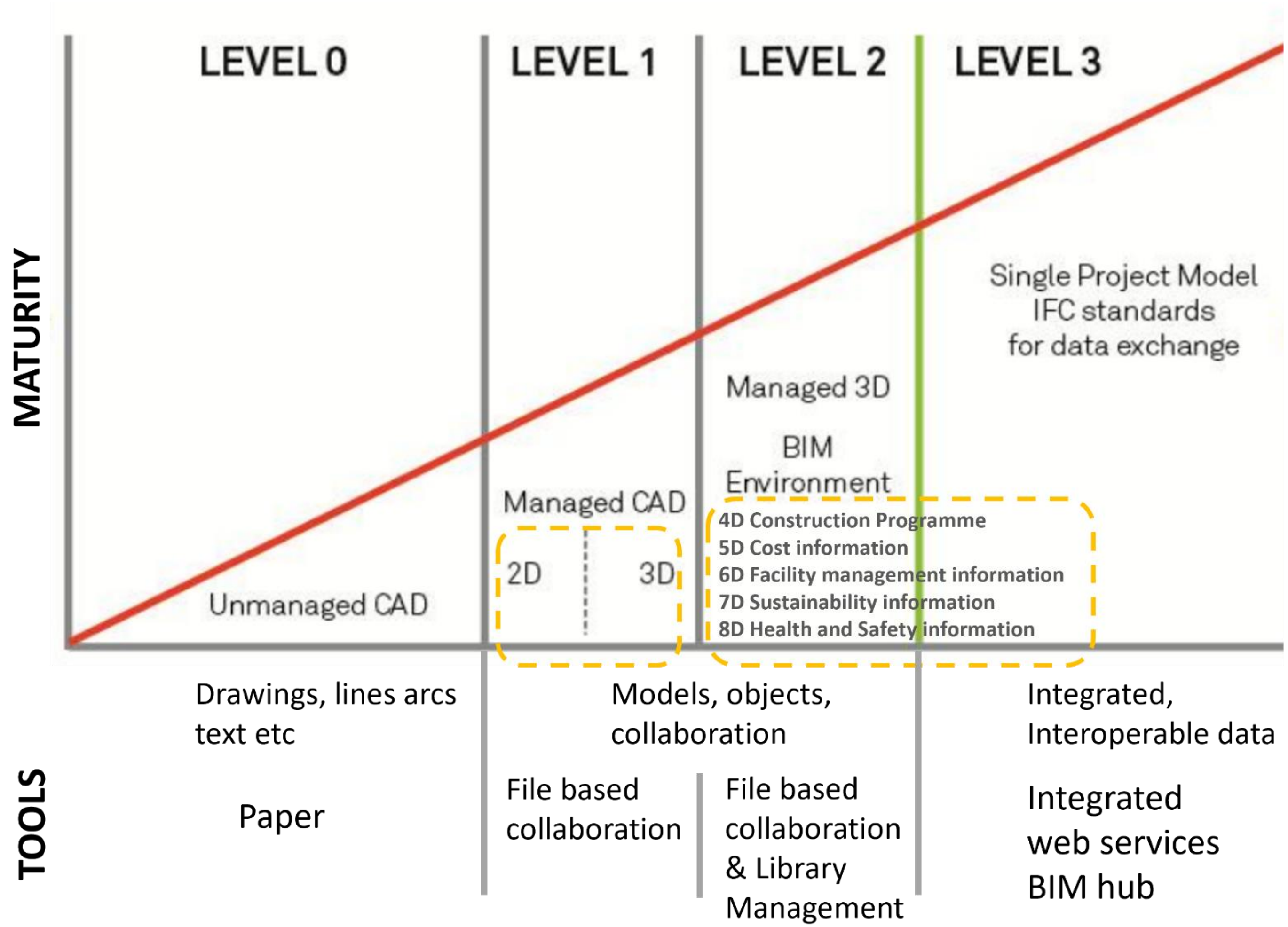

Figure 2.1 Bew-Richards maturity levels with associated tools and dimensions at each level.

Recently in the UK the National Building Specification (NBS) BIM report 2020 mentions that the term ‘BIM level 2’ is too vague and fails to establish the information requirements in a precise manner. The UK BIM Framework has now replaced the BIM Level 2 term (NBS 2020). This new development emerged as this thesis was being developed. However, “BIM Level 2” was the term that was in effect when data collection took place for this research. As such, this thesis uses the maturity levels as established by Bew and Richards where BIM level 2 refers to collaborative working through BIM.

BIM adoption in the UK

In 2016, the UK Government mandated the implementation of 3D collaborative BIM (BIM Level 2) for all public sector projects (HM Government 2012). Since the government mandate, BIM has been increasingly adopted by the UK construction industry.

The National Building Specification (NBS) has run annual BIM surveys from 2011 until 2020, the results of which have been published in annual reports that presented the level of adoption of BIM by the UK industry. In the first annual BIM report in 2011, 43% of respondents were not aware of BIM and only 13% had adopted BIM in their practice. These figures changed dramatically throughout the last decade, with the 2020 report showing 73% of the industry now using BIM level 2 as part of their work practice (NBS 2020). The report also found that the level of adoption is reduced for small practices who find BIM unsuitable for the type of projects that they work on, which tend to be small. Although the level of BIM use has greatly increased in the last decade, the level of maturity of BIM in practice still ranges from just working with 3D parametric models to fully collaborative working (NBS 2020). To provide guidance and standardisation towards a more mature BIM adoption, the UK has made standards and protocol documents available to the UK industry.

2.3.3 BIM standards and governance in the UK context

In the UK, the UK BIM framework establishes the approach for BIM implementation in the UK and provides standards for information management through BIM. Since 2019, the UK has adopted International Organisation for Standardisation (ISO) 19650 standards series for BIM, which includes (BSI 2023; UK BIM Framework 2023):

- ISO 19650-1 - Outlines the concepts and principles and provides recommendations on how to manage building and asset information.
- ISO 19650-2 - Provides information management requirements in the delivery phase of assets.
- ISO 19650-3 - Provides information management requirements for the operational phase of the assets.
- ISO 19650-4 - Complements Parts 1, 2, 3 and 5 by setting out an explicit process, with criteria, for individual information exchanges.
- ISO 19650-5 - Provides requirements for the security-minded management of sensitive information within building information modelling (BIM).

Further to these standards, there are two additional Publicly Available Specification (PAS) and British Standards (BS) documents available in the UK that relate to the implementation of BIM (BSI 2023; UK BIM Framework 2023):

- PAS 1192-6 - Specifies requirements for the collaborative sharing of structured health and safety information throughout the project and asset life cycles.
- BS 8536 – Promotes the smooth delivery and operation of built assets throughout their lifecycle by maximizing the value that can be derived from information and data.

The Construction Industry Council (CIC) has developed documents that aim to support the BIM governance of projects. The Construction Industry Council (CIC) has created a Scope of Services Handbook which identifies the services needed for a project and assigns generic roles to provide them (CIC 2007). The CIC BIM Protocol, which looks at the creation of BIM models at different project stages, also defines the level of detail of the model required at each stage. The Model Production and Delivery Tables (MPDTs) allocate responsibility for BIM model preparation and set the Level of Detail (LOD) of the models at each stage. The MPDTs were replaced by the Responsibility Matrix in the latest version of the CIC BIM protocol to include information as well as model production requirements (CIC 2018). An information manager is assigned to manage the BIM Protocol, the MPDT updating, and the information exchanges. Data Drops take place in accordance with the Employer's Information Requirements (EIR) and the BIM Execution Plan (BEP), with the Plain Language questions defining the data required in each project data drop (BIM Task Group 2013). The EIR document establishes and communicates information requirements for the project, including the models that are required and their intended purposes. The BEP aims to define roles and responsibilities of different stakeholders to ensure BIM deliverables at each design stage. The requirement for a BEP to be established at the offset of the design process has been widely articulated (RIBA 2012; Sinclair 2013).

The investigation of EC information communication through BIM information management forms part of this research. As such, the EIR and BEP documents are important resources where EC information requirements and their management can be traced in the case studies considered.

2.3.4 BIM benefits

A key attribute of BIM is the capability of the BIM model to store and represent project information (Mahdjoubi et al. 2015) which facilitates project data management throughout the building lifecycle (Eastman 2011; Shrivastava and Chini 2012). This can result in a range of benefits that include reductions in clashes, construction time and cost and improvements in design quality (Succar 2013; Blay et al. 2019). As BIM is not merely a software application, but a procedural change of how building information is designed and managed (Succar 2009), one of its key benefits relates to the enhancement of collaboration amongst the construction industry stakeholders (Isikdag and Underwood 2010; Singh et al. 2011). The UK construction industry has been long characterised by fragmentation and inefficient communication amongst its stakeholders (Latham 1994; Egan 1998; Capper et al. 2012; Hardi and Pittard 2015). The need for an integrated project processes approach to address this was highlighted over two decades ago (Egan 1998). BIM promotes and facilitates early collaboration of stakeholders which addresses fragmentation and enables more efficient collaboration between different disciplines of the construction industry (Sacks et al. 2010a; Kim 2015).

Further to the main benefits that BIM can bring to the construction sector, the potential for BIM to support green buildings has also been advocated in literature (Rajendran et al. 2012; Volk et al. 2014; Wong and Zhou 2015). BIM applications have been developed to address sustainability issues in the design process, such as building performance analyses and simulations. These include energy performance analyses (Schlueter and Thesseling 2009; Wong et al. 2010; Schade et al. 2011; Shrivastava and Chini 2012; Kim and Anderson 2013; Wong and Fan 2013), CO_2 emission analyses (Knight and Addis 2011; Basbagill et al. 2013) and lighting simulations (Welle et al. 2012). These applications assist designers in making more informed decisions by providing visualized views of building performance, enabling them to assess the impacts of various design alternatives (Schlueter and Thesseling 2009; Sacks et al. 2010b). Construction waste minimisation can also be achieved through BIM by extracting and processing the component information of each building element in a BIM model (Sacks et al. 2010a; O'Reilly 2012). BIM can also be used to optimize the selection of sustainable building materials and fulfil multiple sustainable objectives in the decision-making process (Inyim et al. 2015; Jalaei et al. 2015). Lu et al. (2017) conducted an extensive review on BIM and green buildings and provided a diagram of BIM supported functions for sustainability analyses. Carbon emissions analyses are part of the functions listed and include Carbon emission calculations and design alternatives for carbon emission reduction (Iddon and Firth 2013).

As this research aims to analyse EC considerations in a BIM-enabled building design process, the benefits of BIM toward green building development and its use in sustainability analyses form an important consideration for this research. The use of BIM to address EC considerations in building design is discussed in more detail in section 2.5.

2.3.5 BIM challenges

The implementation of BIM has been associated with several challenges. Kim (2015) combined literature by Bernstein and H. (2004) and Kiviniemi et al. (2008) to categorise these barriers into: (i) Business and Legal, (ii) Technical and (iii) Human/ Organisational barriers.

At the beginning of BIM implementation, there was lack of standards to guide practice on information management requirements, the level of detail of information required at each project stage and the roles and responsibilities of construction stakeholders with regards to information exchanges (Hannele et al. 2012; Ilozor and Kelly 2012). However, barriers that relate to standardisation are now predominantly addressed through the publication of the ISO standards that relate to BIM governance (see section 2.3.3). Legal barriers relate to liability and BIM model ownership and are still pertinent as the industry is still at Level 2 where the project team models are federated. These legal barriers are most prominent during the novation stage of projects and the importance of building contracts in addressing this barrier has been highlighted in literature (Ghassemi and Becerik-Gerber 2011; Sackey 2014).

Technical barriers of BIM implementation are predominantly related to interoperability between models and tools. Back in 2013, Bryde et al. (2013) found software issues to be the main limitation of BIM use but concluded that these could be addressed through the improvement of software packages offered by IT companies. Technical barriers are indeed being resolved through more and updated software packages with increased interoperability capability that have become available to the industry. The ISO 19650 framework that has been released since 2019 also aims at improving interoperability issues and enhancing information exchanges through the use of data formats such as Industry Foundation Classes (IFC) and Construction Operations Building information exchange (COBie) (NBS 2020). However, for the effective use of BIM and in addition to a BIM data repository, a BIM collaborative framework that sets out clear roles for professionals, establishes specific information exchange points and synchronises with current work processes is required (Jung and Joo 2011; Kim 2015).

The human/ organisational barriers of BIM adoption have been associated with the requirement for cultural changes required for the implementation of BIM (Succar 2009; Eastman 2011). The readiness of the sector to adopt new technologies has been questioned by several studies (Abuelmaatti and Ahmed 2014; Succar and Kassem 2015) whilst it has been argued that people and processes play as important a role as technology for successful BIM implementation (Arayici et al. 2011). The construction industry needs to move away from fragmented and silo working that has long characterised the sector and adopt integrated collaborative processes for efficient BIM implementation (Mao et al. 2007). Effective collaboration in building projects involves people, processes and technology use, with people and processes presenting the aspects thar affect collaboration system implementation the most (Wilkinson 2005). People have been found to present the greatest challenge amongst these three aspects (Soetanto et al. 2003; Deutsch 2011) and Deutsch (2011) has pointed out that the 'human' aspect of BIM has been underrepresented in BIM related research. Research has demonstrated that opportunities to reduce BIM challenges are predominantly socially driven (Blay et al. 2019). The need for a socio-technical approach to BIM implementation has been stressed by various authors (Arayici et al. 2011; Khosrowshahi and Arayici 2012; Sackey 2014) whereas Abdirad and Pishdad-Bozorgi (2014) highlighted the lack of research on in-progress projects that focus on process and BIM model inputs.

Further elaboration on the requirement for a socio-technical approach to analyse the use of BIM in relation to EC is discussed in section 2.6. This research addresses this gap by taking a socio-technical approach to study the use of BIM to facilitate EC considerations in building design.

2.4 Embodied Carbon (EC) overview

Energy consumed by buildings can be divided into two categories, operational and embodied energy. Operational energy is the energy associated with the energy buildings consume during their operation to meet required comfort levels (heating, cooling and lighting) and support the use of equipment (such as cooking, refrigeration and other electrical appliances) (Yohanis and Norton 2006; RICS 2012). Embodied impacts of buildings are more commonly expressed as embodied carbon, which has been defined as:

> *'Carbon emissions associated with energy consumption (embodied energy) and chemical processes during the extraction, manufacture, transportation, assembly, replacement and deconstruction of construction materials or products'* (RICS 2012).

Embodied impacts of buildings can be considered for different life-cycle boundaries and can be divided into five categories (Hammond and Jones 2011; UKGBC 2015):

- Cradle to gate: considers the carbon emitted to bring the construction material from the cradle (earth) to the point it leaves the factory gate and is ready to be used in construction. This boundary includes material extraction, transport to factory and manufacture/ material processing.
- Cradle to site: Cradle to gate plus delivery to the construction site. This boundary includes cradle to gate plus transportation from factory to construction site.
- Cradle to construction: Cradle to site plus assembly on construction site. This is frequently referred to as ‘Upfront carbon’.
- Cradle to Grave: Cradle to complete construction plus operation and end of life processes. These include maintenance, refurbishments, demolition, waste treatment and disposals (grave).
- Cradle to cradle: Cradle to grave plus recycling. This includes the process of making a component or product and then, at the end of its life, converting it into a new component.

Life-cycle stages have been defined by the British Standard (BS) EN 15978 standard which has expressed the stages as ‘information modules’ A, B, C and D (BSI 2014). Figure 2.2 includes the life-cycle stages and boundaries and gives a diagrammatic representation of what is considered as ‘Upfront Carbon’, ‘Embodied Carbon’ and ‘Whole-life Carbon’.

It should be noted that different boundary condition consideration may affect the resulting carbon intensity of construction materials. This mostly applies to recyclable materials which, if assessed according to cradle to gate, have a much higher carbon intensity than if they are assessed to cradle to grave or cradle to cradle boundary (UKGBC 2015).

Embodied carbon is expressed in units of CO_2 equivalence of a range of greenhouse gases (GHGs) that have different warming effects on the earth’s atmosphere. The total effect of the GHGs is found through converting each GHG effect into the equivalent warming effect of CO_2, also known as Global Warming Potential (GWP) (Anderson and Adams 2020).

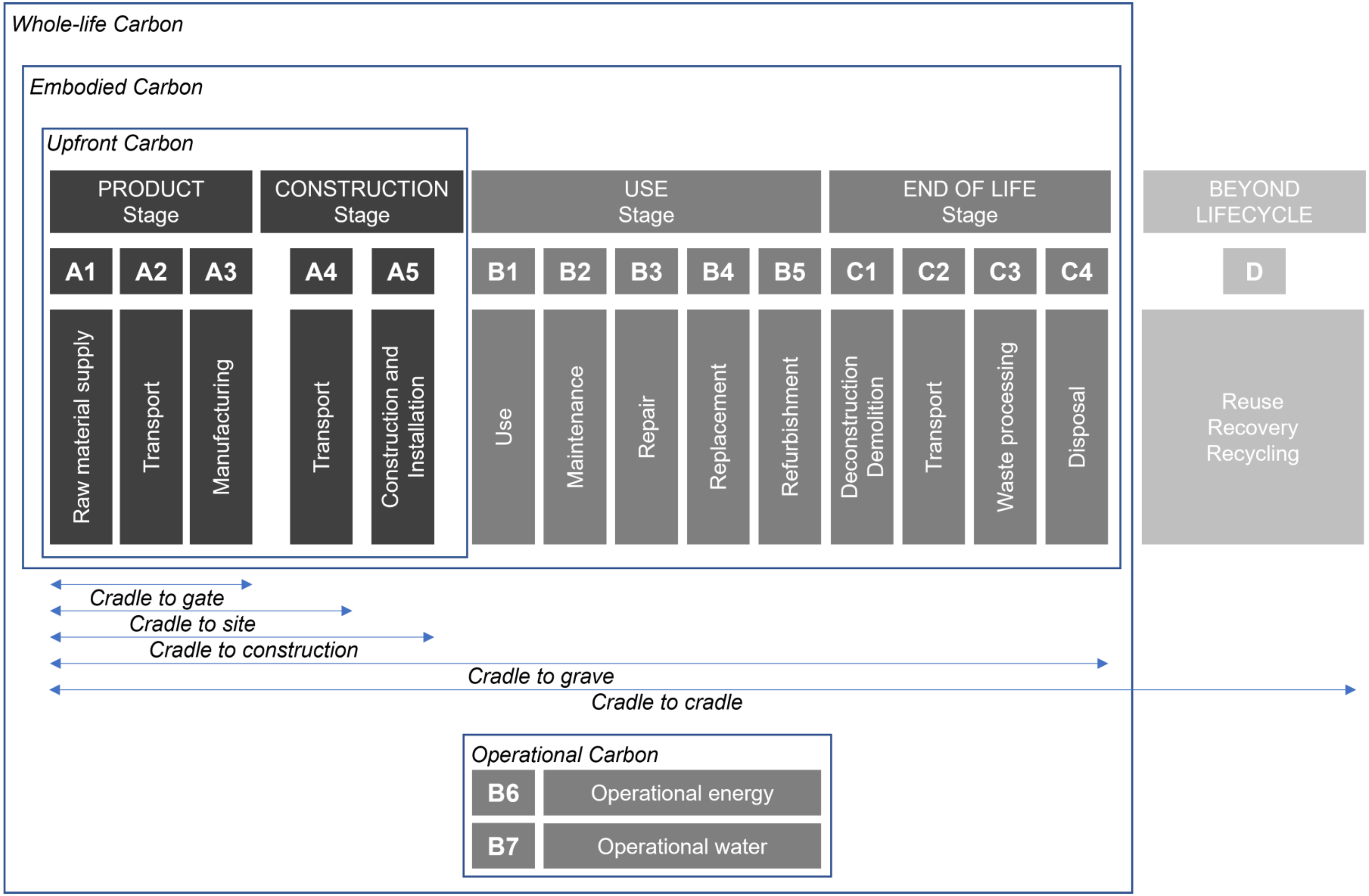

Figure 2.2 Embodied carbon in different life-cycle stages as defined by the BS EN 15978 standard.

2.4.1 Significance of Embodied Carbon in whole-life carbon emissions of buildings

Carbon reduction efforts within the construction industry have primarily focused on Operational Carbon (OC) as it has traditionally accounted for a larger proportion of the overall carbon emissions throughout the lifecycle of a building. However, with the advent of building designs reduce Operational Carbon (OC), Embodied Carbon (EC) has emerged as an increased proportion of the overall carbon emissions in the building lifecycle (Capper et al. 2012; Shrivastava and Chini 2012; Iddon and Firth 2013; Pomponi et al. 2020). Additionally, studies have observed that not only does EC increase in proportion, but it also increases as an actual carbon figure for building designs with reduced OC (Basbagill et al. 2013; Röck et al. 2020). The decarbonisation of the electricity grid also contributes to the proportional relationship of OC and EC, enhancing the relevant significance of EC (Anderson and Adams 2020).

Reducing Embodied Carbon (EC) is crucial not only because it constitutes an increasing proportion in relation to Operational Carbon (OC), but also because it can help mitigate resource depletion. The advantage of EC savings is that they can mostly be achieved at the beginning of a building's lifecycle during the design and construction stage. As research indicates, CO_2 savings within the next five years hold greater environmental value compared to those saved in 10 or more years (UKGBC 2015). In addition, predicting EC can be more precise than predicting OC, as the latter is dependent on varying building user behaviour throughout the building's lifecycle. Furthermore, EC reduction is closely linked to social and economic aspects of sustainability. For instance, one strategy for EC reduction involves sourcing construction materials locally and utilizing local supply chains, which not only supports the local community through job creation but also promotes economic sustainability (UKGBC 2015).

2.4.2 Barriers for Embodied Carbon reduction in buildings

Despite the growing significance of Embodied Carbon (EC) towards buildings' environmental impacts, there are still several challenges in tackling the EC of buildings. These challenges predominantly relate to technical aspects, such as the methodology and data used for EC calculations, and social aspects such as industry's knowledge and attitude towards EC and lack of legislative requirements for EC.

With regards to methodology, there is lack of consistency in various aspects of EC calculations (De Wolf et al. 2017; Giesekam and Pomponi 2018). Moncaster et al. (2018) identified three areas these inconsistencies arise from: temporal differences of the considered stages, spatial differences of material boundaries and physical variations in data coefficients. Consideration of grid decarbonisation also has an impact on EC results for the use and end-of-life lifecycle stages (De Wolf et al. 2017). Inconsistency in methodology can lead to significant variation in EC results, with discrepancies up to 60% (Pomponi et al. 2018).

EC for construction materials is typically expressed as the amount of Carbon Dioxide equivalent (CO_2e) per kilogram of material. Manufacturers often provide EC values for their products in product datasheets or Environmental Product Declarations (EPDs). However, not all products have available EPDs whereas at the early design stages the manufacturer of the product may be unknown. In the lack of product-specific EC values, generic material databases that compile carbon factors for various materials can be used for EC calculations. While these databases can serve as a starting point in the early design stages, they may have a higher level of inaccuracy as the data is sourced from global databases and may not represent precise carbon values (RICS 2012). Each database may draw information from different sources, have different boundary levels, and may have been last updated at different times. As a result, different databases may provide different values for the same materials. Concerns regarding the quality of product and construction data has been stressed in literature (De Wolf et al. 2017; Giesekam and Pomponi 2018). In the UK, the Inventory of Carbon Energy (ICE) is the most widely used EC database and although it has been developed for the UK context, it still presents challenges commonly observed in EC assessments of buildings and construction, such as the applicability of data to specific contexts and the comparability of results with other assessments (Pomponi et al. 2020).

The lack of consistent EC data and calculation results also impinges on the establishment of EC benchmarks against which carbon results of different building types can be compared. At the start of this research there was complete lack of EC benchmark availability in the UK (RICS 2012); however, during the course of this research, literature that focused on establishing expected ranges of initial EC figures and strategies to facilitate the establishment of EC benchmark has been made available. Examples of such literature include Simonen et al. (2017) who studied expected initial EC figures of different building types and highlighted uncertainty factors with an aim to support the establishment of EC benchmarks. Recent years have seen more attention given to EC and the emergence of benchmarks in research studies and in different countries as part of regulation, labelling systems, and sustainability rating schemes. Trigaux et al. (2021) provide a critical literature review that analyses the main approaches and methods of world-wide benchmarking systems to establish the strengths and weaknesses of each system and give recommendations for the development and validation of future benchmarks. In the UK, benchmarks have recently been made available by a range of industry bodies; more information on currently available benchmarks within the UK context is presented in section 2.4.3.

Top-down measures in the form of regulations was found to be the most important determinant for sustainable practices in the UK construction industry (Oluwole Akadiri and Olaniran Fadiya 2013). However, despite attempts by local authorities to introduce EC requirements, such as the Greater London Authority and Brighton and Hove County Council, there is currently lack of a nation-wide regulatory requirement for whole-life carbon assessments and for new buildings to meet specific embodied carbon targets (Anderson and Adams 2020). The lack of inclusion of EC requirements impinges on the UK built environment emissions meeting carbon emission reduction targets. Giesekam et al. (2018) warned that targets set by independent construction companies in the UK are insufficient to achieve national goals for carbon reduction and highlighted the need for the development of a sectoral decarbonisation trajectory for the UK built environment. In 2022 the Environmental Audit Committee conducted a report urging the UK Government to introduce the requirement for assessment and the control of EC for the building sector. This report warns that the UK is in danger of not meeting its carbon budgets if embodied carbon is not tackled and proposes that the government introduces EC assessments as mandatory within the regulatory and planning system and follows up with subsequent establishment of carbon targets for buildings that respond to the pathway set for net-zero (House of Commons 2022a). Apart from impinging on progress in tackling EC emissions for the built environment, the lack of national policy for EC also creates a gap in standardisation of EC calculations and reporting amongst the industry (Pomponi et al. 2020; House of Commons 2022a). Although the UK Government response acknowledges the significance of EC towards whole-life carbon emissions of buildings, it does not provide a clear framework as to when these requirements will be introduced (House of Commons 2022b).

As there is no legislation mandating the inclusion of EC in building design in the UK, it is crucial for the UK industry to take the lead in this regard. Indeed, in the same year that the Environmental Audit Committee report was issued (2022), a proposal for amendments to the UK Building Regulations (Proposed Document Z) was made by industry experts in construction decarbonisation with an ambition that this could be used as a guide to mandate the reporting and limiting of carbon emissions[1]. Although this proposal has been brought together by experts in the field, the industry's knowledge, interest, and experience in working with EC are fragmented across the entire value chain, lacking a cohesive and unified approach (Pomponi et al. 2020) and for the bulk of the industry EC remains a low or non-existent consideration for building design (Orr et al. 2019). This lack of understanding within the industry makes it challenging to establish active drivers for client awareness and engagement in EC reduction. Without effective communication of EC savings, the benefits of considering EC during the design phase will not be fully understood by the industry and clients.

2.4.3 Tackling Embodied Carbon

Although there is currently lack of EC legislation in the UK, Climate emergency declarations have been emerging in recent years and there has been a rising interest by the industry with regards to measuring the EC impacts of buildings. This has enhanced the emergence of available guidance documents by professional institutions in the built environment and updates of certification schemes and databases.

[1] The proposed document as well as the Authors of the document are available through the following website: https://part-z.uk/. The authors are only listed in the website in alphabetical order, as such, it was not feasible to include a complete reference of the report and instead the website is hereby made available.

In 2017 the Royal Institute of Chartered Surveyors (RICS) published a guidance document for the interpretation and implementation of the EN 15978, the European standard that set out a methodology for the life-cycle assessment of the environmental performance of buildings (RICS 2017). RICS published this guidance as a professional statement that mandates the whole-life cycle approach set by the document for its members. Although addressed to the RICS members, this guidance has been the main source of principles and practical guidance across the UK construction industry from 2017 to date.

Since the publication of the RICS professional statement and consistent with its suggested methodology, a plethora of guidance that relate to embodied and whole-life carbon has been published by professional institutions in the UK. In 2018 the Royal Institute of British Architects (RIBA) published a guidance document to introduce architects to carbon assessment and its application through the design process as set out by the RIBA work stages (RIBA 2018). In 2019, Architecture, Engineering, Construction, Operations, and Management (AECOM) prepared a report for the Committee on Climate Change (CCC) on options for incorporating embodied carbon into the building standards framework (AECOM 2019). The same year saw the emergence of the benchmarks that considered embodied carbon in publications by the UK Green Building Council (UKGBC) Net-Zero Carbon Buildings: A Framework Definition (UKGBC 2019) and the RIBA 2030 Climate Challenge (RIBA 2019a). Benchmarks were also published by the London Energy Transformation Initiative (LETI) in 2020 as part of their Climate Emergency Design Guide with an aim for new buildings to meet UK climate change targets (LETI 2020a). In 2020, the Institution of Structural Engineers (ISTRUCTE) also published the first edition of a guide on how to calculate EC (Gibbons and Orr 2020); a second edition of the guide was made available in 2022 (Gibbons and Orr 2022). Further to the recently available guidance, tools such as the Inventory of Carbon Energy (ICE) database, a freely available database of Embodied Carbon Coefficients (ECCs) that has been the main source of material carbon data information used by the UK industry was updated in 2019 (Jones 2019). Figure 2.3 presents a timeline of the main guidance documents that have been made available to the UK industry since 2017.

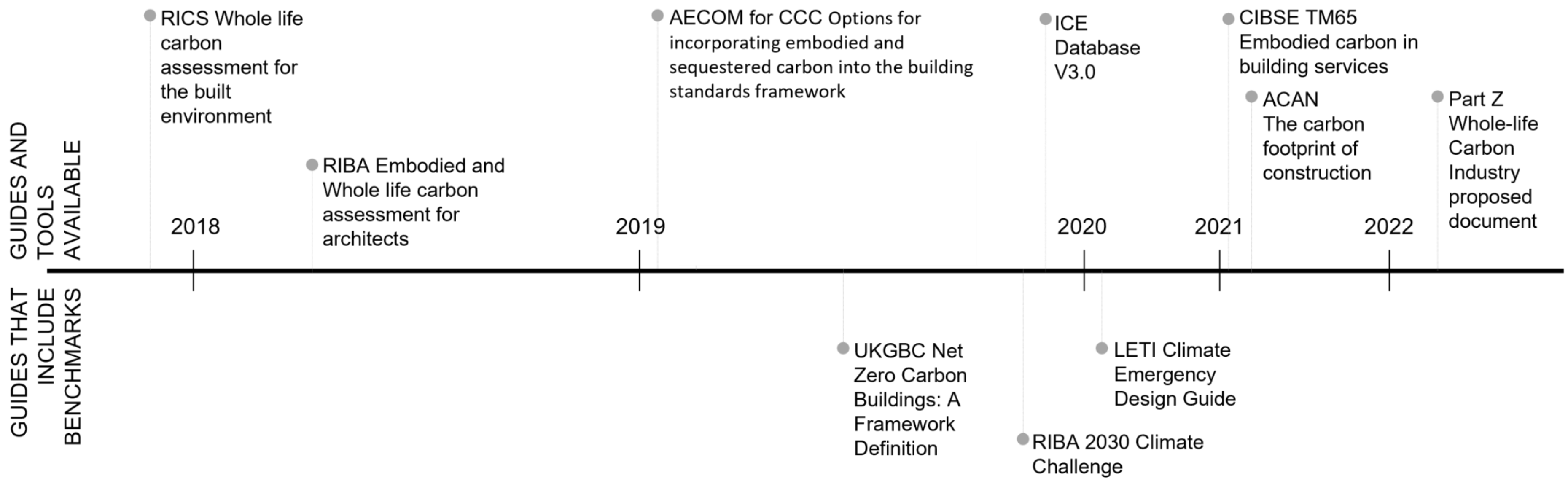

Figure 2.3 Timeline of Embodied Carbon guidance and benchmarks in the UK since 2017

There are various strategies that can be implemented throughout the design process to reduce the EC of building projects. These strategies refer to the building design, as well as material selection and specification. With regards to building design strategies include, design solutions that aim to minimise the quantity of materials and design for durability, adaptability, reuse and deconstruction (WRAP 2015; Pomponi and Moncaster 2016). Pomponi and D’Amico (2018) also suggested EC mitigation through building form optimisation. With regards to material selection and specification, strategies include the selection of materials with reduced EC impacts and aiming to address EC from material transport through the use of local materials (Malmqvist et al. 2018; Pomponi et al. 2020). Literature also suggests prioritising and targeting high-impact materials, known as ‘carbon hotspots’ which make up the majority of the total EC footprint (RICS 2017; Giesekam and Pomponi 2018). The carbon hotspots include building elements such as substructures, superstructures, internal finishes, and external works. Building services were also identified as EC-intensive, but their mitigation potential is limited, and assessing their impact is very complex (RICS 2017). However, guidance to address the complexity of estimating the EC of building services has recently become available (CIBSE 2021). Prioritising a fabric-first approach to the whole-life carbon reduction strategies can lead to a reduction in capital and operational costs, as well as maintenance requirements, by reducing the reliance on mechanical and electrical building systems (Anderson and Adams 2020). The timing of applying these strategies in a project’s lifecycle is crucial as the carbon reduction potential is greater at the early stages of the project development, and it significantly reduces towards later stages such as construction and operation (Häkkinen et al. 2015). In fact, the potential drops below 50% after the design stage completion (HM Treasury 2013; WGBC 2019). Figure 2.4 shows the carbon reduction potential against life-cycle stages of a project.

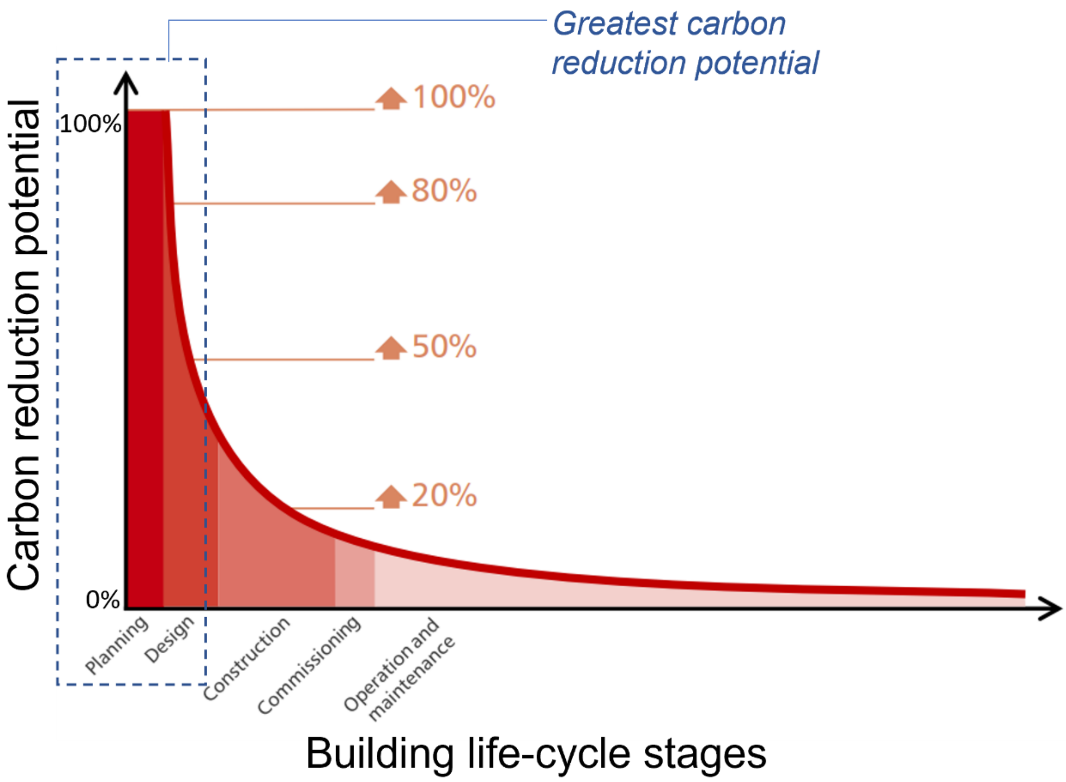

Figure 2.4 reduction potential at different building life-cycle stages Source HM Treasury: Infrastructure Carbon Review, 2013

The EC reduction strategies relate to the building design, the selection of structural materials that are considered as main contributors towards the buildings EC impacts and the building services reliance and selection. As such, the involvement of all built environment stakeholders is crucial for implementing the strategies and achieve EC reduction for buildings (Pomponi and Moncaster 2016).

The Green Building Council proposed that architects, structural engineers, and quantity surveyors should initiate early discussions on EC. They recommended that different professionals should be responsible for EC at various stages of the building's lifecycle, such as the cost consultant or specialist carbon consultant during project completion, the facilities manager during building operation, and the project manager during periodic refurbishment. However, the final decision on these cost-related matters ultimately rests with the client (UKGBC 2015). It is also advised to involve all stakeholders in the supply chain and encourage EC measurement in procurement and sourcing, taking into account recyclable content of products and materials and leasing options during construction. Despite these suggestions, there is still no clear allocation of responsibility for providing EC information or conducting

EC calculations (Capper et al. 2012). Häkkinen et al. (2015) identified the roles of different professionals in design decisions that affect the EC impact of building projects. Architects appeared to affect these decisions the most compared to the rest of the professions, highlighting the importance of the architect as the key stakeholder in designing and specifying reduced EC buildings. The requirement for architects to expand their skillset beyond creative design and visualisation to include technical and environmental competencies in order to address tasks related to the climate crisis has been has been highlighted more than a decade ago by Altomonte (2009). As EC calculations involve quantitative evaluations, Jusselme et al. (2020) suggest that specialist consultants are often required to be added to the design teams as 'new players' to address these quantitative requirements. The results of their investigation of LCA practices in context show that LCA of projects most commonly involves external or internal environmental consultants which necessitates interdisciplinary collaboration amongst professionals with a wide range of backgrounds and skills.

2.5 Embodied Carbon in BIM-enabled building projects

BIM is considered to improve information management across the design team throughout the building lifecycle and reduce the complexity of addressing EC (Capper et al. 2012). BIM has also been characterised as an alternative to stand-alone LCA tools by Ariyaratne and Moncaster (2014), who highlight BIM's capability to incorporate LCA as part of the design process. Bueno and Fabricio (2018) contend that the integration of building components LCA data in the BIM platform presents an opportunity for the seamless incorporation of LCA in the design process.

There are various publications that consider the use of BIM for facilitation of EC reduction efforts that cover a wide range of relevant topics. One of the topics includes the potential of BIM to consider both OC and EC impacts of alternative designs to support design decisions. Capper et al. (2012) examined the incorporation of carbon data of building elements to the BIM model to evaluate both OC and EC of different design solutions. Shadram and Mukkavaara (2018) proposed a framework that aims to help designers make more informed decisions by considering the balance of embodied and operational energy. This framework combines a multi-objective optimization method with a BIM-based design process to find the optimal solution that balances both types of energy.

BIM use has also been explored in relation to its capability to incorporate EC calculations in the early stages of design. Some of these examples are based on hypothetical models while others involve real-life projects. Shrivastava and Chini (2012) used BIM to create alternative structural system models and assess their initial EC. Capper et al. (2012) explored the integration of EC and OC information in a BIM model to consider both factors simultaneously in different design options. This model was applied to a real building case study. Bueno et al. (2018) developed an integration interface of LCA data by manufacturers into the BIM software to support decision making during the initial design stages.

Although the opportunity for EC carbon reduction is greater during the early stages of the design process, this is also the stage when design and material information is not clearly defined. As such, LCA either takes place during detailed design stages using complex BIM models or follows more simplified approaches during the initial stages with limited accuracy. To address this, Cavalliere et al. (2019) proposed a method for LCA throughout the design process using different LCA databases at different design stages to respond to the level of detail of the BIM model at the respective design stage. Palumbo et al. (2020) also focused on addressing the problem of accuracy of LCA at early design stages and presented a method for early LCA through BIM through the use of EPDs.

The opportunities to incorporate LCA into BIM processes throughout the building design have also been examined by Llatas et al. (2020) who proposed and applied a methodological approach for BIM integrated LCA to an architectural workflow. Santos et al. (2019) explored the potential of BIM as a data repository to support automatic LCA through the use of BIM. To improve data reliability and consistency of the BIM model information used for LCA, Cavalliere et al. (2018) developed an information flows matrix that considered the parameters responsible for environmental impacts of buildings.

Other studies focused on tools interoperability and the results of BIM-based LCA. Soust-Verdaguer et al. (2017) conducted an extensive review on BIM-based LCA methods that included templates plug-in applications for BIM software and data and software combinations for the integration of automated LCA processes. In the same study, the importance of the communication of LCA for the reduction of buildings' environmental impact is highlighted. Röck et al. (2018) proposed using BIM to communicate LCA results and visualise the EC hotspots of alternative designs to support design decisions. Other studies have focused on the evaluation of LCA results using BIM software applications. Bueno and Fabricio (2018) conducted a comparative analysis of LCA results from an LCA software and a BIM-based LCA that used a BIM plug-in for the assessments. Hollberg et al. (2020) studied BIM-based LCA results throughout the lifecycle of a real case study to identify the limitations of using the BIM model for automatic quantity tack-off for LCA.

As can be seen from the above, there have been various studies that relate to information and technical issues of BIM-based LCA. However, it has been stated that challenges that relate to the use of BIM for LCA are strongly connected to organisational aspects and practitioner knowledge and workflows (Potrč Obrecht et al. 2020). Bueno and Fabricio (2018) attributed the inconsistency found between LCA results from an LCA tool and a BIM plug-in LCA tool to simplifications of the BIM model made by building designers who lacked LCA expertise. Hollberg et al. (2020) found that LCA results during the design stage were misleadingly higher than the LCA of the final building due to the use of 'placeholder' materials by building designers. This shows that 'people' is an important factor when considering the use of BIM to address EC in buildings and supports the finding of a recent survey that BIM-based LCA presents a challenge to design teams (Balouktsi et al. 2020). Capper et al. (2012) highlighted the potential of BIM-LCA integration changing the traditional roles of team members and the introduction of 'new specialists' acting as experts that provide EC information for the BIM model. There is still need for the roles of the principal design team and sustainability specialists to become understood and integrated in BIM-enabled building design processes (Zanni et al. 2017).

As can be seen from BIM implementation challenges (section 2.3.5) and the barriers for tackling EC (section 2.4.2 and section 2.4.3) people and process are highlighted as the main factors affecting both these aspects. This is also pertinent when considering EC reduction efforts in a BIM-enabled design process. There is a requirement for change in practices for the inclusion of EC considerations to building development as well as the use of BIM to facilitate this, and technology alone is not able to deliver this change. The involvement of building professionals and the way they incorporate the use of technology to their practice is crucial for the process innovation required in the construction sector (Dossick et al. 2019). Harty (2008) defines innovation in construction as a system that involves changes in practices, processes, systems, and technologies. According to Abbot and his seminal work on the system of professions Abbott (1988), changes in technology create new professional tasks and professional jurisdictions, which are most commonly absorbed by existing professions. This suggests that alongside the new advancements that the technology aspect of BIM and LCA bring, the roles of professionals and their involvement in inclusion of EC considerations and the use of BIM as an information management and software tool needs to be further explored. As such a socio-technical perspective that considers people, process and tools for EC considerations in BIM-enabled building projects is required.

2.6 Socio-technical Systems (STS) for BIM and Embodied Carbon

Socio-technical system (STS) theory was first developed at the Tavistock Institute of Human Relations to examine the interrelationships between people, technology, and the environment (Appelbaum 1997). It was initially applied to design jobs and work systems, but as technology has become more prevalent in all industries, the applicability of STS has expanded to many organizational situations. As such, STS has been widely applied in most industrialized nations (Appelbaum 1997).

As defined in section 2.3.2, BIM is not merely a software application but also a collaborative environment and as such, it includes both technical and social aspects. Literature on BIM has predominantly focused on the technological aspects of BIM, whereas BIM studies that take an STS approach predominantly focus on BIM implementation and the barriers to its adoption (Alreshidi et al. 2017; Whyte and Hartmann 2017; Abdirad et al. 2021). Oesterreich and Teuteberg (2019) used an STS framework to analyse the causes of BIM adoption barriers. The framework consisted of a social and a technical sub-system that included ‘people and structure’ (social) and ‘process, technology, and tasks’ (technical) components. The study found that although many barriers were related to technical components such as technology and tasks, the causes of these barriers were rooted to social components, mainly people and social arrangements (structure) of the construction industry. Abdirad et al. (2021) conducted an ethnographic study that investigated how information exchange requirements incorporated to the design process by BIM that don't align with existing routines are perceived, interpreted and acted upon by the design team. Blay et al. (2019) investigated the benefits and challenges of managing change in BIM Level 2 projects and found that behaviours are shaping the social requirements for BIM Level 2, highlighting the requirement for a socio-technical approach for the successful implementation of BIM. Whyte and Hartmann (2017) highlighted the effect of digitising building information on the relationships, roles and responsibilities of professionals who are involved in the building design process. Dowsett and Harty (2019) also focused on BIM implementation by examining the constitutive elements of the BIM implementation process through an information systems approach. Other research has taken a broader focus on innovation and technology uptake in the construction sector using a socio-technical networks approach (Harty 2005,2008; Schweber and Harty 2010).

Similarly, literature on tackling EC has primarily considered EC as a technical problem and has focused on estimation methodologies, databases and tools (Azari and Abbasabadi 2018). There have however been some studies that considered social aspects that relate to tackling EC. Moncaster et al. (2019) took a socio-technical approach to investigate the contexts that influence design decisions to reduce EC. The study identified enablers at the policy level (such as regional authority EC target requirement) and project levels (such as professional leadership by design team members) for innovative case studies in reducing EC building impacts. Orr et al. (2019) conducted a study that focused on practitioners' perspectives (structural and civil engineers) on material efficiency. The study found that EC is a low priority in structural design and identified that there is a lack of consensus in the sector regarding material efficiency. Hollberg et al. (2022) focused on user-centric development of LCA tools and developed and tested a framework that integrated professionals' requirements. Other studies had a macro-level scope and looked at technological transition for sustainable building construction (Rohracher 2001) whilst an STS approach has also been used to study transitions in environmental sustainability, energy systems and policy (Markard et al. 2016; Geels et al. 2017).

In recent decades, environmental issues that have gained worldwide attention are described as 'socio-technical' because of their complexity as they involve new technologies, policy changes, user practices, and cultural meanings (Verbong and Geels 2010). Both BIM and EC considerations in building design present new challenges to the construction industry requiring a transition to current practices. These new challenges introduce changes to the current professional roles and practices which calls for new professionalization across the building professions and clients (Bresnen 2013). However, literature that considers both BIM and EC has taken a technical approach, despite the establishment of the requirement for a socio-technical approach (see section 2.5). As such, there is a gap in literature of studies that consider BIM and EC under a socio-technical perspective.

2.7 Conclusion

This chapter reviewed literature that relates to the research topic with an aim to give an overview of key aspects that have been considered and present the research gap that this thesis aims to address. The chapter started by giving an overview of the building design process which has highlighted its social nature. An overview of BIM then presented the evolution from traditional drafting to modelling which was followed by a definition of BIM and the available standards that relate to it in UK. The perceived benefits and challenges of BIM were then presented which highlighted the importance of people in BIM implementation and led to the identification of a research gap on in-progress BIM-enabled projects that focuses on process and BIM model inputs. An overview of Embodied Carbon followed which described its definition, important aspects for its consideration and its growing significance in building whole-life carbon emissions. Following this, the available guidance, main strategies and the role of building professionals in tackling embodied carbon is discussed. The requirement of the involvement of all building professionals in EC reduction efforts is highlighted, with the identification of the architect and environmental consultants as the key professionals involved in EC considerations and assessment during the design stage of projects. However, a gap in the clear allocation of responsibility in relation to EC information provision and EC calculations has been identified. Finally, literature that considers EC through the use of BIM was reviewed, and a gap in research exploring the roles of professionals in addressing EC considerations through the use of BIM was identified. The requirement for a socio-technical systems approach that considers how EC considerations are set and addressed in BIM-enabled projects was established.

This study addresses this gap by adopting a socio-technical approach according to which the ontological position of the research becomes important. The following chapter includes a discussion of different research philosophies and a justification for the selection of critical realism as the philosophical stance of this study (section 3.2). Given that critical realism includes an abductive approach to theorisation, the first phase of this research explored how EC considerations are set and addressed in a BIM-enabled project and informed the second phase, which was both empirically and theoretically informed. A more substantive theoretical literature review is included in Chapter 5 where an overview of socio-technical systems is presented and a justification of the selection of structuration theory for the development of the analytical framework is given (section 5.2). The following chapter presents in more detail the research design and methods used to address the identified research gaps.

Chapter 3 Methodology and Research Design

3.1 Introduction

'What we observe is not nature itself, but nature exposed to our method of questioning' (Heisenberg 1959)

This chapter presents the theoretical background that the research methodology followed and the research design that was applied in order to achieve the aims and objectives of the thesis. It gives an overview of the research philosophy and approaches adopted by the thesis and presents the research methods that were identified as the most appropriate to address the research aim and objectives. After setting up the theoretical background, the design of this research is described in more detail and the data collection and analysis approaches are presented.

3.2 Research philosophy, approaches and methods

3.2.1 Research philosophy and perspective

A research paradigm or philosophy is the system of beliefs and assumptions that is adopted by a research study for the development of knowledge (Saunders et al. 2016). This system is defined by *ontological* and *epistemological* assumptions; *Ontology* relates to assumptions about the nature of reality, whereas *Epistemology* relates to assumptions about what constitutes knowledge (Silverman 2014).

Two of the most extreme positions of research philosophy in relation to ontological and epistemological assumptions are Positivism and Constructionism. Positivism is characterised by an objective view of reality which is independent of human interpretation (Bailey 2017). The epistemological position of positivists is that knowledge derives from measurable facts that can lead to law-like scientific generalisations (Saunders 2016). Constructionism at the other end, adopts a subjective ontology which entails multiple socially constructed realities. As such, it adopts a subjective view of reality, which is considered as socially constructed. Epistemologically, Constructionism adopts a relativist epistemological approach where knowledge and meanings are elicited from social interactions (Denzin and Lincoln 1994; Leavy et al. 2014). Critical realism is a philosophy that bridges the two extreme positions (Bygstad et al. 2016) by adopting a realist ontology that preserves the view that reality exists independently of social perceptions but has a relativist epistemology that acknowledges that there are multiple ways of knowing (Stutchbury 2022). For Critical Realism, the purpose of research activity is to conceive the observed reality as an expression of deeper-lying processes (Alvesson and Sköldberg 2018).

The research philosophy and the assumptions that are associated with it define how the research is conducted, the research approach that is taken, how data is collected, analysed and interpreted and ultimately lead to different types of knowledge contributions (Guba 1990; Saunders 2016). As such, the research philosophy adoption needs to be aligned with the researcher's ontological and epistemological system of beliefs and guided by the research aims of the research (Orlikowski and Baroudi 1991).

This thesis aims to investigate how EC considerations are set and realised in a BIM-enabled design process. As part of this aim, this research seeks to analyse the conditions and mechanisms that affect EC considerations and how these are communicated and addressed through the use of BIM. As such, the research considers that there is an objective reality with regards to EC considerations in BIM-enabled building design, for which the deeper-lying mechanisms that affect it are to be investigated. This aligns the research objectives to the critical realist philosophical approach, which has an aim to study the mechanisms that explain the observed empirical outcomes (Sayer 2000; Bhaskar et al. 2018). Therefore, a critical realist philosophy is adopted to guide the research process of this research.

3.2.1.1 Critical Realism main tenets

Critical Realism (CR) assumes that an external reality exists and can be subject to analysis (Danermark and Ekström 2019). It considers a stratified view of reality that consists of three realms: the real, the actual and the empirical (Bhaskar 1975). *The real* refers to natural and social elements that exist independently of human perception, knowledge and understanding. Within this realm lie the structures and causal powers that have capability to produce events under certain conditions and the potential for certain kinds of change (Sayer 2000). The realm of *the actual* is where these causal powers are activated and includes the events that occur in time and space, which are independent of human observation. What we can observe lies within the realm of *the empirical*, which refers to human experiences and perceptions. However, according to CR, existence is independent of human perception, as there are unobservable entities that affect what we observe (Sayer 2000).

This ontology suggests that what happens is not predetermined as causal powers may or may not be triggered and exercised in different contexts that may constrain or enable what can happen. As such, for CR, the world is characterised by emergence, according to which, causal powers create tendencies of possible events (Danermark and Ekström 2019). In social systems causal powers don't act independently as they are embedded in a system of relations and dependencies. As such, it is causal relations rather than isolated powers that affect the system as a whole and these causal relations are contextually bounded (Lawson 2000).

Causation is a central feature of CR; however, causation in CR does not consider a regular succession or repeated occurrences of events as, according to CR, the regularity or frequency of occurrence of an event does not explain why the event took place (Bhaskar 1975; Sayer 2000). Instead, causation in CR seeks for explanations through the identification of *causal mechanisms* and through developing an understanding of the conditions under which these mechanisms are activated and operate. The same causal mechanism may have a different outcome when activated in different contexts with distinct socio-spatio-temporal relations. As such, the analysis of contextual conditions is crucial for developing explanations of events based on causal mechanisms (Sayer 2000). As can be deduced from the above, causation in CR is contextually dependent, emergent and varied.

3.2.2 Research approaches in relation to theory and data

3.2.2.1 Research approaches in relation to theorisation

Research approaches can be considered with regards to the relationship between theory and collected data (Bryman 2001). The two main research approaches that relate to the research approach to theory are the *deductive* and the *inductive* approach. In a *deductive* research approach, theory is the starting point of the research which is then tested. Data collection is commonly used to test a research hypothesis that occurs from the theory and to prove it false or true. The results are generalisable and derive from measurable facts from a research sample that is of a sufficient size (Saunders 2016). This approach is usually followed in positivist research in natural sciences and most commonly involves quantitative research (Bryman 2001). On the other hand, in *inductive* reasoning, theory is the outcome of the research that is reached through observations and research findings (Bryman 2001). The aim of this approach is to create a deeper understanding of the observed phenomenon and in many cases a conceptual framework is developed as the expression of theory creation (Saunders 2016). The context that this phenomenon occurs is important to this research approach and therefore smaller samples are more appropriate. This approach most commonly deals with qualitative data and a variety of methods to collect them (Saunders 2016). A third research approach that particularly relates to the use of theory is *abduction* which involves the theoretical redescription of observed phenomena for the discovery of meanings and connections beyond what can be observed (Danermark and Ekström 2019; Stutchbury 2022). According to Habermas (1972) abduction provides a mode of inference through which new ideas are introduced and which can broaden knowledge about empirical observations and stimulate the research process. Abduction enables the reinterpretation of observed phenomena through a theoretical frame or an introduced set of ideas (Danermark and Ekström 2019).

Critical realism adopts an abductive form of reasoning and introduces *retroduction* and *retrodiction* as necessary procedures in explanatory social science (Danermark and Ekström 2019). *Retroduction* operates between the realm of the empirical and the real. Through retroduction, the researcher advances from what is observed empirically to the constitution of knowledge through conditions of social relationships and mechanisms. As such, retroduction in CR is the process by which the causal powers of structures are identified. *Retrodiction* refers to the investigation of how different mechanisms interact and affect social events (Elder-Vass 2012). Danermark and Ekström (2019) proposed a guideline model in which these procedures are presented as five stages of the overall process of critical realist explanatory research. Figure 3.1 presents a summary of these steps and the movement from the ‘concrete’ of stage 1 to the ‘abstract’ in stages 2-4 and back to the concrete in stage 5.

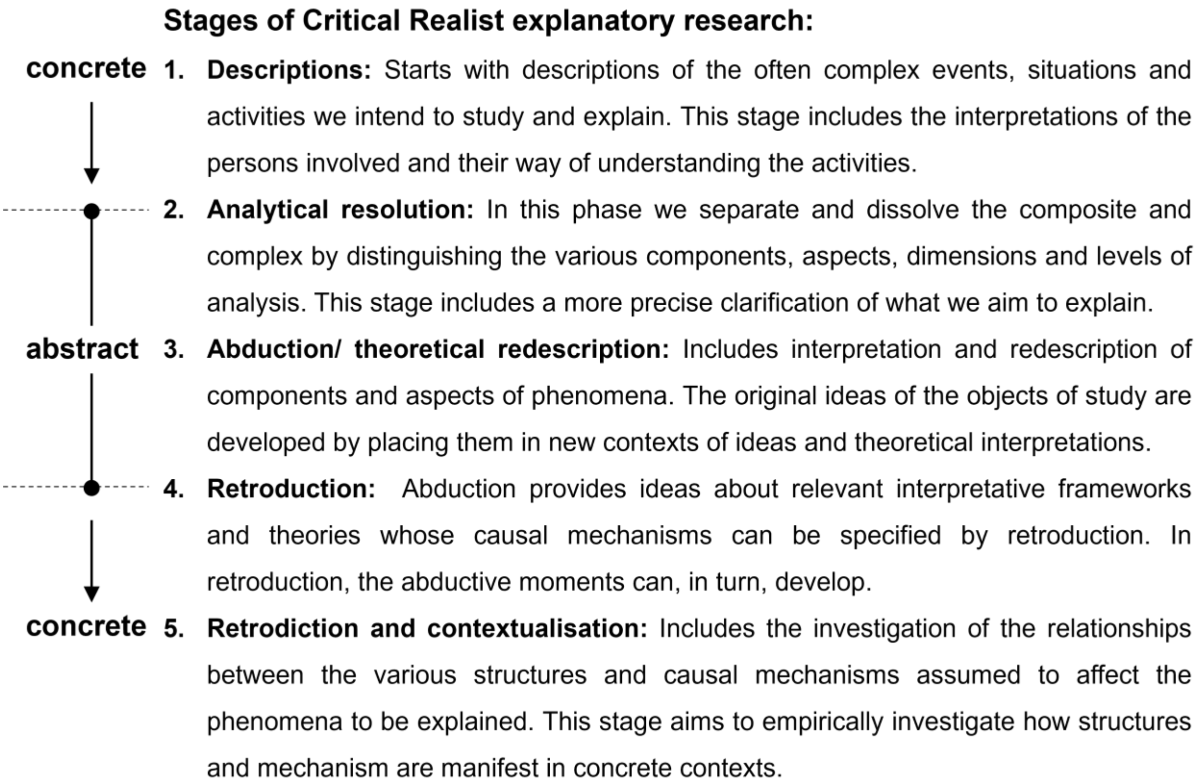

Figure 3.1 Critical realist explanatory research steps adapted from Danermark and Ekström (2019).

The research approach in relation to theory that this thesis follows is aligned with the critical realist philosophy adopted. As such, the thesis has an abductive form of reasoning where theory is used for interpretation and redescription of the empirical observations. Retroduction and retrodiction are also used as procedures to identify mechanisms and their relation to contextual structures. These approaches are used at different stages of the research; these different approaches and their corresponding stages are described in detail in section 3.3.

3.2.2.2 Research approaches in relation to data

Research approaches can also be considered in relation to the type of data that is collected during the research. There are two main approaches that relate to data type, the *quantitative* and the *qualitative* approach. A very basic distinction between the two is that the former involves collection of data that are measurable and quantifiable whereas the latter does not (Bryman 2001). The differences between the two approaches extend to the approach to theory as well as epistemological foundations of research. As mentioned in section 3.2.2.1, when considering the approaches to theory, quantitative research lends itself to deductive reasoning and is related to natural science, a positivism paradigm. On the other hand, qualitative research is more commonly used when an inductive approach to theory is adopted and when a deeper understanding of phenomena is required which is linked to constructionist research (Bryman 2001).

Critical realism research does not fall into a qualitative or quantitative distinction, but rather is characterised by methodological pluralism that includes *extensive* and *intensive* research designs that can embed either (or both) quantitative and qualitative approaches (Sayer 2000; Danermark and Ekström 2019). *Extensive* research lends themselves to quantitative approaches as they intend to study the effect of different contexts on a mechanism and aim to generate taxonomies. *Intensive* research primarily uses qualitative approaches to identify mechanisms in known and specific contexts (O'Mahoney and Vincent 2018). Intensive studies focus on substantial relations of connection to respond to questions of how a process works in a particular or small number of cases, what produces a certain change or what did the agents actually do (Sayer 2000).

This thesis aims to explore the process of how EC considerations are set and addressed in BIM-enabled projects. It takes a close look to analyse the conditions and mechanisms that affect how EC targets are set, communicated and addressed through the use of BIM. This thesis also considers in-practice application of BIM and investigates the actual potential of its use to facilitate EC considerations as an information management and software tool. As such, this thesis can be characterised as intensive research and uses a qualitative approach in relation to data.

3.2.3 Research strategies and methods

Research strategies can be defined as a plan of how a researcher will attempt to answer the research questions (Saunders 2016). Merriam (1998) mentions five basic strategies of qualitative research: basic or generic qualitative study; ethnography; phenomenology; grounded theory and case study. Although there are differences between these strategies, they share common qualitative research characteristics which include an inductive approach, the aim to produce meanings and understanding, the researcher being the main instrument of data collection and analysis and the production of rich and descriptive findings. Therefore, they can be used in conjunction with one another (Merriam 1998).

For intensive critical realist research, the research strategies that have been identified as appropriate are case study and comparative case study, action research and intensive realist literature evaluations (O'Mahoney and Vincent 2018). The choice of research strategy depends on the research question and the level of detachment of the researcher (Edwards et al. 2014). For critical realist studies that aim to identify mechanisms, case study has been identified as the most useful research strategy as it enables in-depth exploration of empirical events to abduct causal mechanisms. Comparative case studies enable the exploration of the interaction of context and mechanisms (O'Mahoney and Vincent 2018).

This thesis aims to identify the mechanisms that affect how EC considerations are set and addressed in BIM-enabled projects and to analyse the impact of context on EC targets and EC calculation in a BIM-enabled project. As such, the case study and comparative case study strategy is adopted.

3.2.3.1 Case study research strategy and associated data collection methods

Yin (2009, p. 18) defines a case study as 'an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident'. Benbasat et al. (1987) highlighted the benefits of case study research, including the opportunity to acquire knowledge about the state-of-the-art of the field as their focus is on contemporary events in specific contexts. Case studies enable deep understanding of the complexity of the processes being examined and provide insights into emerging topics in the field of investigation. Case study research is versatile in relation to research methods and can adapt to the requirements of different research approaches (Walsham 2006; Yin 2014). Data collection involves different methods from one or multiple sources within the context under study (Benbasat et al. 1987). Research methods for intensive critical realist research strategies involve the study of agents in their causal contexts and include interviews and ethnographic methods of data collection (Sayer 2000).

Ethnography as described by Hammersley (1995, p. 3) '*involves the researcher participating, overtly or covertly, in people's daily lives for an extended period of time,* *watching what happens, listening to what is said, and/or asking questions through informal and formal interviews, collecting documents and artefacts – in fact, gathering whatever data are available to throw light on the issues that are the emerging focus of inquiry'*. The main characteristic of ethnography is that it aims to create a deep understanding of behaviour within a specific context. It is particularly useful when exploring unknown or new behaviours and investigates the meanings that are shared within this context that are considered salient in understanding group behaviours (Hammersley 1995; Punch 1998). The focus is on the meanings that people involved in the setting give to actions, and therefore considers the perspective of the participant (Punch 1998). Ethnography has the strength to investigate relationships and influences of complex cases where a wide range of variables is forming the observed reality (Punch 1998). It is therefore particularly useful when analysing a social process within a complex setting that includes organisations and institutions (Hammersley 1995).

In latest years that BIM has started to be used in the construction industry, researchers have used ethnographic methods for construction research studies that relate to BIM. Such studies include BIM's influence on collaboration and communication when used for mechanical, electrical and plumbing (MEP) system coordination by Dossick and Neff (2010), the challenges of its implementation in building design, construction and operation by Kerosuo et al. (2015), and an investigation of the on-site work and BIM use of site managers by Mäki and Kerosuo (2015). Studies that focused on low carbon buildings have also used ethnographic methods, such as Zapata-Poveda and Tweed (2014) who employed ethnographic methods to study the tools deployed by the design team to embed energy performance in building design. However, ethnographic studies that have focused specifically on EC are very limited, with the exception of Ekundayo et al. (2019) who studied the open source UK tools for EC counting.

Ethnographic research includes multiple data collection methods, such as interviews, document analysis, field notes and participant observation (Hammersley 1995; Speziale 2007). The research is flexible and emergent and its structure is continually developing as the study unfolds (Punch 1998; O'Leary 2004). Ethnographic studies include a small number of cases, the number of cases is defined by the research aims and the literature findings (Creswell 2017). Ethnography may not focus on the entire setting but on a particular aspect of the scene, which may be a process that is followed within the setting (Atkinson 2001). When this is the case, multiple case study can be used where several bounded cases are analysed through observation of that particular process included in all cases (Creswell 2017). The process under investigation unfolds before the researcher within a number of case studies where similarities and differences are highlighted in order to reach to a deeper understanding of both the process and the affecting factors that influence it. Ethnographic research is likely to be conducted in a small number of case studies to enable an in-depth investigation (O'Leary 2004; Silverman 2010). Considering the above, this study aims to focus on three or four case studies to enable a detailed investigation while facilitating the breadth of the study. This enables a better understanding of the process under investigation.

This research focuses on a particular aspect of building design, the inclusion of EC in design decisions and how it can be facilitated through BIM application, therefore ethnographic methods of non-participant observation, interviews and document analysis were applied through a selection of multiple case studies. This selection included a small number of cases to enable intensive research to be carried out.

3.2.4 Summary of research philosophy, approaches, strategies and methods adopted by this thesis

This thesis adopts a critical realist philosophy, according to which, a stratified ontology and relativist epistemology is followed. An abductive approach in relation to theory is adopted where procedures of retroduction and retrodiction are included as part of the critical realist philosophy adopted (section 3.2.1.1). The study follows an intensive critical realist research approach, according to which qualitative data is gathered (section 3.2.2.2) through case study and multiple case study strategies (section 3.2.3). Data collection methods follow an ethnographic approach and include non-participant observation, interviews and document analysis (section 3.2.3.1). Table 3.1 presents the above summary whereas the following section (section 3.3) describes in further detail the research design of the thesis.

Table 3.1 Summary of research decisions in relation to philosophy, approaches, strategies, and methods

Level of decision	Adopted by thesis
Research philosophy	Critical Realist
Approach to theory	Abductive
Approach to data	Qualitative
Research Strategies	Case study, Multiple case study
Research methods	Ethnographic methods: non-participant observations, interviews, document analysis

3.3 Research Design

This section describes in more detail the research design of the thesis in consideration of the main research principles that were adopted (see section 3.2.4) that aims to address the research objectives. The research objectives of the thesis are included in section 1.3.1.

The research design of the thesis follows the steps suggested by Danermark and Ekström (2019) for the development of explanations under a critical realist approach. These steps are covered in two phases, that correspond to the research objectives of the thesis. The first phase consists of an exploratory investigation of how EC considerations are set and addressed in a BIM-enabled project. This phase corresponds to objective 1 and includes description of how EC considerations are embedded in the sustainability approach of the project, how they are included in different building design stages, what aspects of EC are addressed and how and the way BIM is used for information management and assessment of EC. The main actors involved in the process are considered and the aim is to understand the process through observation and interpretations of the actors involved in the respective processes. The analysis of the phase 1 findings aims to move from description to analytical resolution through distinguishing and organising the various components that the findings brought to light thematically. Ultimately, Phase 1 analysis informs Phase 2. Phase 2 starts with the review of relevant theories in light of Phase 1 empirical analysis to identify a theoretical framework that can guide further data collection and analysis. This aims to enable theoretical reinterpretation and redescription of the phenomenon of setting and addressing EC considerations in a BIM-enabled design process. The development of a theoretical framework that draws from theoretical concepts and is informed by phase 1 findings follows; as such, the theoretical framework is theoretically and empirically informed. The framework is then applied and tested to enable the identification of causal mechanisms (retroduction) and the investigation of relationships between the identified mechanisms and their manifestation in specific contexts (retrodiction and contextualisation). This phase corresponds to objectives 2-4, whereas objective 5 draws from the achievement of the previous objectives to propose recommendations to facilitate EC considerations in BIM-enabled projects. Figure 3.2 presents the thesis phases and objectives against the five stages of critical realist explanatory research proposed by Danermark and Ekström (2019).

Thesis phases &Objectives	**Stages of Critical Realist explanatory research:**
Phase 1: Exploratory	
Objective 1*: Explore how EC considerations are set and addressed in a BIM-enabled project*	**1. Descriptions** **2. Analytical resolution**
Phase 2: Explanatory	
Objective 2*: Analyse the conditions and mechanisms that affect EC target setting and their communication through BIM* ***Objective 3****: Analyse the conditions and mechanisms that affect BIM use for addressing EC considerations*	**3. Abduction/ theoretical redescription** **4. Retroduction**
Objective 4*: Analyse the impact of context on setting and addressing EC considerations in a BIM-enabled project*	**5. Retrodiction and contextualisation**
Objective 5*: Propose recommendations to facilitate EC considerations in a BIM-enabled project*	

Figure 3.2 Research phases and objectives in relation to the stages of critical realist explanatory research as suggested by Danermark and Ekström (2019).

3.3.1 Unit of analysis and case study boundaries

In case study research, defining the unit of analysis is essential in order to establish the focus of the study (Yin 2009). The unit of analysis refers to the entity on which the research focuses (DeCarlo 2023). The unit of analysis defines sources of data which may include individuals, roles, social artefacts and relationships (Valerdi and Davidz 2009). This research focuses on the design stage of building projects to analyse EC considerations and the use of BIM to facilitate them. As such, the unit of analysis is the design stage of the building projects considered in the research as case studies. The sources of data, or units of observation, include individuals, roles, artefacts, and relationships involved in the design process that relate to EC considerations and the use of BIM.

A case study is a bounded system that has clear boundaries that define it. These boundaries relate to the group of people that form the case study, the geographic area that the case study is located and the time boundaries that define the beginning and ending of the case for the purposes of the study (Yin 2009). In this research study, the case studies refer to building projects therefore the group of people included in the case study are the professionals that take part in building design process and the client. This includes the principal design team: the architect and engineers, the project client, and expert consultants such as sustainability and BIM consultants. However, the list is non-exhaustive and the relevant professionals can vary on a case-to-case basis depending on who is involved in the setting and addressing EC considerations within the case study. Since the context of this research is the UK, the UK forms the geographical boundary of the case studies. As such, the stages of the building lifecycle considered cover the design process (Stages 1-4) as defined by the RIBA Plan of Work 2013 (section 2.2.2), a framework which is widely used in the UK.

3.3.2 Sampling and Case selection

As mentioned in sections 3.2.2.2 and 3.2.3.1, intensive critical realist research and ethnographic methods that are adopted for this thesis call for a small number of cases to enable in-depth analysis of the process that is being investigated (Alvesson and Sköldberg 2018). As such, this research considers three case studies for investigation. Purposive sampling of cases that represent specific characteristics enables comparisons between them and refinement of theoretical development (Dubois and Gadde 2002; Ritchie et al. 2014). The selection of the case studies followed purposive sampling to enable identification of mechanisms that affect how EC considerations are set and addressed in a BIM-enabled building design process (Phase 1), and the how these mechanisms are manifested in different contexts

(Phase 2). Due to the scope of this study, the selected case studies were projects for which high sustainability aspirations were set either by the client or the design team. The sustainability aspirations needed to be inclusive of EC considerations. The use of BIM was also a selection criterion, to enable the exploration of EC considerations in a BIM-enabled building design process. The case selection criteria applied to all cases to ensure cases were within the scope of the study are summarised as follows:

- Sustainability approach that is inclusive of EC considerations
- BIM use (BIM level 1 and above)

The case study for the exploratory phase of the research (Phase 1) aimed to explore EC considerations in a BIM-enabled project that represents the industry status-quo. As EC considerations are not considered separately but as part of the overall sustainability aspiration of projects (commonly as part of sustainability rating systems' requirements), the case that was considered during the exploratory phase did not consider EC separately, but as part of the sustainability rating system target of the project. Phase 2 aimed at the analysis of conditions and mechanisms for EC considerations in BIM-enabled projects and how they are manifested in different contexts. As such, the selection criteria for the cases considered in Phase 2 aimed at the enhancement of observations for cross-case comparison. The selection criteria related to differences with regards to EC expertise appointment for the projects and the use of BIM for information management and as a tool for EC calculations. The case criteria selection for Phase 2 and the potential for cross-case comparison in relation to each criterion is summarised in Figure 3.3.

Case study characteristics	Case Study 1	Case Study 2	Case Study 3	Cross-case comparison potential
EC considered separately	No	Yes	Yes	Case study 1 --- Case study 2&3 In relation to the inclusion of EC as a separate consideration to overall sustainability targets
EC expertise appointed	No	Yes	No	Case study 2 --- Case study 3 In relation to professionals involved in addressing EC considerations
BIM model used for EC calculations	No	No	Yes	Case study 2 --- Case study 3 In relation to the use of BIM as a software tool for EC calculations
BIM Level	Level 2	Level 2	Level 1	Case study 2 --- Case study 3 In relation to BIM as an information management tool for addressing EC
	Limited EC considerations BIM Level 2 (industry status quo)	EC considered but differently in relation to EC expertise appointment and BIM model use. Sampling difference to enable cross-case comparison		

Figure 3.3 Case study characteristics and sampling

3.3.3 Data collection methods

As mentioned in section 3.2.4, the thesis follows ethnographic methods of data collection that include interviews, observation and document analysis. These methods are described in more detail in the sections below.

Interviews are categorised as structured, semi-structured and un-structured depending on the planning and standardisation of questions and response categories (Punch 1998). In structured interviews, questions are pre-established and are standardised so that the same questions are asked to all respondents in the same order and manner and the responses fall into pre-set categories. These types of interviews are more appropriate when the focus of the research is the rationale of the respondents rather than emotional responses (Punch 1998). On the other hand, unstructured interviews are open-ended and follow a more flexible pattern. There are no pre-planned questions but rather, the questions are general at the beginning and then specific questions emerge as the interview unfolds. This type of interview is more appropriate when emotional responses are sought for. In the middle ground of these two extreme approaches to interview structuring are semi-structured or focused interviews (Punch 1998). In semi-structured interviews some structure is provided through an interview guide which may include questions or fairly specific topics to be covered during the interview. However, there is flexibility to add or remove questions according to the responses during the interview and the interviewee can expand on questions or topics (Bryman 2001). Converting verbal interviews into written transcripts allows for the organisation and closer analysis of interview conversations. Transcription enables a more systematic examination and serves as an initial step of the analytical process (Hammersley 2010). The extent and style of transcription can vary based on the type and objectives of the research. For example, the inclusion of pauses, repetition and tone of voice is necessary for psychological interpretations, whereas verbatim transcription is necessary for linguistic analyses (Kvale 1996).

Non-participant observation in research aims to document in detail participant behaviours in order to develop a narrative account of their actions (Bell et al. 2022). Furthermore, through observation the researcher gains access to events and behaviours within participants' work environments. As such, observation is inherently naturalistic occurring in the natural context of the observed events with the typical individuals involved in interactions that follow the natural flow of everyday life (Adler 1995). Observation extends the type of data that can be captured through semi-structured interviews with an extended focus on identifying and documenting specific incidents (Bell et al. 2022).

Document analysis enables the enhancement of the rigour of the study. However, the researcher needs to be critical of the integrity of the documents and acknowledge that documents inherently contain the interpretations of their creators (Knorr-Cetina and Harré 1981). By examining the embedded interpretations within texts, the researcher can provide validation and clarification of data obtained from other sources, such as interviews and observations. Documents thus enhance the ability of the researcher to interpret texts and the events they represent whilst taking into account their contextual mediation (Gephart 1993).

This thesis employed semi-structured interviews, non-participant observation and document analysis as methods for collecting data. However, there was variation of their use during the different research phases. Sections 3.3.5 and 3.3.6 present in more detail the data collection methods and analysis applied during the two phases of this research.

3.3.4 Ethical considerations

Patton and Patton (2002) suggested a list of ethical issues to be taken into consideration whilst conducting research that included: explaining the research purpose, informed consent of participants, participant confidentiality and advice. This research considered all these issues prior to data collection. An information sheet that included the research aims and specification of information about the data collection methods, data confidentiality and anonymisation, data retention and results dissemination was made available to the participants. A consent form was developed in accordance with Cardiff University guidelines so that, in conjunction with the information sheet provided, participants could provide their informed consent to participate in the research. Ethics approval was granted for both the interviews and the case studies by the Research Ethics Committee of the Welsh School of Architecture under references EC1709.334 and EC1711.347 respectively. The application process included the submission of the information sheet, the consent form, the interview guides and the Case Study Engagement Specification document. All the above documents are included in the Appendix.

3.3.5 Phase 1: Exploratory phase

This phase of the research corresponds to the first two stages of the critical realist research plan suggested by Danermark and Ekström (2019); it firstly aims at a thorough description of how EC considerations are set and addressed in a BIM-enabled building design process and secondly at analytically resolving the complexity of the process through identification of components, actors, dimensions and levels of analysis. This phase corresponds to research objective 1 (see Figure 3.2). Phase 1 data collection was extensive and included multiple sources of data that did not all prove relevant to the research focus. As this phase also aims to inform phase 2 data collection, phase 1 data collection methods are also analysed in relation to their usefulness for data collection refinement in Phase 2.

Phase 1 data collection included:

- **Professional Perspective Exploration Interviews:** semi-structured interviews with industry stakeholders to explore industry views about the role of Embodied Carbon (EC) in building design, Building Information Modelling (BIM) application and its potential to facilitate the inclusion of EC in building design. These interviews were not related to a specific building project, and captured the experience of the participants from various projects that they have been involved in.

- **Exploratory Case Study (Case Study 1):** involved collection of data for a specific building project Case Study (CS) where EC considerations and BIM application was investigated within the context of a building design process. The data collection for the CS included meeting observations, interviews with the project stakeholders and project document analysis.

The professional perspective interview data collection and analysis started at the beginning of the engagement with the exploratory case study and informed the engagement with the case study project. Figure 3.4 presents a timeline that shows when the professional perspective interviews took place in relation to the researcher's engagement with the case study.

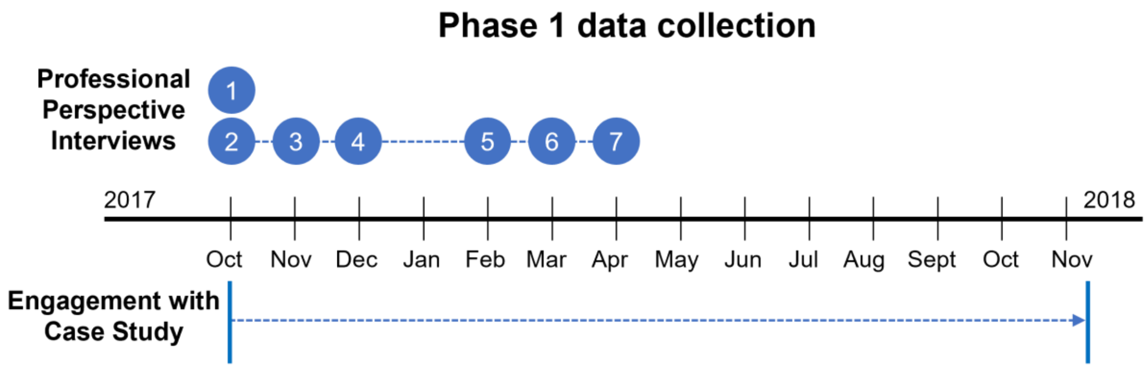

Figure 3.4 Timeline of data collection during Phase 1

3.3.5.1 Data collection

3.3.5.1.1 Professional Perspective Interviews

Seven semi-structured interviews were held with industry professionals to grasp their views on the role of EC in building design, the drivers and challenges for EC considerations in design and how EC information and assessment takes place throughout the design stages. The interviews also discussed the professional's views of BIM application in relation to EC information management and assessment and the potential of BIM to facilitate EC consideration and assessment for building projects. As the interviews were mainly aimed at informing engagement of the researcher with the Exploratory Case Study, the number of interviews was sufficient to guide the researcher engagement. Table 3.2 presents the main interview topics that the interviews covered. A more extensive interview guide was used for the interview process, particularly in adapting to the two different professions participating in the interviews. The interview guides for both professions are included in the Appendix.

Table 3.2 Professional perspective interview main topics

Interview topics					
Participant background information	Role of EC in building design	EC consideration drivers and barriers	EC consideration and EC assessment	BIM Application in relation to EC information and assessment	BIM potential to facilitate EC considerations and assessment

The interview respondents represented two main professions that are involved in building design and participate in addressing EC considerations: 1) Life Cycle Assessment (LCA) consultants /sustainability consultants and 2) architects (see section 2.4.3). The professionals that participated in the interviews were two LCA consultants, one sustainability consultant and four architects. The respondents were selected so that they represented a range of experience in the field. The architects selected had different expertise in relation to sustainability and BIM and their practice covered a range of project and client types (private/ public).

Table 3.3 presents the interview participant information in relation to the aspects described above. As this research's geographical focus is the UK, the participants were within the UK context. Interview duration was sixty to ninety minutes and took place either face to face (four interviews) or online using a real-time video conferencing tool (three interviews). All interviews were recorded and transcribed verbatim.

Table 3.3 Professional perspective interviews' participant information

Participant Number	Profession (acronym)	Years of experience	Company Type	Project types	Client types
1	LCA Consultant (LCA.C)	10	Global Sustainability Consultancy	All	Mostly big private developers
2	LCA Consultant (LCA.C)	5	Environmental Consultancy with focus on LCA (SME)*	Mostly commercial	Mostly private clients
3	Sustainability Consultant (Sust.C)	15	Sustainable Design Consultancy (Micro-enterprise)	All	Both private and public
4	Architect with Sustainability expertise (ARCH)	8	Architectural Practice (SME)*	Most types excluding small domestic	Both private and public
5	Architect with Sustainability expertise (ARCH)	4	Architectural Practice (SME)*	Residential, commercial, retail	Both private and public
6	Architect with BIM expertise (ARCH)	25	Local Government	Mostly education, as well as commercial, leisure and some social care	Public sector
7	Architect (ARCH)	4 years	Architectural Practice (SME)*	Residential, commercial	Private
* SME: Small Medium Enterprise					

3.3.5.1.2 Exploratory Case Study

Confirmation of researcher engagement with the project took place in October 2017 during the project's RIBA Stage 1. Data collection started at the beginning of concept design, RIBA Stage 2 of the project. The engagement lasted fourteen months and covered the entire design stage (see Figure 3.5). The data collection included non-participant observation of key project meetings, interviews with relevant project stakeholders and document analysis.

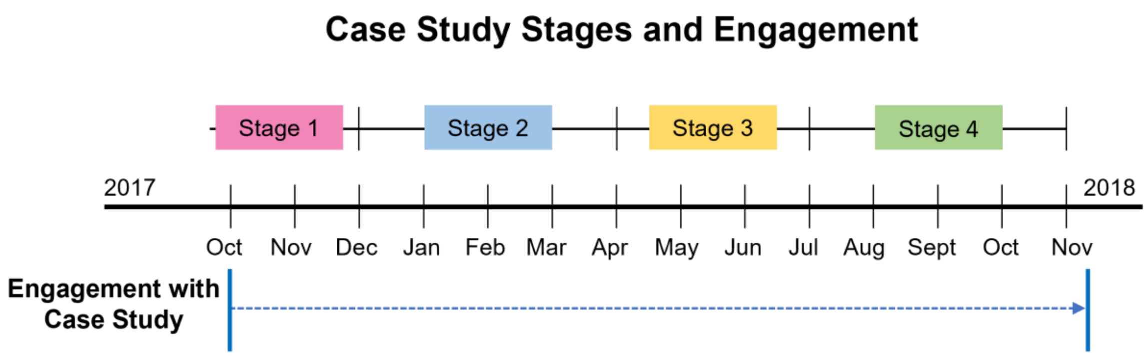

Figure 3.5 Phase 1 Exploratory Case Study RIBA stages and researcher engagement

The sections below discuss in more detail each mode of data collection, the project meeting attendance, the interviews with project stakeholders, and the project document review. As mentioned in section 3.3.5, the purpose of this exploratory case study is twofold. The first purpose is to explore how EC considerations are established and enacted in a BIM-enabled building design process. The second purpose is to inform and refine further data collection for Stage 2. Therefore, the results presented also consider the usefulness of the data collected through the data collection methods in relation to their relevance to the research topic and aims.

Non-participant observation – Project meetings

Non-participant observations took place during attendance of project meetings (listed in Table 3.4). The type of meetings attended were decided after the initial meeting with the lead architect in relation to their relevance to the research topics. The main project meetings relating to design development were the Design Team and Progress Team meetings (DTMs and PTMs respectively).

The DTMs aimed at coordination amongst the different design teams whereas PTMs served as an update of the state of the design from all teams to the project manager and the client. The researcher attended these meetings with an aim to observe how the design team coordinated with specific focus on a) material selection which relates to the project's EC impacts and b) design development which relates to both EC impacts and BIM use. Although the design team meetings were aimed to be just for the design team, most of them also included a project manager and a client representative. Therefore, the DTMs and the PTMs were very similar in context and for dates that they coincided they were combined.

Other meetings such as a User Group meeting and a BIM coordination meeting were also attended. The User Group meetings' aim was for the designers to understand the users' needs. These were more relevant during RIBA Stage 2 at the early stages of design and the researcher attended one such meeting with the aim of identifying if there was any consultation taking place from the designers to the users in terms of material selection. However, as the users and the client are separate for this case study, it was identified and confirmed by the design team that these meetings were aimed for the designers to understand the user needs rather than for the designers to provide consultation to the client. Therefore, User Group meetings were deemed unrelated to this research and the researcher stopped attending them. The BIM meeting took place during RIBA Stage 3 aimed at coordinating the team and signified the start of a federated and coordinated model between the design teams. The researcher attended this meeting to observe how the teams discussed BIM use for coordination between the teams and BIM model use. There were no further BIM meetings that took place during the researcher's engagement with the case study.

Meeting minutes as well as field notes from meeting attendance were used as data collected from the meetings. Meeting attendance started in January 2018 and spanned across ten months, covering RIBA Stages 2-4. Overall, 12 face-to-face meetings were attended resulting in 40 hours of meeting observation. For a further 4 meetings when attendance was not feasible, meeting minutes were used for analysis.

Table 3.4 includes a list of the meetings that were used for data collection and analysis. In bold are the meetings that were attended by the researcher, and the rest are the meetings that were analysed through meeting minutes. A review of the information that was gathered by meeting attendance and meeting minutes is also included and compared to the information gathered by project documents review to identify if meetings contributed any additional information to the information gathered through project documents.

Table 3.4 Exploratory Case Study meetings used for data collection.

Project stage	Meeting No.	Date	Type of meeting (code)	Information additional to minutes review
Stage 2	**1**	**17/01/18**	**User Group meeting (UGM)**	
	2	**24/01/18**	**Design Team meeting (DTM)**	Information too generic
	3	07/02/18	Design Team meeting (DTM)	
	4	21/02/18	Combined Design Team meeting and Progress meeting (DTMPM)	
	5	**07/03/18**	**Design Team meeting (DTM)**	
	6	**21/03/18**	**Design Team meeting (DTM)**	
	7	**21/03/18**	**Progress meeting (PM)**	
	8	16/04/18	Design Team meeting (DTM)	
Stage 3	**9**	**02/05/18**	**Design Team meeting (DTM)**	Available in meeting minutes
	10	**15/05/18**	**BIM coordination meeting (BIMM)**	
	11	**16/05/18**	**Combined Design Team meeting and Progress meeting (DTMPN)**	
	12	**30/05/18**	**Design Team meeting (DTM)**	
	13	**13/06/18**	**Combined Design Team meeting and Progress meeting (DTMPM)**	
	14	27/06/18	Design Team workshop (DTW)	Available in meeting minutes
	15	**18/07/18**	**Combined Design Team meeting and Progress meeting (DTMPM)**	Information too generic
Stage 4	**16**	**04/10/18**	**Design Team meeting (DTM)**	

Colour coding key for 'Information additional to minutes review'

	No contribution: information irrelevant
	Some contribution: Additional information that is either not significant or available in meeting minutes
	Contribution: Information that is both significant and was only available through meeting attendance (not in meeting minutes).

Although meeting attendance aimed to enrich information and data collected for this case study, it was observed that it did not have a significant contribution to the data collected from the project documents and almost any contribution they made was either not very important or available through the meeting minutes. More specifically, as it can be seen in Table 3.4, only four out of sixteen attended meetings offered valuable insight which was only recorded in the researcher's notes from meeting attendance and not included in documents such as the meeting minutes. In four other attended meetings, information that was additional to the information gathered from documents was available but was either too generic or available in meeting notes.

Interviews with Case Study stakeholders

Acquiring information from key stakeholders didn't always take the form of a formal interview but included opportunistic interviews during the attended meeting breaks and information gathered from the stakeholders through email exchange.

At the start of the engagement with the case study, the project lead architect and the sustainability consultant were interviewed to get an understanding of the project characteristics, sustainability aspirations and design team professionals. The initial interview with the project lead architect took place during RIBA Stage 1 of the project. It was aimed to discuss the project and establish if the project satisfied the criteria for inclusion as a case study for this research. During the discussion, information about the project timeline, the design team, the basic sustainability aspirations and BIM use was gathered. Further to this, a plan for the researcher engagement with the project was discussed and the meetings that would be relevant to be attended by the researcher were identified. This interview didn't have an interview guide, the 'Case Study Engagement Specification' document (Appendix) was used to guide the discussion that related to researcher engagement with the case study. Detailed notes were kept by the researcher as a record of the interview.

During RIBA Stage 2, an interview with the project's sustainability consultant took place to understand more detail of the project's sustainability aspirations. This interview was audio recorded and transcribed, and a complete interview guide can be found in the Appendix.

The topics that were discussed included:

- the project's sustainability strategy,
- information requirements for EC material impact assessment,
- when these occur in the design process and
- the design team professionals that are expected to give the material information.
- BIM use for this project in relation to the exchange of the above information was also discussed.

During RIBA Stages 2 and 3, meeting attendance was also used to facilitate opportunistic interviews with project stakeholders. As these interviews took place during meeting breaks or after the meetings, they were not transcribed verbatim; however, notes of the discussion were taken by the researcher. These opportunistic interviews involved the client, members of the principal design team and sustainability consultant and took place at least once per design stage.

Project document review

The main project documents reviewed included the project's Feasibility report, RIBA stage reports, BREEAM reports, and the main BIM project documents. Other documents reviewed included the Architectural Outline Specification, the Design and Access Statement and National Building Specification material specifications (55 documents). Other documents such as the project drawings, risk registers and value engineering options were also reviewed to gain a general understanding of the project.

The complete list of documents used for data collection and analysis are presented in Table 3.5. The last column highlights the relevance of documents in relation to the research focus.

Table 3.5 Exploratory Case Study reviewed documents.

RIBA Stage	Date published	Document title	Relevance to Sustainability EC and/ or BIM: Yes (Y) /No (N)
Stage 0	November 2016	Feasibility Report	N
Stage 1	November 2017	**RIBA Stage 1 Report**	Y
Stage 2	April 2018	**BREEAM End of Stage 2 Report**	Y
	June 2018	**RIBA Stage 2 Report**	Y
Stage 3	May 2018	**BREEAM Stage 3 Actions**	Y
	May 2018	**Pre-tender BIM Execution Plan (BEP**)	Y
	May 2018	**Master Information Delivery Plan (MIDP)**	Y
	May 2018	**Model Production Delivery Plan (MPDT)**	Y
	July 2018	**Design and Access Statement**	Y
	August 2018	**Outline Architectural Specification**	Y
Stage 4a	October 2018	National Building Specification (NBS) material specifications	Y
	November 2018	**BREEAM Stage 3 Report**	Y

3.3.5.1.3 Navigating the Labyrinth: Reflections on the challenges and insights in engaging with the Exploratory Case study and data collection

The engagement with the exploratory case study during the first phase of the research involved extensive data collection through meeting observation, project document review and interviews with case study stakeholders. As the case study did not have a strong EC consideration approach nor a strong BIM approach, the data collected did not initially appear to have relevance to the research topic. As such, the researcher struggled to comprehend their usefulness in addressing the research objectives and informing the research process. This created a feeling of frustration to the researcher who was in a ‘lost in the data’ environment and was trying to find ways to make sense of the data collected. As part of an evaluation of the engagement with the exploratory case study, the researcher appreciated their exposure to a real-life setting that represented the industry status quo. This helped the researcher realise the place of EC in the building design process as well as the use of BIM, both of which were hidden and unclear amongst the myriad of decisions and struggles that design team was being presented with. What proved challenging was that a lot of time was dedicated to observing meetings that did not yield information that was related to the research topic.

During this phase the researcher developed an appreciation of the insights that were brought by what was 'not there' rather than what was being observed. This also made the researcher reflect on how insights of the phase 1 data collection process can inform subsequent engagement with case studies in phase 2. An evaluation of relevance and usefulness of phase 1 data collection was added to the analysis for each data collection method in an attempt to make sense of the situation. This evaluation facilitated a more targeted approach to data collection during phase 2, which only included project document analysis and interviews with project stakeholders.

3.3.5.2 Data analysis

Thematic analysis was employed to analyse the findings of Phase 1. Thematic analysis is defined as the process of sense-making and reduction of a volume of qualitative data in an effort to identify core consistencies and meanings (Patton and Patton 2002). The analysis began with open-coding which entails breaking down qualitative data into discrete parts for close examination and identification of similarities and differences (Saldaña 2013). This step generated first-order themes. In the next stage a second coding cycle was conducted which is defined by an aim to *'develop a sense of categorical, thematic, conceptual, and/or theoretical organization from the array of First Cycle codes*' (Saldaña 2013, p. 207). This coding cycle employed focused coding, which aims to organise the first order themes according to thematic similarities (Saldaña 2013). A final step was conducted to organise the themes into aggregate dimensions and consider the relations between the identified themes. Axial coding *'describes a category's properties and dimensions and explores how the categories and subcategories relate to each other'* (Saldaña 2013, p. 209), as such it was deemed appropriate for this step. The coding process was facilitated through the use of Computer-aided Qualitative Data Analysis Software (CADQAS); the software used was NVivo11. Although the use of qualitative software facilitated assigning excerpts of texts from interview transcripts or project documents to codes, decisions about coding and interpretation of data cannot be done by the software and are based on the researchers creativity (Bryman 2001). The aggregate dimensions and the links between themes that fell within the same or different aggregate dimensions corresponded to Leavitt (1965) model which highlights the interdependence the socio-technical parts of the analysed system. Diagrams were used to visualise the moving from first to second order themes (Figures 4.1 and 4.2) and aggregate dimensions and a Venn diagram (Figure 4.3) was used to show the final aggregate dimensions with the corresponding themes and their relationships (Checkland and Scholes 1999).

Phase 1 results and analysis are presented in detail in Chapter 4. As mentioned in section 3.3.5, this exploratory phase aimed to inform Phase 2 in relation to data collection and the identification of the theoretical underpinnings that Phase 2 would follow. A summary of Phase 1 is presented in Figure 3.6.

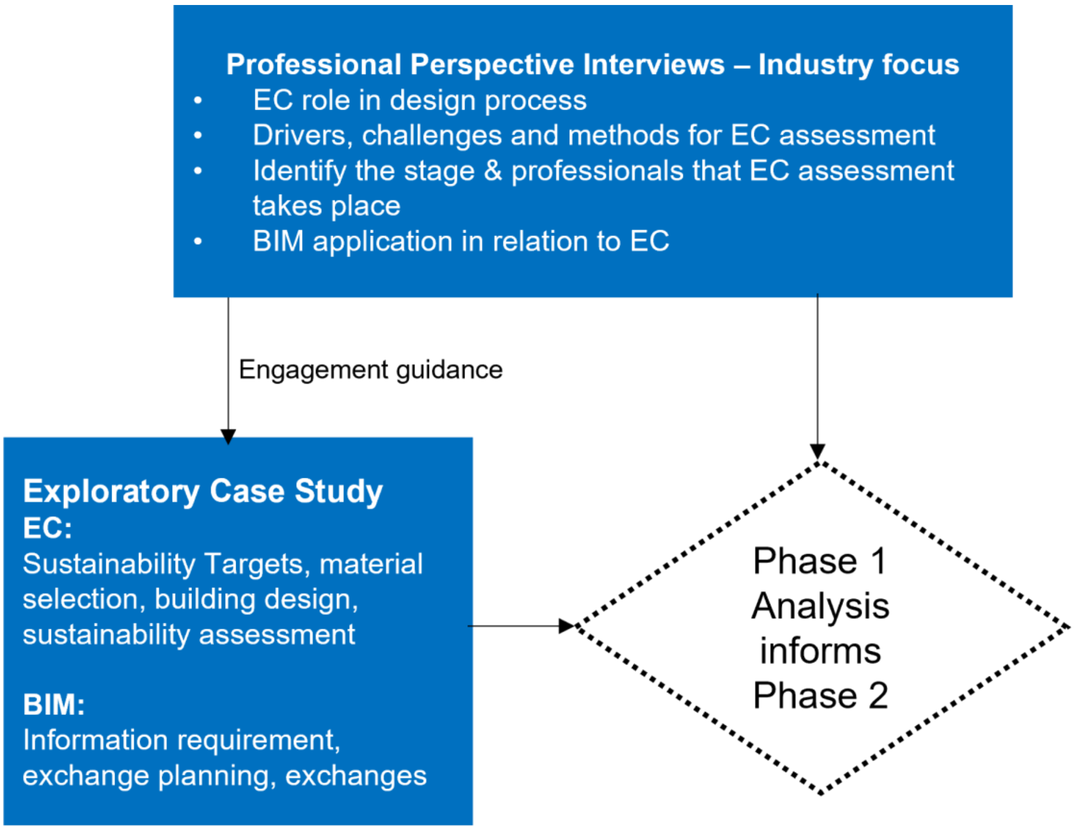

Figure 3.6 Summary of Phase 1: Exploratory phase of the research

3.3.5.2.1 Navigating Complexity: Reflections on the nuances of Phase 1 thematic analysis

Phase 1 analysis entailed addressing complexity through a great amount of decisions. During the thematic analysis conducted in phase 1, moving from the empirical data to the generation of themes and eventually their organisation to aggregate dimensions was not always straightforward. Themes correlated and impacted each other and in many cases a clear association with an aggregate dimension was not apparent. The organisation of the themes in dimensions required the critical comprehension of the researcher and introduced subjectivity to the analysis which is inherent in qualitative research. Although the themes were organised in aggregate dimensions according to the critical interpretation of the researcher, the complexity encountered and the correlations between themes was expressed through the inclusion of links between the different themes amongst and within the aggregate dimensions.

3.3.6 Phase 2: Explanatory

Phase 1 analysis highlighted the importance of the people dimension and a requirement for further exploration of the relationship between people and structures. The initial step of Phase 2 was to review relevant socio-technical theories in order to identify an appropriate framework to study the interdependence of agency and structure. Structuration theory was found to be aligned to the research aims as informed by Phase 1 analysis and the most appropriate framework to draw the theoretical underpinnings for the Phase 2 analytical framework development. The critical realist philosophical stance of the thesis considers that an external stratified reality exists, which may be considered inconsistent with structuration theory's duality of structure, according to which, structure is recursively reproduced through agency and is both the medium and the outcome of social practices. However, this is reconciled in the thesis methodologically rather than ontologically, as reality is considered to 'hold still' for the purpose of the data collection and analysis of the social system under investigation. The Phase 2 analytical framework was based on structuration theory and empirically informed by findings of Phase 1 analysis. The development of the structuration theory-based Phase 2 analytical framework is presented in detail in Chapter 5. The developed Phase 2 analytical framework was then applied to the case study project considered in Phase 1 (Case Study 1) and two more case studies (Case Study 2 & 3). These analyses are presented in Chapter 6 and correspond to objectives 2&3. A final step of this research Phase was the cross-case comparison that considered similarities and differences amongst the three cases to analyse the impact of context on setting and addressing EC considerations in a BIM-enabled project. The cross-case comparison is presented in Chapter 7 and corresponds to objective 4.

3.3.6.1 Data collection

Phase 2 data collection and analysis was theoretically driven and informed by Phase 1 analysis and data collection method review. Therefore, in Phase 2 data collection was more targeted and only included document analysis and interviews with key stakeholders of the case study projects. This also enabled the retrospective engagement with the case studies, as meeting attendance was not part of the data collection methods for this phase. This section presents the data collected for the case studies considered in phase 2. Since Case study 1 was the Exploratory case considered in Phase 1, presentation of the collected data for this case has been included in section 3.3.5.1. While this section focuses on the data collected for Case Study (CS) 2&3. Data collection for cases 2&3 did not take place simultaneously; data collection and analysis for CS2 was completed before the initiation of CS3 data collection. As such, CS2 analysis informed subsequent data collection for CS3 and enabled more focused data collection for CS3.

Case Study 2

The researcher engagement with Case Study 2 started in February 2018, when the project was in RIBA Stage 3 and covered RIBA stages 1-3 as the design moved to the contractors at RIBA Stage 4. The engagement started with an initial interview with the LCA consultant. This interview gave useful insights about the EC assessment for the project and gave direction on structuring the rest of the interviews for the case study. A set of interviews were conducted in May 2018, just after the end of Stage 3 and when the project was entering Stage 4, and included an interview with the Client, the lead architect and the LCA consultant (see Figure 3.7). The interview guides that were used for these interviews can be found in the Appendix. The interview with the client resulted in further data collection that included email conversations between the client, the BIM consultant and the LCA Consultant which referred to the use of the BIM model for LCA assessment for the project. The emails were forwarded to the researcher by the client and formed a very useful resource as they demonstrated the client ambitions for using BIM to facilitate the LCA process, and the solution that was given on this matter by the collaboration of the BIM and LCA consultants to achieve this ambition. The data collected for this case study also included project documents such as the end of stage RIBA reports and BIM information management project documents. The complete list of the reviewed documents is presented in Table 3.6. As there were separate RIBA report documents conducted by each of the principal design team professional groups, the following abbreviations have been added at the end of RIBA document title to distinguish between the different professional group documents:

ARCH: Architects

MEP: Mechanical, Electrical and Plumbing Engineers

STR: Structural Engineers

Other documents such as project drawings, risk registers, component schedules, were also reviewed to grasp a better understanding of the project but are not listed in Table 3.6 as this information was included in the project reports.

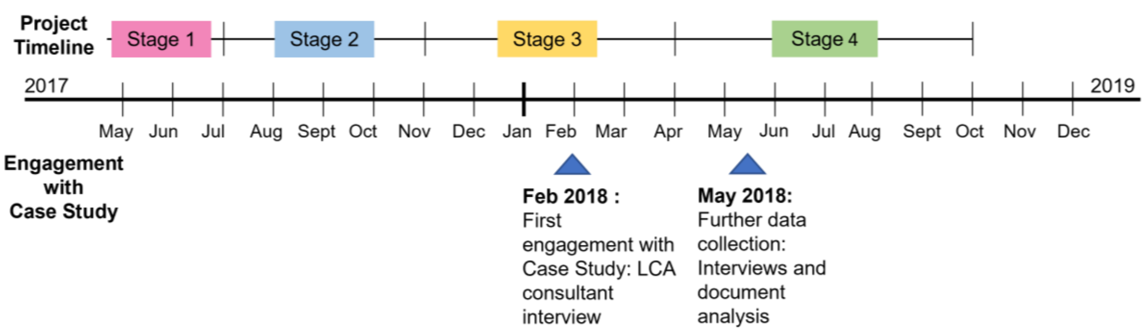

Figure 3.7 Case Study 2 project timeline and researcher engagement

Table 3.6 Case Study 2 Project documents reviewed.

RIBA Stage	Date published	Document title
Stage 1	July 2017	RIBA Stage 1 Report ARCH
	July 2017	RIBA Stage 1 Report STR
	July 2017	Employer Information Requirements (EIR)
	July 2017	Pre-tender BIM Execution Plan (BEP)
Stage 2	September 2017	Request for Information documents – Façade Carbon Footprint Data
	October 2017	RIBA Stage 2 Report ARCH
	October 2017	RIBA Stage 2 Consultant report
	October 2017	RIBA Stage 2 STR
	October 2017	RIBA Stage 2 comments Client
Stage 3	April 2018	RIBA Stage 3 Report ARCH
	April 2018	Specification A and Z sections
	April 2018	RIBA Stage 3 Report STR
	April 2018	STR Concrete Specification
	April 2018	STR Steelwork Specification
	April 2018	RIBA Stage 3 Report MEP
	April 2018	Pre-construction Services Agreement (PCSA) Report
	April 2018	Lighting Design Report
	April 2018	Client comments on Stage 3 Reports
	April 2018	Allocating Model and Drawing Production

Case Study 3

As mentioned in section 3.3.6.1, the data collection for this case study was informed by the analysis of CS2, therefore less data was collected but it was more focused. The engagement with Case Study 3 started in April 2021 when the project had entered its construction stage (RIBA Stage 5). This initial engagement included review and analysis of one key project document, the project's Embodied Emissions Assessment report and a research project report (Anderson and Adams 2020) which included CS3 as an example of tackling and assessing embodied carbon. After the analysis of the above documents, further data was collected in the form of an interview with the project's lead architect, who conducted the Life Cycle Assessments (LCA) for the project (see Figure 3.8). As the project was a BIM level 1, no BIM information management documents such as the Employer's Information Requirements (EIR) or the BIM Execution Plan (BEP) were produced for the project. The use of BIM in relation to embodied energy calculation was captured by the Embodied Emissions Assessment report and the interview with the lead architect who conducted the LCA for the project.

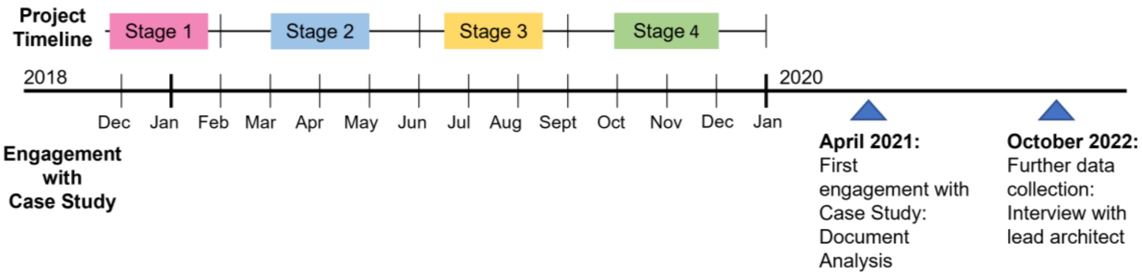

Figure 3.8 Case Study 3 project timeline and researcher engagement

3.3.6.2 Data analysis

Phase 2 data analysis was based on the analytical framework developed based on structuration theoretical concepts and Phase 1 analysis findings. The developed framework includes two analytical steps: the *Conditions analysis* and the *Analysis of strategic conduct.* The *Conditions analysis* studies the relationship amongst contextual conditions whereas the *Analysis of strategic conduct* studies the impact of conditions on agency. Social Network Mapping (SNM) was used to visualise the relationships amongst contextual conditions (in Conditions analysis) and the impact of conditions on project outcomes (in Analysis of strategic conduct). Some basic Social Network Analytics (SNA) were used to highlight attention points and address the complexity of the network being analysed; however, the networks were mainly used for visualisation rather than an extensive Social Network Analysis. The two analytical steps and the use of SNM are presented in more detail in Chapter 5. The two analytical steps led to the establishment of Condition-Mechanism-Outcome (CMO) configurations for each case study. The CMO configurations summarise the contextual conditions that enabled or constrained project outcomes and establish the causal mechanisms that contributed towards the project outcomes (Pawson and Tilley 1997). A cross-case comparison was then conducted which aimed to identify contextual similarities and differences amongst the three cases and analyse the impact of context on setting and addressing EC considerations in a BIM-enabled design process. The cross-case comparison provided a deeper understanding that led to explanatory accounts of what affects EC considerations and how they are addressed in BIM-enabled projects. The cross-case analysis concluded with the generation of pathways that consider the conditions and mechanisms required for setting and addressing EC considerations in BIM-enabled building design. The cross-case comparison is presented in detail in Chapter 7 and contributes towards the fifth research objective of the thesis.

3.3.7 Summary of Research Design

The Research design section of this thesis provided a description of the research unit of analysis and system boundaries (section 3.3.1), presented information about the sampling and the selection criteria of the case studies (3.3.2) and presented an overview of the data collection methods used (3.3.3) and the ethical considerations of the research (3.3.4). The two main phases of the research were presented in detail in section 3.3.5 and section 3.3.6. Table 3.7 provides a summary of the two main phases of this research. A table that includes the roles of the professionals interviewed during the two research stages is available in the Appendix.

Table 3.7 Summary of Research Design: Research phases, data collection and analysis, corresponding objectives and chapters in thesis.

Research Phase	Data collection	Data analysis	Corresponding objective	Results chapter in thesis
Phase 1: Exploratory				
Professional perspective Interviews	Semi-structured interviews	Thematic Analysis using coding.	1. Explore how EC considerations are set and addressed in a BIM-enabled project	Chapter 4
Exploratory Case study (Case study 1)	Participant observation Document analysis Interviews with key stakeholders			
Phase 2: Explanatory				
Three Case Studies: Case Study 1, 2&3	Document analysis Interviews with key stakeholders	Analytical framework based on structuration theory and informed by Phase 1 findings SNM visualisation	2. Analyse the conditions and mechanisms that affect EC target setting and their communication through BIM 3. Analyse the conditions and mechanisms that affect BIM use for addressing EC considerations	Chapter 6
Cross-case comparison		Based on cases analyses: identification of contextual similarities and differences amongst the three cases and analysis of the impact of context.	4. Analyse the impact of context on setting and addressing EC considerations in a BIM-enabled project 5. Propose recommendations to facilitate EC considerations in a BIM-enabled project.	Chapter 7

Chapter 4 Exploratory Phase results and analysis

4.1 Introduction

This chapter presents the results and analysis from the Exploratory (Phase 1) data collection. This phase included two aspects of data collection and analysis: 1) Professional Perspective Exploration Interviews and 2) Exploratory Case Study (Case Study 1) as discussed in more detail in section 3.3.5. This chapter is divided into two main sections that present the results and analysis the Professional Perspective Exploratory Interviews and the Exploratory Case Study respectively. An analysis that considers all findings of this Exploratory phase follows and conclusions are drawn to inform the data collection and analysis of the subsequent research phase: Explanatory phase (Phase 2).

4.2 Professional Perspective Exploratory Interviews

As discussed in detail in section 3.3.5, the Professional Perspective Exploratory Interviews were not related to a specific project and mainly aimed at informing engagement of the researcher with the case study. The interviews explored the professionals' views about the role of Embodied Carbon (EC) in building design, Building Information Modelling (BIM) application and its potential to facilitate the inclusion of EC in building design. The interview respondents represented two main professions that are involved in building design and participate in addressing EC considerations: 1) Life Cycle Assessment (LCA) consultants /sustainability consultants and 2) architects. The participant selection criteria are discussed in section 3.3.5.1.1 and participant information is presented in Table 3.3.

The interview topics are included in Table 3.2 and are used to present the results and analysis of the interviews. Reference to participant quotes is made at the end of each quote, by combining the participant profession acronym and participant number as presented in Table 3.3, for example: LCA.C-1, Sust.C-3, ARCH-4.

4.2.1 The role of EC in building design

The role of EC in building design was discussed and parameters that affect it such as procurement routes, types of building projects and the client were considered. The role of EC was found by most participants to be non-existent in their practices, only two architects mentioned one or very few projects in their practice that included

EC considerations. They found that EC is not included in the sustainability considerations for projects:

> *'I think that EC is way at the bottom of the list in fact it's in an invisible list for most people' (ARCH- 6).*

Sustainability in projects is mostly driven by the sustainability rating system achievement ambition and Part L regulations:

> *'Apart from BREEAM[2] there is no other reason for an architect to consider these things' (ARCH-6).*

Both regulations and BREEAM have a clear focus on Operational Carbon (OC) which is reflected in the sustainability approach of projects:

> *'Most of sustainability decisions that are made are based around BREEAM requirements, planning requirements and still most of the energy and sustainability work is done in terms of OE and part L regulations' (ARCH-4).*

One of the participants mentioned that although the industry is behind in relation to EC inclusion in building design, practices that focus on the use of timber tend to be an exception to this:

> *'Very few practices who focus on this, particularly practices that work with cross laminated timber, they tend to look a little bit more on EC as their unique selling point' (ARCH-4).*

The future role of EC in building design was also discussed with the participants, to get their views on the growing importance of EC in the whole life carbon contributions of buildings. All the respondents acknowledged the growing importance of EC in the overall carbon impact of buildings, and it was acknowledged that the current focus of regulations on OC has resulted in more efficient buildings with regards to their operation, making EC the next thing to tackle:

> *'I would actually say that it is more important that OC now' (ARCH-4).*

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[2] Building Research Establishment Environmental Assessment Method (BREEAM) is a sustainability rating system widely used in the UK.

'Part L has improved significantly the performance of buildings and therefore other factors like EC start to permeate trough' (Sust.C-3).

With regards to when EC reduction is going to enter legislation, there was a range of opinions from 3-20 years:

'I think that is not too far off, within a frame of 3-5 years' time we will be seeing regulations in some form' (LCA.C-2) 'I am sure it will get to a stage, I don't think it's soon, in 15-20 years that we will start seeing some EC legislation' (LCA.C-1).

With regards to project related factors that affect EC considerations, it was found that, the client has a greater influence on the role of EC in projects, regardless of the procurement route. This includes Design and Build procurement where the contractor has more control over the final product. The contracted deliverables and targets set by the client at the project's outset need to be fulfilled; as such, the contract and targets established by the client play a crucial role in shaping EC considerations throughout the project:

'As long as the right conditions are set by the client either in the form of contractual obligation but also the particular type of team relationships and hierarchy and organisation each project follows it is effectively down to that' (LCA.C-2),

'It depends what's in the contract, if a specific requirement for EC is in the contract then the contractors can' really change that. So Design and build is usually thought of as weak in terms of the contractors coming and doing whatever they want but it really depends' (ARCH-4).

4.2.2 EC consideration barriers and drivers

4.2.2.1 Barriers

Current UK building legislation on conservation of fuel and power (Part L) and Sustainability rating systems such as BREEAM heavily focus on OC. This has impacted the knowledge and understanding of overall carbon impacts by building professionals:

'If you ask how sustainable your building is they will talk about energy and renewables, not other aspects of building design' (Sust.C-3).

This lack of understanding has led building professionals to perceive EC considerations as an additional layer of complexity that they don't find meaningful adding to the design process:

> *'they don't find it important to add another layer of complexity to all the layer of stuff they have to consider', 'You have to try and lead people, make it justifiable so that any effort they make about learning these things has a payback, has a meaning' (ARCH-6).*

Adopting a method where information is added as intuitively as possible was highlighted as a way to address this complexity through the use of tools that link to the design process:

> *'entering information in an as intuitive a method as possible will help you to ensure that the results you get are not only meaningful but it also overcomes architect's reluctance to even consider these things because at the moment we have all these different things in our heads, we all know it to be a holistic process, and the trick is if we can try and make the software understand the different parts in the process so we can link it so LCA analysis helps you to make more informed choices at the design stage, that is the holy grail. We will automatically end up then with much more sustainable buildings with low EC as a natural outcome of the process and if we can get to that stage that will be the best for everybody.' (ARCH-6).*

For professionals who have been involved in the assessment of EC for their designs, the main barrier identified was related to building material EC data:

> *'Industry wide it [the main barrier] is having a reason to do it in the first place but assuming that you want to do it I think the main issue is data' (ARCH-4)*

> *'You can only get so much primary data from the client and the supply chain, so a lot of the lifecycle has to be filled in with secondary data' (LCA.C-1).*

The difficulty to build up a secondary database for building materials and the accuracy of the industry-wide available databases were mentioned as the main concerns in relation to the use of secondary data:

> *'it is a lot of effort to build up the database' (ARCH-4),*

‘Secondary data are then used to fill the gaps with variant degrees of quality’ (LCA.C-1).

The OC focus of regulations and sustainability rating systems also affects how clients prioritise sustainability requirements of building design:

‘But for a client it [embodied carbon] tends to have a lower priority because other considerations tend to have a regulatory impact so if you don’t get a certain part L result then you won’t get a BREEAM assessment good score and it might be visibly less sustainable to the market’ (ARCH-4).

This OC focus leads to lack of a market drive for EC inclusion in building design, particularly if its inclusion also results in additional capital project cost:

‘I would say that if it something has a specific cost implication, that is more likely to be value engineered out than something else’ (ARCH-4).

The appointment of an LCA consultant to guide EC cardon reduction which adds to the capital cost of the project is therefore not frequent and it is most common for large projects:

‘the larger the project the more likely that the client will have a fee that they can pay to a carbon consultant. If it is a very small project, chances are that you wouldn’t really be able to add a consultant for something so specialist.’ (ARCH-4).

In cases where LCA assessment has taken place during the building design, this was not formally mentioned in the project documents:

‘one client had a consultant measuring EC and that was kind of a general push to reduce it but there was not a contractual requirement and it was not part of the brief’ (ARCH-4).

Architects often advise clients in setting up the brief, however, effective communication of client requirements is not always achieved:

‘One thing that is absolutely certain is that clients are really, really bad at writing briefs, architects are not particularly good at it either, but clients are spectacularly bad. Architects in many cases are not very good at

communicating with clients and are not very often aware of their needs.' (ARCH-6).

The lack of a formal inclusion of EC in project documents hinders EC carbon reduction efforts of the design team to be actioned during the construction stage, particularly for Design and Build contacts:

'The issue is if the client doesn't ask for it and it is a Design and Build, we can't tell the contractor that they have to stick to the material because it has a certain EC because if they ask the client can we use a cheaper material with a higher EC, and the client doesn't care they will choose that material and there isn't much we can do about it' (ARCH-4).

This creates a barrier for the building design team to take leadership and make a bottom-up effort to include EC considerations in building design. In the cases where there is an EC target for the project, this commonly refers to an overall figure for the building rather than targets that refer to building elements:

'We specified a raised access floor which has a much lower EC than most raised access floor systems, and the contractor didn't proceed with that and went to a traditional system with a much higher EC, but what they could do is to try and reduce EC from somewhere else in the building by for example increasing the GGBS content of the concrete. So it kind of depends where the contractual requirement lies, but it usually lies at the carbon overall figure, rather than in specific specifications.' (ARCH-4).

This relates to both the carbon target setting and the contractual requirements that relate to the project's procurement. As mentioned in the quote above, for a Design and Build project, the contractor could change the design team specifications that were aiming at further EC reductions by meeting the EC target that was at building level.

4.2.2.2 Drivers

A top-down leadership approach to push for the inclusion of EC considerations in building design has taken place by building professionals through consulting relevant industry bodies for the creation of EC regulatory requirements:

‘we have done a lot of work in trying to promote some sort of regulatory requirement through the London Plan Consultation, so we’ve been trying to put EC requirement in the London Planning Policy’[3] *(ARCH-4).*

The top-down approach was considered an effective way to enable EC considerations and assessment to be addressed within the industry:

‘So what we wanted to do is to raise the issue so that contractors and developers would be reporting the carbon emissions on a level plain field using the same methodology. And at that point you start to get competition, and there would be some sort of reason for people to start trying to reduce carbon and it would basically open the door to allow target setting’ (ARCH-4).

Increasing their market competitiveness was mentioned as a driver for different members of the construction industry, which included contractors and the building material supply chain:

‘Contractors are doing it [EC assessment] to a degree for their own sake and corporate responsibility as well which also adds to their marketability from a commercial perspective’ (LCA.C-2)

‘a lot being done on individual product level and on EPDs[4] *to communicate their impact against their competitors and in the hope that this will get picked up by the procurement team’ (LCA.C-1).*

Top-down approaches that set requirements to industry were considered to enhance the visibility of EC matters such as recycled material use. Visibility can also be enhanced through the sustainability assessment method applied for projects:

‘The Welsh Government has a minimum requirement for recycled content in a building it is 15%. So that is visible, and it is a requirement we have to meet’. (ARCH-5)

‘Once you become serious about sustainability you need align with the sustainability assessment methodology otherwise there is no means of

[3] The latest version of the London Plan was published in March 2021. At the time of the interview, the earlier version was being revisited, and the consultation mentioned related to the new version and took place between December 2017-March 2018.

[4] Environmental Product Declarations (EPDs) are documents that quantifiably demonstrate the environmental impacts of a product.

quantify what you have done, what's the point, because it is not visible' (ARCH-6).

The new BREEAM 2018 version acknowledges the EC growing importance for overall carbon reduction and was anticipated to have an impact on practice:

> *'I would realistically say in the next two years you will start to see people upskilling and understanding what you need to do for BREEAM 2018 and as a result they will become more familiar with this process and will start to inform decision making – not drive, but inform decision making' (Sust.C-3).*

Although BREEAM was found to be one of the enablers for EC considerations in building projects, it was highlighted that it can bring a very narrow view of sustainable design solutions for projects:

> *'BREEAM tends to be very narrow in terms of how it measures things, very prescriptive and it adds too much weighting on things that are not strictly sustainability related or they are fixed in the design' (ARCH-6).*

This can lead to a cost-effective points approach that merely aims to BREEAM point achievement, when a more holistic approach to sustainable design is required:

> *'we are missing the whole point if we just generate reports to hit BREEAM points: 'If we don't deal with these things properly then sustainability fails because we are missing the whole point.' (ARCH-6).*

The appointment of an LCA consultant can greatly facilitate EC considerations and assessment, and the integration of the consultant to the design team is key for adopting a whole-life carbon approach:

> *'More importantly it is establishing the role of carbon assessment, where the whole life environmental assessment is integrated and works side by side. The soft side of is very important rather than just the technical one. It is important to stay integrated and to ensure that you are in touch with the project progress and it's not just an assessment that just happens and is carried out by an external body and there is no interaction whatsoever' (LCA.C-2).*

The early integration of the LCA consultant to the design team was also deemed important both in relation to the magnitude of EC savings that can be achieved and to avoiding complexity:

'Early engagement of sustainability consultants was also linked to BREEAM and ensuring points are secured to avoid later costs for the project: 'We engage a BREEAM assessor because if we don't do it early enough you don't get enough credits and that means burning money you have to buy them later, so we always appoint them at our design stage to help us guide our design, at stage 2 to 3, it varies depending on the project' (ARCH-6).

4.2.3 EC considerations and EC assessment

The EC considerations and EC assessment process was investigated in terms of when EC considerations are introduced to the building design, the professionals involved in the EC assessment process and the approaches and tools used. The building design stages that were considered with regards to when EC considerations are introduced in design follow the Royal Institute of British Architects (RIBA) plan of work stages (see section 2.2.2). Interviewees mentioned that the EC assessment would not take place during the design stage, but rather, during or after the construction stage:

'Most of my work at the moment has come through retrospective review' (Sust.C-3).

For projects that EC is introduced during the design stage, this would most commonly occur at the end of the design stage:

'I think that for most projects in the industry it would be at the end of Stage 3 maybe or even at the end of Stage 4' (ARCH-4).

As can be easily understood, when EC assessment occurs at the end of the design stage or during the construction stage, it is not done with an aim to inform design. It is most commonly part of an attempt for the project to secure additional BREEAM points, as BREEAM included credits for completing an LCA assessment regardless of whether this assessment informed the building design:

'It was simply to buy bream points, not because it was meaningful, in fact when we had the data it wasn't meaningful' (ARCH-6), 'So you're now seeing buildings which are 2011 or 2014 approaching completion saying oh, blimey, we haven't met scores, let's do that LCA thing' (Sust.C-3).

However, for projects where the client had high sustainability aspirations, EC considerations would start from concept design:

'So if it is a project that has high environmental aspirations we would get involved fairly early, around later than concept design RIBA Stage 2' (LCA.C-2).

With regards to the professionals involved in the process, the LCA assessment is most commonly performed by LCA consultants appointed by the client. The information required for the LCA information, such as material and quantity information is given by the design team professionals that are involved in material specification. Material quantity information is most commonly given by the cost consultant/ quantity surveyor and during detailed design information such as transport distances are defined by the sub-contractors and suppliers:

'From the design team side they need to provide quantities of materials and a spec [specification] and as the project progresses more aspects of the lifecycle come in like transport distances, this information needs to collated by the design team where the designated sub-contractors and suppliers have come in' (LCA.C-2),

'the QS would have a better idea of the quantities of materials' (LCA.C-1).

In the cases where the LCA assessment takes place during or after the project construction, the design team may no longer be available, particularly when the project follows a design and build procurement strategy. In these cases, the LCA consultants gather the information from the main contractor:

'I go to the contractors website and I will strip out all of the section drawings, elevations, plans and I get a good understanding of the materials from there and I start by understanding the building profile' (Sust.C-3).

The material information is commonly included in drawings and the BIM model, and sections drawings have been found most useful as they provide material thicknesses:

'So I look at the elements and then I look at section drawings to see the materials in those elements and if there are thicknesses, and there usually are

thicknesses in the section drawings I get the areas for the materials. So, I am in a situation where I have thicknesses from sections and areas, and the BIM models are very good at providing total areas of a given wall type so I calculate broadly the volume.' (Sust.C-3).

The carbon impact of materials is defined either through EC databases or through the collation of EPDs, with the latter considered more reliable:

'We have our own EPD database and are trying to use and populate it as much as possible to get it up to date and current and specific data as possible and obviously the data sources depend on whatever each carbon assessor is using. There is a number of software-based tools that come with EC databases made for them, so it depends on the tool basically but we depend on EPDs mostly. We went through the process of collecting and transcribing EPDs so that we can use them in our assessments.' (LCA.C-2).

With regards to the boundary condition considered for the assessments, cradle to practical completion (see section 2.4) is what is most commonly requested to be considered, but the consultants push for the consideration of whole-life impacts, as it gives a more holistic picture and can be aligned with the whole-life cost impacts:

'we tend to get asked for the cradle to practical completion, modules A1-5, quite often but we always encourage clients to take it a bit further because it makes a lot of sense from the cost perspective as well; […] looking at whole life it directly links to the whole life cost, so it makes sense to look not just at the capital cost either monetary or carbon of your building but the whole life picture' (LCA.C-2).

With regards to the tool used for the assessments, this was either in-house created spreadsheets or LCA calculation software:

'Either SimaPro or OpenLCA but if it is just carbon we'd use an excel model and spreadsheet and build on from the past project' (LCA.C-1),

'We use an inhouse spreadsheet-based tool we have developed and keep on developing' (LCA.C-2).

BIM was only mentioned as a tool for LCA assessment by one interviewee, who found that its use could lead to unrealistic EC results:

> *‘that BIM models have an arbitrary volume that is just a block. So, with LCA it is not the block, it is the materials that create this block element that you need information for. So, at the moment we have an industry that uses this BIM model that 9 out of 10 doesn’t split down these individual materials of the block elements’ (Sust.C-3).*

The accuracy of BIM model data input is therefore crucial if the BIM model is going to be used directly for LCA assessment.

4.2.4 BIM Application in relation to EC information and assessment

BIM application includes a technological and an information management aspect, as described more extensively in the section 2.3.2. This section considers the application of BIM in relation to both EC information management as well as its use as a technology for EC information collation and assessment.

Collaborative 3D BIM (BIM Level 2) has been mandated by the UK Government for all public sector projects since 2016 which has resulted in most buildings currently being at BIM Level 2. However, the BIM approach varies for different BIM Level 2 project:

> *‘There is a variety of levels within level 2 and that really comes down to what do you need it [BIM] for’ (Sust.C-3).*

In relation to BIM and EC information management, the BIM documents, namely the Employers Information Requirements (EIR) and the BIM Execution Plan (BEP) of the project communicate what information is required and set the plan for the information exchanges to happen during the building design. According to industry-wide BIM standards (PAS 1192-2) the EIR document sets the client’s information requirements at the start of the design stage, and this would be where EC information requirements would be communicated by the client. The EIR document however is most commonly put together by the project architects with input from the client, and this would not happen at the start of the design process:

> *‘Usually we’ll do the work for the client for producing EIR and that will, for most of our projects, be around stage 2 or 3’ (ARCH-4).*

The inclusion of EC information requirements in the EIR document is mostly driven by the client's ambitions for the project:

> *'the key question is what is the expectation of the client - that tends to be the driver' (Sust.C-3).*

However, even when EC considerations are included in a project, it is not common that they are formally included in project documents as previously mentioned in the section that discusses the EC consideration barriers. Including EC information requirements in the project's EIR is important for EC to be considered in projects; however, the importance of ensuring the team involved has the appropriate knowledge and skills was also highlighted:

> *'you can include it in the EIR but this assumes that people understand enough and care enough about EC to count the right things. As with anything, if you don't count the right things all your data is garbage, in fact it is worse than garbage because it makes you come to false conclusions.' (ARCH-6).*

With regards to the use of the BIM model for EC information collation and assessment, there were several issues mentioned by the participants. Lack of BIM model standardisation resulting in various levels of detail of the BIM models was considered a barrier to being able to use the BIM model for more than a three-dimensional visualisation of the project:

> *'some of the models I got have been very very good, others have been good but not as detailed some of them may have weight features attributed to them but there is no standardisation, what's is the protocol?' (Sust.C-3).*

As mentioned in the EC information and assessment process section, the accuracy of BIM model data input is very important, and this variation of BIM models' accuracy creates lack of trust in using the BIM model to extract material quantities, or for using it directly to perform the EC calculations:

> *'at the moment I don't trust the BIM model, I like to manually understand what my volumes, my areas my weights are. I can trust the section drawing; what I don't trust is the BIM model to automatically populate all these items, I know some aspects are volumes and not the materials in it' (Sust.C-3).*

This relates to the variety of BIM level 2 mentioned above and shows that the BIM approach of the project plays an important role in how thoroughly BIM is used in a project. BIM standardisation and how it can be applied to the specific circumstances of individual projects was also mentioned in relation to the lack of trust in the BIM model:

> *‘Even the major contractors don’t use the BIM model because they don’t trust it. Now if the biggest contractors don’t trust the BIM model for quantities take off it indicates that there are still some big questions to be asked in terms of the BIM process. It can work really well but it needs a particular set of circumstances to work optimally. Making it mandatory is like them emperor’s new clothes, it is a really good tool for many things, but it needs to be put in a particular context, outside which the BIM notion of efficiency and productivity and communication breaks’ (ARCH-6).*

Lack of trust in the BIM model was found to be relevant not only to lack of standardisation, but also in how practitioners use and maintain the BIM model accuracy:

> *‘The most important thing is not the BIM model is the people that drive the BIM model and more importantly the people checking it, because we find nobody checks the BIM model! Nobody really checks them’ (ARCH-6).*

Another issue regarding to BIM model use related to the skills of the practitioners involved in building design. It was mentioned that the cost consultants, who are the profession that is closely linked to material quantities, are not familiar with BIM technology/ software and use pdf documents rather than the BIM model for information relating to material quantities:

> *‘the cost consultants there are very few of them that use BIM data, they still prefer to use the digital pdfs to measure things the EC and BIM didn’t overlap in any of the projects that we worked on’ (ARCH-4).*

Contractors were also mentioned to be unfamiliar with BIM software:

> *‘Contractors don’t know Revit [BIM software], so everything is translated to 2D’ (ARCH-7).*

This creates a barrier in the continuity of the BIM model use, particularly for Design and Build projects. The use and sharing of the BIM model between different teams and at different stages of the building design was also raised as an issue in relation to the project contract:

> *'Because BIM level 2 is not about the level of detail we put into the model, it is about the process of sharing. And with Design and Build as a client it's very difficult to do that. Because the legal implications of us using our BIM model and allowing the consultants to use our BIM model means that we assume any risks as a result of any inconsistencies arising from our BIM model we can't have that, because we have only dealt with the concept design. It's for the contractors team to realise that in terms of a detailed design. So, allowing them to use our BIM model as part of their construction solution has legal implications that we are not happy with. So, although notionally we are able to comply with BIM level 2, the model information that we put complies with BIM level 2, the contractual complications mean that BIM level 2 is not meaningful for us. Because there is a disconnect from concept design to detailed design' (ARCH-6).*

The project's contract in relation to its procurement strategy is therefore relevant to both EC considerations as well as BIM application, and in the case of BIM it relates to legal and risk implications with the use of the design team BIM model by the contractors during novation.

4.2.5 BIM potential to facilitate EC consideration and assessment

The potential of BIM to facilitate EC consideration and assessment was acknowledged by all interviewees. Two respondents mentioned that using the BIM model to store EC data and material quantities could result in automation of the EC calculation process enabling an iterative process for assessing alternative building designs:

> *'With the BIM model you have all of the quantities and you could in theory have a database inputted in a parameter and you can automatically get a calculation out of that and you can get very quick iterative processes' (ARCH-4)*

'We are trying to interrelate interlink and interact and to have an interface between carbon and BIM and see how they can work together and how BIM can be utilised to extract data that would feed into the carbon calculated process in a streamlined fashion that would facilitate automation' (LCA.C-2).

The use of the BIM model for visualisation and communication of EC results to the client, particularly during early design stages was also mentioned by one interviewee:

'to supply carbon data into the BIM model like you do for any other attribute or property of components so this could add to visualisation and communication with the clients and it could help at early stage iterations when you have more generic figures attached to certain components and look at a few major variants to form the design' (LCA.C-2).

Visualisation was deemed very important by another interviewee in making EC results meaningful to both the client and the design team:

'there is potential for BIM to be the pivotal means of delivering meaningful changes in EC. If it is done properly. And that is because you have everything in one place, all data quantifiable and measurable, software aggregates it and can spit it out in a meaningful form. It is data crunching, the bit that I think is going to make demonstrable benefit in how information is presented. The presentation of the data needs to help people understand it' (ARCH-6).

The interview participants' views about the BIM potential to facilitate EC considerations and assessment mostly focused on the technological side of BIM. The information management aspect of BIM was not as evident in the participants' responses when asked about this topic. With regards to BIM documents facilitating EC considerations by establishing EC information requirements, the participants found that it would depend on the role of EC and the client's ambitions and if EC is included in the BIM documents:

'if people know that it is important enough to measure, then you stick it in the BIM EIR and you can do it' (ARCH-6).

So, the EIR document would facilitate EC information management, however, EC would have to be something that the client wants to consider for it to be included in the EIR document in the first place. Although the BIM model was considered as the aspect of BIM that facilitates EC assessment, this potential cannot be realised without efficient information management.

> *‘I think that the software is there and is very very good, I think it is the front end which is lacking’ (Sust.C-3).*

The process of information management sets the project’s information requirements and establishes the responsibilities of the design team’s BIM model data input to ensure that the BIM model is appropriate for use. The skills of the design team to use BIM as an information management process as well as a software tool are essential to realise BIM’s full potential:

> *‘People don’t get BIM’s full potential, upskilling people is important’ (ARCH-5).*

4.2.6 Summary and themes

The industry perspective interviews covered topics that related to the role, drivers and barriers of EC in building design, the process of EC information and assessment and BIM application and potential in relation to EC considerations and assessment.

The role of EC in building design was found to be mostly dependent on the **client aspirations**, who sets the sustainability ambitions for building projects. The **heavy focus of regulation and sustainability rating systems on OC** has influenced the visibility of EC as an aspect of sustainability in building design and has led to a lack of market drive for its inclusion by clients. This lack of market drive has also resulted in lack of understanding of EC by professionals, who perceive EC considerations as an **additional layer of complexity** in the building design process. For EC to be considered in a project, **LCA consultants need to be appointed** to bring this expertise to the design team. However, this is not common, as it incurs additional capital **cost** for projects, which clients are not incentivised to cover. Even in few cases where EC considerations were included in projects, the **EC target** is most commonly set at building level and is not formally mentioned in the brief. This hinders low EC specifications made by the design team to carry through during the construction stage, particularly for Design and Build **procurement contracts**. Finally, an industry-wide barrier that relates to the calculation of EC is the availability and reliability of **EC secondary data**. **Professional leadership** has taken place by some practitioners to provide consultation for the creation of EC regulatory requirements in an effort to create a top-down push for the inclusion of EC in building design. The new BREEAM (2018) version, is a step towards that direction, even if the EC requirements included are still relatively limited. On project level, the **appointment and early integration of an LCA consultant** within the design team facilitates EC considerations and assessment for projects, however, this is mostly applicable to large projects and clients that have high sustainability aspirations for the project.

With regards to the EC assessment, this commonly takes place as a retrospective exercise rather or late in the design process, which reduces the opportunity for EC reduction. The professionals that perform the assessment are most commonly LCA consultants appointed by the client, and the information for the assessments is given by the design team for the material specifications and the cost consultant for the material quantities. The tools used for the assessment are spreadsheets or LCA software, whereas **the BIM model was not trusted** to provide quantities or be used directly for the LCA calculations.

Although the main potential of BIM to facilitate EC considerations was through the use of BIM model to streamline the EC assessment process and to help with EC result visualisation, the **BIM model data input** is not thorough enough to allow this. The BIM models have various levels of detail which is a result of the ambiguity **of BIM Level 2 standardisation** and the lack of **professional skills** by the professionals involved. To enable BIM's potential in relation to EC consideration and assessment, better data input to the BIM model is required. This can be facilitated by ensuring a strong BIM level 2 information management approach that sets the information requirements and planning in the project's EIR and the BEP. However, this cannot be achieved if the professionals involved are lacking the skills to apply this strong BIM Level 2 approach.

Through the analysis of the interview results, recurring themes that relate to the interview topics were identified. Some of these themes were industry related and refer to the UK construction industry context, whereas others were project related and, as such, can vary within each project. Table 4.1 summarises the industry and project related themes identified for each interview topic.

Table 4.1Themes identified within the Phase 1 Professional perspective exploratory interview topics

Interview topic	Industry related themes	Project related themes
Role of EC	• Regulation and Sustainability Rating System OC focus	• Client
EC consideration barriers	• Regulation and Sustainability Rating System OC focus • EC secondary data reliability	• Cost • Contract
EC consideration drivers	• Professional leadership • Sustainability rating systems	• Team appointments • Competitiveness
EC process	• EC secondary data reliability	• Client • Team appointments
BIM application	• BIM standardisation	• Professional skills • Contract
BIM potential	• BIM standardisation	• Professional skills

The client appears a dominant theme associated with the interview topics. The role of EC is mainly affected by the client who sets sustainability ambitions for the project. **The OC focus of regulation and sustainability rating systems** create a barrier for clients to be incentivised to add EC considerations in projects. As EC considerations result in additional **cost** for appointing relevant LCA expertise, clients don't see the added value of addressing EC in the lack of a regulatory requirement or a sustainability rating reward. However, the addition of LCA consultants to the **team appointments** is crucial, and their early integration to the design team is key for addressing EC reduction.

Professional leadership has been evident in consulting relevant professional bodies to push for regulatory EC requirements. This however is from niche practices that understand the importance of EC. EC understanding by industry professionals is however limited and the expertise to assess EC impacts is primarily through LCA consultant appointment, which depends on the client. **Professional skills** were also linked to the **BIM model data input** and **BIM model use**, resulting in various level of detail of BIM models and **lack of trust in the BIM model** as a source for material quantities or a tool for LCA assessment. **BIM standardisation** was also considered a key theme affecting information requirements and planning and the process of incorporating this information to the BIM model.

Finally, the **project contract** in relation to its procurement strategy affected both EC and BIM application in projects. A design and build procurement strategy can create a barrier for the design team to ensure that low EC materials that were specified during design are not replaced with higher EC impact materials during the construction stage. With regards to BIM model use, design and build procurement can have legal and risk implications for BIM model sharing between the design team and the contractor.

The professional perspective interviews were a first step in exploring how EC considerations and assessment take place in a BIM-enabled project. This first step informed the engagement of the researcher with the exploratory case study and together with the literature review guided the case study data collection and analysis process.

4.3 Exploratory Case Study

The exploratory case study follows an ethnographic approach during which the design process of a building project is used as a case study to explore how EC considerations are set and addressed in a BIM-enabled project. The real-life case study enables exploration of how EC considerations are included in different stages of the building design, what aspects of EC are addressed and how, and the way BIM is used for information management and assessment of EC.

This case study considers the design of an educational building project in South Wales classified as D1 Non-residential institutions according to the Town and Country Planning (Use Classes) Order 1987[5]. The client is a Higher Education Institution, which is classified as a non-profit institution serving households (s.15). The project aims to achieve a BREEAM ‘Excellent’ rating and is registered under the BREEAM 2014 version. A project Design and Build procurement route is followed, according to which the design team is involved in design development until the end of RIBA Stage 3 and then the design responsibility is passed to the contractor at the

[5] The Use Classes were last updated on 1 September 2020 and Class E more broadly covers uses previously defined in the revoked Classes A1/2/3, B1, D1(a-b) and ‘indoor sport’ from D2(e).

start of RIBA Stage 4. Table 4.2 summarises basic information about the CS use, location and size.

Table 4.2 Case Study 1 basic information

Case Study	Building use/ Use Class*	Location	Area
1	Educational/ D1 Non-residential institutions	South Wales	10,000 m^2

The principal design team consists of the architects (ARCH), the structural engineers (STR), the Mechanical, Electrical and Plumbing (MEP) engineers and the quantity surveyor (QS). As the project had high sustainability aspirations, the principal design team was selected so that they could deliver a highly sustainable project and a sustainability consultant was appointed to give further guidance in achieving the targeted BREEAM rating. Together with the client, the principal design team and the sustainability consultant are the main stakeholders involved in this case study. Table 4.3 includes information about main stakeholders' companies: the type and size, the sustainability expertise, or in the case of the client sustainability aspirations. Sustainability expertise information for the design team was gathered from companies' website information and the projects that they have delivered. Depending on whether sustainability was core to their practice, sustainability expertise was ranked as low, medium or high. The rankings were colour-coded red (low), amber (medium) or green (high) respectively. The client aspirations were consulted by the project documents that stated the client's sustainability aspirations for the project which included the BREEAM rating target. The architectural design for this case study is delivered by a collaboration of two architectural practices. As company information is anonymized in this thesis, these are referred to as 'Practice 1' and 'Practice 2' in the table below. The same company covered both Structural and MEP engineering for the project, therefore they are listed in the same column.

Table 4.3 Case Study 1 main stakeholder information.

	Client	Architect	Sustainability Consultant	Structural & MEP	Quantity Surveyor
Type/ size	Higher Education Institution	**Practice 1:** Nine studios in UK and one internationally **Practice 2:** One office in UK and one internationally	1-person consultancy	Global company with offices in 28 countries.	Global consultancy with offices in 20 countries
Sustainability Expertise/ Aspirations (for client)	BREEAM Excellent target	**Practice 1:** Sustainable design stated as principle and projects include sustainability. **Practice 2:** Sustainable design stated as principle and projects include sustainability.	10 years in large company focusing on Environmental Management. Own consultancy since 2017.	Leader in green buildings	Sustainability stated as part of the Property & Asset Management Services offered.

The data collection for the CS included meeting observations, interviews with the project stakeholders and project document analysis. The collected data for the exploratory case study are presented in detail in section 3.3.5.1.2.

The case study results are presented in relation to the two main areas of the research focus, EC considerations and BIM application in relation to EC. Separate topics within these wider areas are used to organise the result presentation. These topics are informed by the literature review (Chapter 2) and the industry perspective interview analysis that was presented in section 4.2.6. It was identified that target setting is key for EC considerations to take place in the design process and that material selection and specification is the main way to address EC impacts of the building. Performing carbon assessments that include EC impacts can help inform design decisions in relation to achieving the targets. With regards to BIM application in relation to EC, the two main aspects of BIM were identified which relate to information management and BIM model use. The BIM information management focuses on information requirements and the way these are communicated throughout the design process. BIM model use considers BIM model data input, and the way the design team professionals use the BIM model for design coordination and data storing.

As such, EC Considerations and BIM application results for the case study are organised in the topics below:

- Targets
- Material selection and specification
- Carbon Assessment
- BIM information management
- BIM model use

Within the sections that describe the above topics, reference to empirical data is made as described below:

- Interviews: Int.(number indicating RIBA stage the interview took place)-(profession code).

  Eg. Int.4-ARCH: Interview with architect during RIBA Stage 4.
- Project documents: (document title as presented in Table 3.5)-St.(number of RIBA stage).

  Eg. RIBAreport-St.1: RIBA Stage 1 report
- Meeting attendance: (meeting code as presented in Table 3.4)(meeting number as presented in Table 3.4)-St.(RIBA Stage Number).

  Eg: DTM9-St.3: Design Team Meeting 9, during Stage 3.

When design stages are mentioned in the text, these refer to RIBA stages. ‘Stage’ and ‘RIBA Stage’ are used interchangeably.

4.3.1 Targets

The target to deliver a BREEAM Excellent building informed the team appointments of the design team, who were appointed based on the professional skills to deliver a highly sustainable building:

> *‘their entire ethos is to design and deliver a building that is sustainable. [they] are very, very good looking at sustainable design principles and that is hard wired to why they get appointed. So there won’t be anything in the brief that*

says 'you need to have sustainability criteria' but they have been appointed because they have that. The whole project team is working towards the same aim.' (Int.2-SC).

Team appointments also included the early appointment of the project's Sustainability Consultant, which was done before the start of RIBA Stage 1:

'I think I was the first person to be appointed. It doesn't often happen, but [the client] knew the need to pick up BREEAM' (Int.2-SC).

The main aim for this was to secure the achievement of the BREEAM Excellent rating in a cost-effective manner:

'My involvement relates to managing and facilitating the BREEAM process. To de-risk achieving a rating of excellence and make it cost effective' (Int.2-SC).

It is therefore clear that the BREEAM target drives the sustainability approach of the project. The project's sustainability targets were defined in the RIBA Stage 1 report. The main targets mentioned were that the project would pursue a BREEAM target of excellence and compliance with Part L legislation. In the same report, EC reduction efforts are mentioned as an additional sustainability aspiration by which design scenarios are to be considered during stage 2 with the aim to *'reduce the carbon footprint of the building'* (RIBAreport- St.1).

There was no specific target established in relation to EC, as setting up a specific target was considered a risk by the Sustainability Consultant due to EC assessment complexity and the lack of industry-wide EC benchmarks to guide the target setting process:

'you would be at big risk if you were to have a specific [EC] target, because there are so many variables you just don't know – if you were to say that we will have a max amount of embodied carbon for this project, you just don't know what the building is going to be designed to and how realistic that is […] because we don't have a benchmark to compare against.' (Int.2-SC).

As no specific EC target was set for the project, the BREEAM target and BREEAM assessment issues[6] guided the EC reduction efforts:

[6] BREEAM rating scores are a calculated percentage of achieved BREEAM assessment issues.

'So this project will be looking at embodied carbon but within the concepts of BREEAM' (Int.2-SC).

The overall BREEAM rating[7] is the hard target for the design team and although this creates a driver to include low energy and carbon considerations in building design, it is also a barrier for the design team to push for further carbon reductions if the overall target is met:

'We've got the realistic opportunity to go up to 80%, but we need 70% so my overarching role is to get us comfortably to 70%. Also mindful that there are options that cost a lot and others that don't, and that's what I bring to the table, so I will comfortably get us a rating of 70%, it's how we collectively play with these figures' (Int.2-SC).

As can be seen, the project followed a cost-effective point scoring approach to achieve the overall BREEAM target whereas a holistic approach to sustainability was not part of the leadership shown by the professionals involved in the design process. Apart from BREEAM, cost also appears to be an important issue driving sustainability decisions.

4.3.2 Material selection and specification

Cost and local market skills and preferences highly influenced the material selection for the project. During Stage 1, concrete, steel, and timber were mentioned as the main materials to be considered for the project's superstructure, and timber's sustainability credentials were acknowledged by the design team (RIBAreport-St.1). However, timber, which had the lowest environmental impact amongst the three material options, was not further developed due to lack of market expertise that would result in higher capital cost:

'[timber frame superstructure is] not yet commonplace in the UK and requiring new site skills, anticipated costs are higher than the more traditional concrete and steel options. Providing a timber option was therefore discounted at early Stage 2 design development' (RIBAreport-St.2).

[7] A BREEAM 2014 Excellent rating is given when a project achieves 70% or above assessment score.

During Stage 2, three options that included concrete and steel materials were considered for superstructure, for which sustainability credentials were not considered. Local supply chain material preferences and cost were the factors that influenced material selection during this stage:

> *'Steel frame and metal decking is where the market is going, and it is not worth to ask for a different solution as it wouldn't be as cost effective and easy as the one that the market does now' (DTM6-St.2).*

During Stage 3, steel frame was selected after consultation with the supply chain by the Project Manager and the Cost Consultant, and the decision was based on cost reduction:

> *'Project Manager and Cost Consultant advise they have gone to the supply chain to weigh up concrete vs steel and all are advising steel frame. Concrete induces extra cost to make internal structure look better' (DTM9-St.3).*

It is therefore evident that the local market is an influencing factor for material selection; however, the resulting cost of certain materials either due to lack of local supply chain skills or due to additional work required for material internal finishes was the main consideration for material selection.

Sustainability considerations for material selection were different for different members of the design team. As mentioned above, although timber was not selected as a superstructure material, its sustainability credentials were acknowledged by the structural team. Material considerations for the architect team; however, was mainly based on aesthetics, practical considerations and budget, with no mention of sustainability credentials of materials (RIBAreport-St.2).

At the end of stage 2, the Sustainability Consultant stated the requirement for the architect team to specify building elements that have a Green Guide (GG) rating of A or A+ and to also consider specifying individual materials that have an Environmental Product Declaration (EPD) certificate during Stage 3. This formed part of the Mat 01 Life Cycle Impacts BREEAM assessment point (BREEAMreport-St.2). Material specification started during Stage 3 and was completed during Stage 4a. The architect team confirmed during Stage 4a that GG ratings were included in their specification criteria for the products, (Int.4-ARCH). This, however, was only mentioned as an ambition for the project's low impact and resource efficient design during Stage 3, whereas material specification requirements that related to OC were more thoroughly reported (Design&AccessStatement-St.3). Material specification mentions specific values required for aspects of the material that relate to regulation compliance and the building's operational energy performance, such as U-values. Although specific materials and manufacturers were mentioned in the specifications, similar materials to the ones specified can be considered by the contractor during construction stage. Low EC impact was not included as a condition where 'or similar' was mentioned in the specifications. Therefore, there is no effort by the design team to secure low EC impact material specification during the construction stages. This highlights the impact of the heavy OC focus of regulation on the design team professional's approach to sustainability. However, professional leadership was shown in relation to pushing for a sustainable procurement policy implemented by the appointed contractor during the construction stage. Although this is part of BREEAM Man 03 Responsible Construction Practices assessment point and refers to the construction stage, it is an example of efforts to set requirements during design stage that contribute towards the overall sustainability of the constructed building.

4.3.3 Carbon assessment

The main sustainability assessments that took place for the project related to the achievement of the project's BREEAM target. BREEAM target monitoring was thorough throughout the design development to ensure that the target would be reached. As such, carbon assessment was mainly focused on the operational stage. Embodied carbon assessment has only been considered in terms of the life-cycle impacts of building elements as part of BREEAM's Life-cycle impacts assessment point. It was also observed that different professions within the design team were responsible for different BREEAM points. The points that relate to operational energy and carbon were primarily addressed by the Mechanical Engineering team whereas the points that relate to EC were targeted by the architects and structural engineer teams. Furthermore, when assessing carbon saved over the building lifetime, only OC was considered. This shows fragmentation of the design team and highlights the lack of a holistic approach to energy and carbon reduction.

The requirement for a whole-building Life-Cycle Assessment (LCA) was mentioned by the sustainability consultant during Stage 2:

> *'for MAT 01[8], there is a total 3 (credits) and you can get 2 of them by doing a life-cycle IMPACT[9] compliant evaluation. So, I have suggested - haven't really mouthed it because I would put myself forward for doing the work, but it is actually a cost-effective way to get 2% [against the overall score]. (Int.2-SC).*

The LCA assessment requirement was linked to the BREEAM assessment and was considered a means towards achieving the overall BREEAM target rather than an effort to reduce the life-cycle impacts for the project. This reinforces that a cost-effective points approach to sustainable design and development is observed for the project. The above quote by the sustainability consultant also relates to professional skills and shows that the sustainability consultant is not comfortable to perform the LCA assessments. The appointment of an LCA consultant who would have the expertise to undertake a whole-building LCA was included as a requirement in the BREEAM end of stage 2 report. However, due to the additional capital cost this would incur, the appointment didn't place during the design stage and, as such, the opportunity for the LCA to inform the project's design was lost. Life-Cycle Costing (LCC) was, however, undertaken at the end of all the design stages (2,3 and 4). This highlights the importance of cost and the neglection of EC considerations for the project.

4.3.4 BIM Information management

During Stage 1, the requirement of a detailed Employer's Information Requirements (EIR) document was mentioned in the RIBA stage report. However, this document was not prepared by the client. A pre-tender BIM Execution Plan (BEP) was anticipated to be issued by the architect team at Stage 2 and a post-tender BEP was anticipated to be issued at stage 4 (RIBAreport-St.1). During Stage 2, a first draft of the pre-tender BEP was issued by the architects for the design team and client to comment on. Although a pre-tender BEP draft was issued during Stage 2, the first

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[8] BREEAM Mat 01 is the Life-cycle impacts assessment issue.

[9] IMPACT for Life Cycle Assessment (LCA) is a specification and database for software developers to incorporate into their tools to enable consistent Life Cycle Assessment (LCA) and Life Cycle Costing (LCC).

BIM coordination meeting took place during mid-Stage 3, at which stage the pre-tender BEP document was still not finalised.

The lack of an EIR document demonstrates that there is lack of engagement by the client to provide the necessary information to the design team and to enable improved project information management. There is therefore a need for clients to either take a more professional role or to appoint relevant professionals to undertake such tasks. This need was identified by the architect team who suggested the appointment of experts that can provide consultation in relation to information management and ensure a more robust BIM application:

> *'We also would like to see the opportunity to appoint the specific roles of lead BIM coordinator and lead information manager to make the project's BIM delivery more robust' (RIBAreport-St.1).*

However, this appointment did not take place which resulted in a poor BIM approach for the project where BIM was applied as an afterthought and therefore the opportunity for its use to enhance collaboration and coordination has been reduced significantly.

It was mentioned by the design team that the project programme was too tight to allow design iterations to be costed:

> *'[…] refining the design and then getting it costed for every iteration; this needed to be included in the programme to allow time for the design iterations to happen and be costed' (DTM12-St.3).*

Time restrictions were mentioned in relation to cost assessment of design iterations. However, this would also apply to carbon assessment of design iterations. A more robust information management could inform the project's scheduling to ensure that information exchanges and assessments of design iterations were accounted for.

4.3.5 BIM model use

The pre-tender BEP of the project mentions that separate BIM models would be used by each design discipline which would feed into a federated model. The architect team was responsible for the federated model and its fortnightly circulation amongst the design team. Although this coordination was formally mentioned in the pre-tender BEP during Stage 3, coordination through the federated model had already started informally during mid-Stage 2 (Int.2-ARCH). The federated model circulation aimed to coordinate the team with the most up-to-date model. However, BIM federated model circulation delays by the ARCH team hindered other teams to proceed with their part of the design and to perform planned analyses and simulations (DTM12-St.3). Further to circulation delays, BIM model discrepancies between teams were also highlighted during Stage 4a (DTM16-St.4a). Both the above observations demonstrate that although tools and processes to enhance collaboration are established for the project, they are either not being used or the way they are used creates a collaboration barrier. The delay in circulating the BIM model can also be linked to the tight project scheduling which was mentioned in the BIM Information management section.

In relation to the information requirements of the BIM model, the architect team mentioned that since the client doesn't have an ambition to use the BIM model for facilities management, there is no need for the team to be working towards a data rich model. The federated BIM model would only be used for coordinated spatial design at Stage 3 (RIBAreport-St.2). This demonstrates that the BIM model use as perceived by the architects is restricted to spatial coordination whereas a data rich model would only be required for facilities management. This view was reinforced by the sustainability consultant:

> *'it's the information within each element which is what you need [for an LCA assessment], they [the design team] could spend a lot of time populating it but it could be redundant, so they won't.' (Int.2-SC).*

For the project the only assessment that related to EC was the Green Guide (GG) ratings of building elements. For these assessments, material information for building element build-up and element specification was given through project documents and element glossaries. Two dimensional drawings were also used to extract material information whereas a structural 3D drawing was only used to extract information about the upper floor slab. Information about the quantity of materials was extracted from the RIBA Stage 3 Order of Cost Review document, which was conducted by the cost consultants. The BIM model was not used for material or quantity information.

4.4 Phase 1 Analysis and Emergent themes

The professional perspective interviews and the exploratory case study investigated how EC considerations are set and addressed in a BIM-enabled project. The results highlighted barriers and enablers for EC considerations in building design and the application of BIM as an information management and software tool. Thematic analysis was employed to analyse the findings of Phase 1 using coding to identify first and second themes (see section 3.3.5.2). The second order themes were used to create three aggregate dimensions that were informed by the Leavitt (1965) model. The three dimensions are defined as below:

- People: This dimension refers to the project stakeholders, namely, the client and the professionals that comprise the design team.
- Process: This dimension combines the 'tasks' and 'structure' elements of the Leavitt (1965) model and refers to the industry-wide available standards, protocols, rating schemes, guidance documents, as well as project-level structures.
- Tools: This dimension expands the 'technology' element of Leavitt (1965) model to encompass other technical tools such as EC databases and benchmarks.

Figure 4.1and Figure 4.2 show the analytical process off aggregating first and second order themes to the socio-technical dimensions.

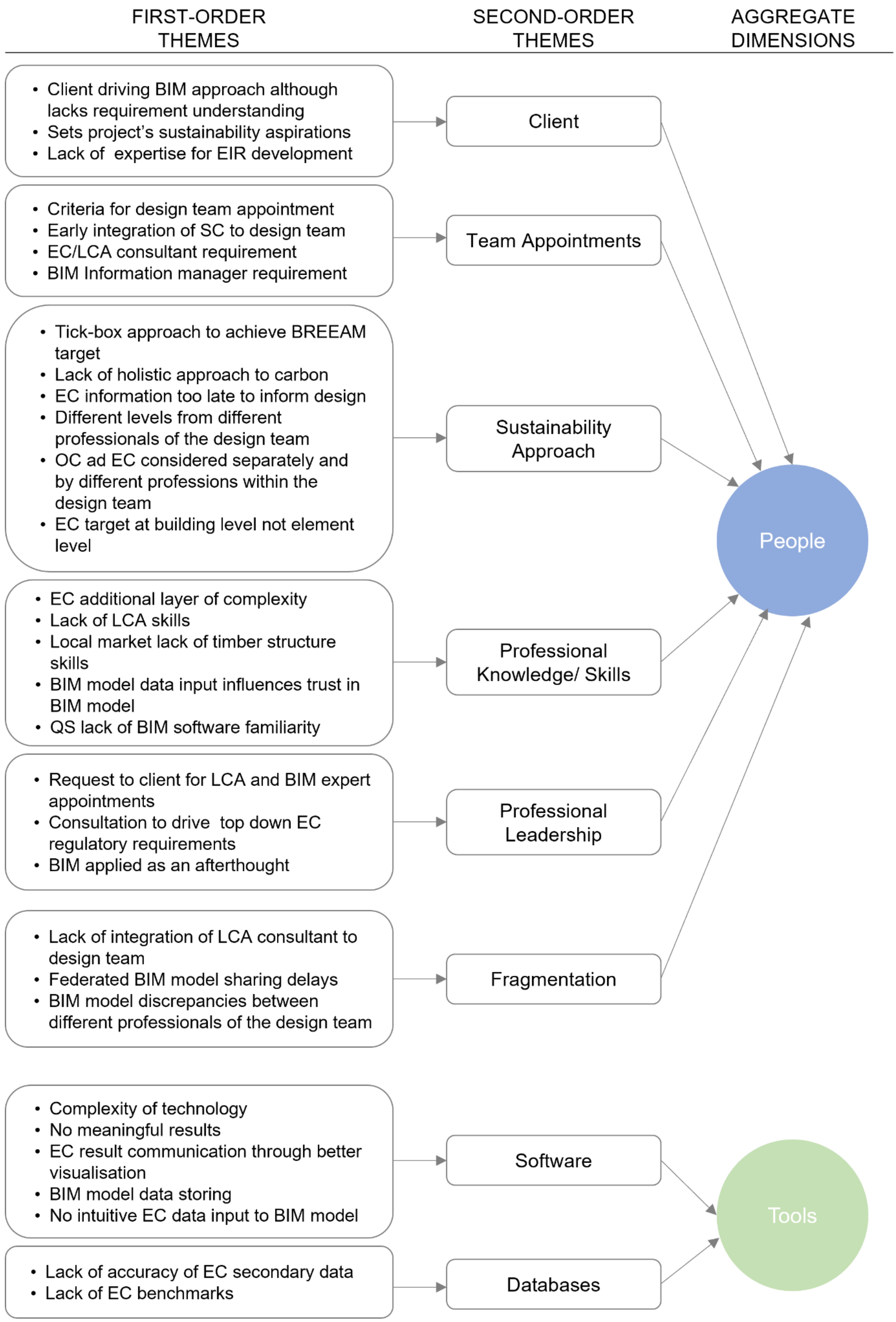

Figure 4.1 Phase 1 first and second order themes to analytical dimensions: People and Tools

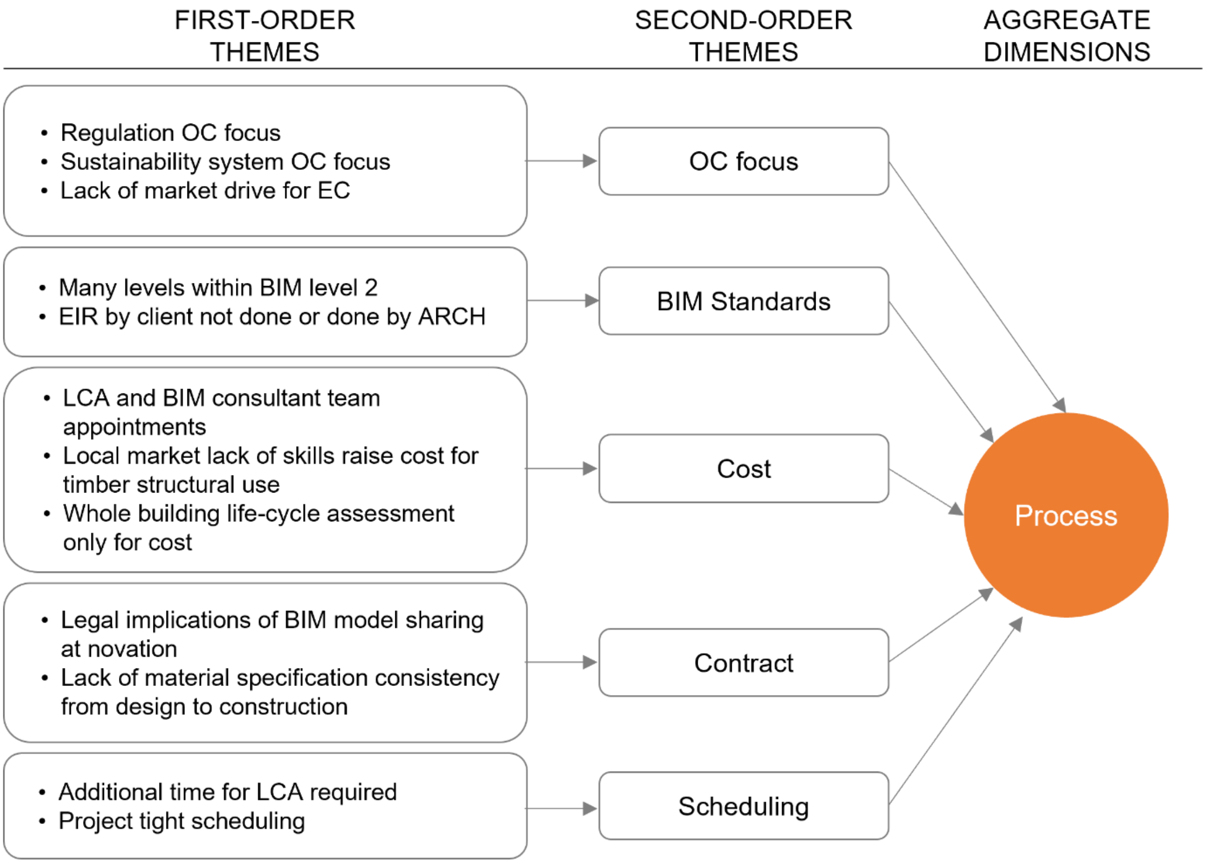

Figure 4.2 Phase 1 first and second order themes to analytical dimension: Process

During the analysis links between themes that fell within the same or different aggregate dimensions were identified that indicated relationships of influence between themes. This corresponds to the interdependence of dimensions that the Leavitt (1965) model presents and shows that the different dimensions cannot be considered in isolation, as they operate as a system with interdependence between its socio-technical parts. To visualise the interdependence between different dimensions and the links amongst the themes that fell within them, the three dimensions are presented in a Venn diagram that includes the second-order themes of each dimension in Figure 4.3. The links between the themes are represented with arrows in the diagram. The three aggregate dimensions and the links between their respective themes are further described in the sections below.

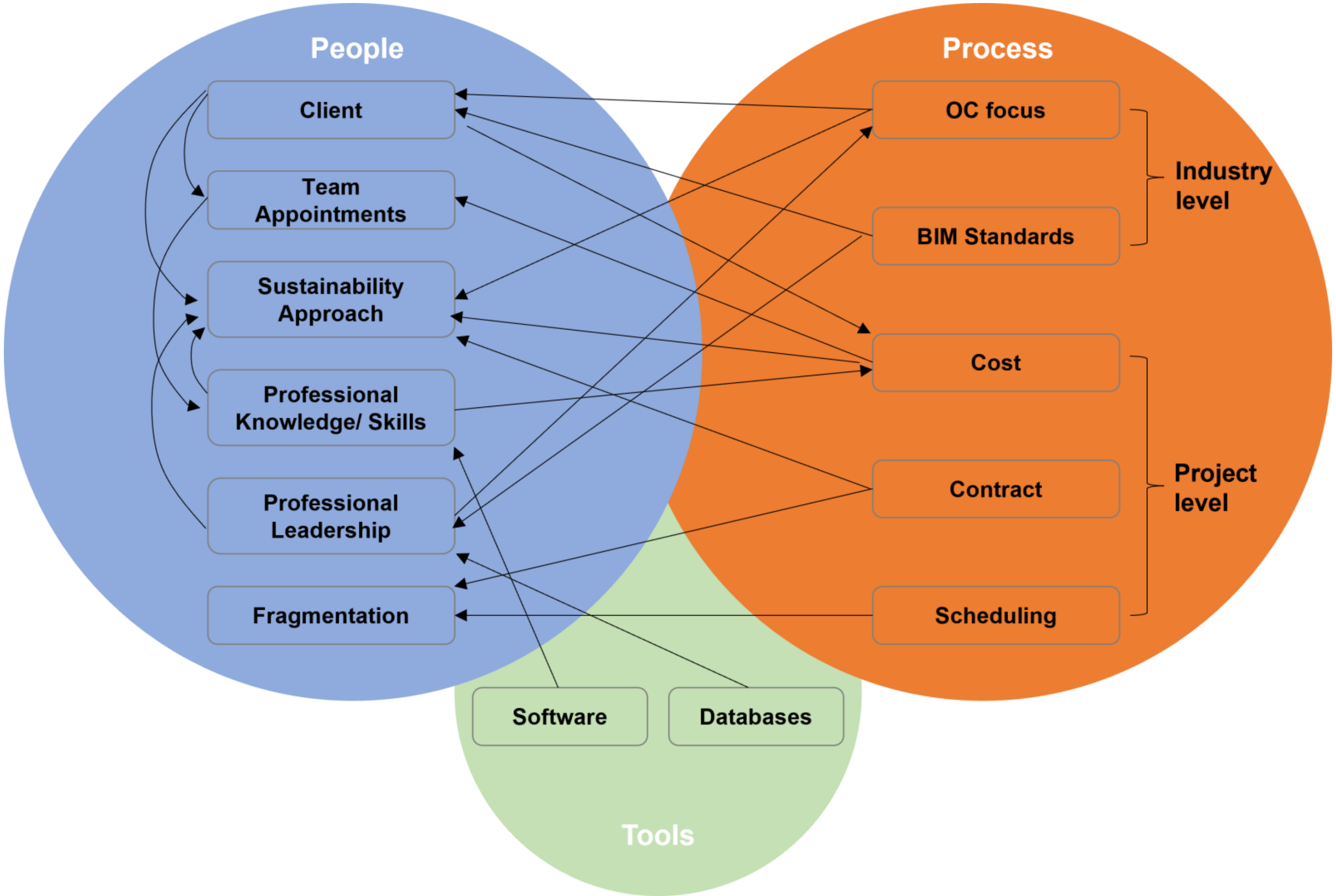

Figure 4.3 Phase 1 Analytical dimensions and links between second-order themes.

4.4.1 People

The client is responsible for many aspects that affect the project's sustainability approach. **Team appointments** for the project is one such aspect that highly influences the project's sustainability approach. Through team appointments, the **professional knowledge and skills** of the design team are defined. For the case study, team appointments informally considered the sustainability input that the professionals would bring to the project and a sustainability consultant was appointed during the early stages of the design process. The early integration of a sustainability consultant (SC) was identified as an enabler for EC inclusion in the industry perspective interviews; however, the lack of LCA expertise by the SC made the appointment of an LCA consultant required in the case study. Although this was requested by the SC showing **professional leadership** for EC inclusion, this appointment was not actioned by the client due to the additional capital cost this would incur. It can therefore be seen that the client has a greater influence on the project carbon approach than the early engagement of the sustainability consultant. Professional leadership was also shown at an industry level through professionals' consultation of relevant industry bodies for the development of future regulatory requirements of EC inclusion. In the case study, the design team also demonstrated professional leadership through requesting the appointment of a BIM information lead to ensure a stronger BIM information management for the project. However, this appointment was not actioned by the client which resulted in a poor BIM approach for the project, both in relation to information management as well as the BIM model use. The BIM model was only used for spatial coordination and was not used for material build up or quantity information. Apart from the BIM model lacking rich data, the lack of BIM model use was also linked to professional skills, as the quantity surveyors lacked familiarity with the BIM software. **Professional skills** were also linked to considerations related to building material environmental impacts. In the case study, the project design team demonstrated a variation of approaches with regards to how environmental impacts of material options were considered by different professions of the team. Material selection was also related to the skills of the local market. Although using the local market for project procurement is a common measure to reduce EC impacts of a building, the lack of skills of the local market to support the use of construction materials with lower environmental impact such as structural timber created a barrier to the reduction of environmental impact through material choices as the team prioritised cost and local supply chain familiarity over reduced EC material choices. EC considerations were also absent in the material specification requirements at the end of the design stage. Therefore, as the case study followed a Design and Build procurement route, the contractor can suggest material changes during construction stage that the client is responsible to approve. This returns the responsibility of the final material selection to the client, who is not expected to have the required sustainability expertise to secure the selection of low EC impact materials.

4.4.2 Process

The industry-wide regulations and sustainability systems **OC focus** creates a lack of incentive for the clients to include EC considerations as part of the sustainability approach of the projects. The lack of visibility of EC through sustainability rating systems was evident in the case study where the BREEAM target was the main sustainability driver for the project. The client as well as the design team had a lowest capital cost approach to achieving the BREEAM target which resulted in a tick-box exercise towards securing the required BREEAM points, rather than taking a more robust and holistic approach to sustainability and carbon. EC targets were not set for the project and EC impact considerations for materials were too late to inform the building design. This demonstrates that following a consistent approach to achieving a high BREEAM rating is not sufficient for EC considerations to be integrated in building design development. The available **BIM standards** allow for flexibility in the way that Level 2 BIM is applied in projects, which can lead to a poor application of BIM. The Employer's Information Requirements (EIR) was identified as a potential enabler for EC inclusion within project targets. However, as the EIR creation falls within the responsibility of the client, this depends on the client to firstly deliver these requirements and secondly to include EC considerations and targets within the EIR. Clients however lack the expertise to address this requirement, which leads to the requirements being created by the design team or not created at all. In the case study, a poor BIM application was observed which was characterised by a complete lack of EIR delivery by the client, limited information management and limited BIM model use. This shows a discrepancy of what is expected by standards and what actually happens in a real context. Discrepancy is also observed in industry guidance, according to which, Quantity Surveyors are the profession expected to be most involved in tackling EC due to their familiarity with project material quantities (section 2.4.3). However, this was not the case in the case study, they were not involved in EC considerations and their lack of BIM software familiarity reinforced the poor BIM model use.

At project level, **cost** was identified to be an important factor affecting both EC reduction efforts as well as BIM application. The cost implications of LCA and BIM expertise appointment can become a barrier to secure this expertise for projects which, as observed in the case study, can be crucial for a holistic sustainability approach and a strong BIM application. Cost also affects procurement in relation to both material options and sub-contractor selection. The importance of cost was also evident in the case study by the fact that whole building life-cycle assessment were only made for cost. The project **contract** also affects both EC considerations and BIM application, particularly for Design and Build procurement routes in relation to specification and BIM model sharing. With regards to EC considerations, the contract can affect discrepancies between material specification by the design team during the design and what is actually built during construction. BIM model sharing between different design teams can have legal implications during novation. This creates fragmentation of the design team and reduces the collaboration benefits that can be achieved through BIM. Design team fragmentation can also be caused by the project tight **scheduling**, resulting in delays of sharing the most up-to-date federated BIM model across the design team. Tight scheduling also prevents alternative design option assessment, which is required to achieve EC reduced building designs.

4.4.3 Tools

BIM **software** tools' data storing capacity was considered an enabler to streamline the EC assessment process and to facilitate communication of EC assessment results through visualising EC assessment results. However, the complexity of their use and the lack of an intuitive way to add the required information to the software was a barrier in producing meaningful results. It also created lack of trust in the use of the BIM model for information required for the EC assessment, such as element material build up and material quantities. The BIM model data use is also affected by the professional skills of the design team who often lack familiarity with BIM software or a drive for creating a data rich BIM model. The lack of EC secondary **data** reliability hinders EC assessment creating an additional layer of complexity to EC assessment when primary EC data is not available. The lack of available EC **benchmarks** creates a barrier in establishing an EC target for building projects, as was observed in the case study. Both the above hinder professionals to take leadership in incorporating EC considerations in building design.

4.5 Conclusions and insights for the Explanatory phase (Phase 2)

This chapter presented the results and analysis of the Exploratory phase (Phase 1) of this research, which aimed to explore how EC considerations are set and addressed in a BIM-enabled project. This phase included industry perspective interviews to gain initial insight on the research topics and to guide the engagement with a real-life context ethnographic case study. The exploratory case study enabled a deeper exploration of what affects EC considerations in a project and how BIM is used as an information management process and tool in relation to EC information collation and assessment. Thematic analysis was used to identify emerging themes from the collected data, and the themes were then organised into three aggregate dimensions: 'People', 'Process' and 'Tools'. Links between themes within and amongst these dimensions were identified which highlighted the interdependence of these dimensions.

The themes included in the 'People' dimension had the most links within and between different dimensions, making 'People' the predominant dimension affecting how EC considerations are set and addressed in a BIM-enabled project. Process and Tool elements can become barriers or enablers to EC considerations and BIM application depending on how people enact and use them. Phase 1 analysis also highlighted the requirement for new expertise to tackle EC and to ensure effective information management and BIM model use. Professional leadership is crucial in driving the integration of these new roles within the design team as clients are influenced by higher industry structures' OC focus and lack motivation to facilitate this requirement. Further to this, the client has the power over the required resources such as project budget and team appointments. This highlights the need to further investigate how industry-wide structures affect the way project level structures are controlled through people agency and the power relations between project stakeholders, namely the client and the design team.

The people involved in projects and the industry and project level structures of processes and tools form the conditions of case study outcomes that relate to how EC considerations and BIM use are addressed. Phase 1 analysis and the links identified between people and structures show that further investigation of the relationship between these conditions is required to understand how they in turn affect these project outcomes. For the next stage of this research, a theoretical framework that considers both structure and agency and how these affect each other as well as power relations between different project stakeholders is used. Data collection and analysis during Phase 2 is theory driven and uses the themes identified in Phase 1 to define case study conditions. As such, data collection is more targeted and only includes interviews and document analysis. The relationships between conditions and how these affect the case study outcomes are then analysed. Commonalities and differences between the conditions and their relationships are identified for three case studies and the resulting agentic power relationships are considered to analyse the project outcomes.

Chapter 5 Explanatory phase analytical framework development

5.1 Introduction

The previous chapter presented the exploratory phase of this research (Phase 1) which gave insights for the development of the theoretical framework of the explanatory phase (Phase 2). The conclusions of Phase 1 analysis (section 4.5) identified the importance of the 'People' dimension in affecting how EC considerations are set and addressed in a BIM-enabled project. The client and the design team were identified as the main actor groups involved in the process interacting with project and industry level structures. This highlighted the requirement for a distinction between the two actor groups and the division of structures at industry and project level. Furthermore, the links identified between people and structures emphasised the importance to further investigate how industry-wide structures affect the control of project-level structures through individual agency and the power dynamics between the client and the design team.

The requirement of a socio-technical approach to study how EC considerations are set and addressed through the use of BIM as an information management and software tool has been identified in the reviewed literature (section 2.7). The findings of the exploratory phase of this research enabled the refinement of the approach to address the knowledge gap and established the requirement of the adoption of a theoretical framework that considers the interdependence of agency and structure, agency of different actor groups and the power dynamics between them and enables the division of structure at different levels.

5.2 Socio-technical Systems overview and the selection of Structuration Theory for the development of the explanatory analytical framework

Socio-technical systems (STSs) are complex systems with interactions between humans, tools and contextual aspects of the work system. As part of their key characteristics, STSs include interdependent social and technical parts in their internal environments, adapt to external environments and pursue goals in them (Baxter and Sommerville 2011). As such, Socio-technical Systems Theory (STST) has been applied to study and promote change through the introduction of new technologies or process changes in organisations by considering both technical and social factors of the system under study (Cherns 1976). In more recent years, STST principles have evolved to consider advancements in technology and the effect these have on management and work practices (Clegg 2000). However, the basic characteristic of STST which relates to the consideration of both social and technical parts of the STS is still a basic tenet of the theory. The STST has been adopted in a wide range of studies that included technology-driven organisational changes (Baxter and Sommerville 2011), redesign of professional roles (Challenger and Clegg 2011) and the integration of new technology in existing practices (Mumford 2006).

Despite its wide adoption by a wide range of studies, STST has received some criticism. The main criticism relates to its descriptive nature (Nardi 1996; Majchrzak and Borys 2001) and the weakness in providing an analytical framework that enables the explanation of the forces that drive or challenge change in STSs (Sackey 2014). However, recent use of the theory has involved empirical studies (Scacchi 2004) and scholars have developed context specific analytical frameworks to enhance the analysis of socio-technical systems.

The criterion of selection of one theoretical framework over the another is not with regards to its ability to provide an objective view of reality (Halverson 2002). The use of different theoretical frameworks aims to highlight relevant issues and is closely related to the aim and objective of the study; in the words of (Barthelmess and Anderson 2002): *‘it is only useful to the point that it provides relevant insights about the objects it is applied to’.*

Structuration theory (ST) aims to reconcile opposing views in social theory such as determinism and voluntarism, individualism and structuralism, and micro and macro distinctions (Giddens 1984). The theory places practice at its centre to link these opposing views and as such, it is considered a practice theory by scholars (Whittington 2010). The duality of structure is a key concept, which addresses the interdependence of structure and agency. Human agency draws on and reproduces social structure; human agents utilise structural properties to either maintain or modify them, allowing for consideration of both structural continuity and change

(Cohen 1989). On the other hand, social structures are considered both enabling and constraining, which renders the studying of the impact of social system conditions important (Giddens 1979). ST has been considered useful for examining complex and fluid social settings such as contemporary organisations (Whittington 2010).

Some scholars created adaptations to ST to study technology and its use. DeSanctis and Poole (1994) proposed ‘Adaptive Structuration Theory’ to explore the utilisation of technology as a way of appropriating the structures embedded within technology. Orlikowski (1992) introduced the concept of ‘the duality of technology’ as a means of examining the use of technology within organizations. Stones (2005b) made an extension of ST, Strong Structuration Theory, with which he aimed to enhance conceptual and methodological elements of the theory. One of the adaptations to the original ST was the differentiation of structures to external (conditions of action) and internal (within the agent) (Stones 2005b). This differentiation enables deeper investigation in relation to the agents and their explicit or tacit knowledge and their general dispositions.

As can be discerned, Adaptive Structuration Theory places its focus on technology and how it is appropriated, whereas Strong Structuration Theory incorporates the investigation of agentic cognition and qualities to the analysis. Giddens’ original Structuration Theory focuses on practice and its approach to agency and structure as mutually dependent allows for both aspects to be considered as equal parts of the socio-technical system under study. This thesis focuses on a meso-level as this level enables the analysis of a range of the socio-technical system components and their connections, including different actors and their contribution to socio-technical change (Savaget et al. 2019). ST provides an appropriate framework to study the interdependence of agency and structure and enables the analysis of the conditions and mechanisms that affect how EC considerations are set and addressed in a BIM-enabled design process. This chapter elaborates further on Structuration Theory, its basic concepts, and its use for the development of the Phase 2 analytical framework of this thesis.

5.3 Structuration theory overview

Structuration theory was developed by Anthony Giddens as an endeavour to overcome dualisms of determinism and voluntarism, individualism and structuralism and micro and macro distinctions in social theory. Practice is placed at the centre of the theory to link the extreme positions in social theory, therefore structuration theory is characterised as a practice theory by practice theory scholars (Whittington 2010). The key notion of the theory is the duality of structure, with which the dualism between structure and agency is addressed as the two are considered mutually dependent. Through structuration, human agents draw on structural properties and either reproduce or amend them. As such, structuration allows to consider both structural continuity and innovation or change. Structuration theory allows researchers to study alternative use of resources that may lead to alternative ways of acting and at the same time can facilitate the interpretation of system reproduction process (Cohen 1989)

Giddens' structuration theory is not the only theory that contends that structure is shaped by human activity, in fact, Thrift (1983) places Giddens, Bhaskar and Bourdieu in a 'structurationist school', elements of which were first introduced by Berger and Luckmann (1971). Although the theories developed by the above three theorists bear some basic similarities that categorises them as 'structurational', they also have important differences, mainly in the way they view the relationship between structure and agency. Bourdieu (1990) places the 'habitus' a set of objective dispositions between social structure and agency, which acts as a guide to day-to-day activity. Agency is not completely dictated by it, agents can still influence outcomes, but within the constraints set by the habitus. Therefore, agency for Bourdieu is largely opportunistic. Bhaskar (1989) takes a critical realist approach that views structure as more rigid and preceding action and as such structure has a foundational role for agency. As will be presented in more detail in this chapter, in Giddens' theory of structuration, structure and agency are a '*mutually constitutive duality':* human agency draws on social structures and at the same time agency reproduces social structure (Jones and Karsten 2008). Whittington (2010) mentions that structuration theory is particularly relevant when circumstances are *'plural and fluid'* and gives as an example contemporary organisations that are undergoing constant change.

5.4 Key elements of Structuration Theory

5.4.1 The agent and agency

Giddens (1984) views agents as knowledgeable actors that constantly reflect on and monitor their actions and the contexts in which their actions take place. Through reflexive monitoring and rationalisation of their actions, actors develop an understanding of the base of their actions. Whilst reflexive monitoring and rationalisation of action refer to the intention and reason of action, motivation refers to the wants that prompt it and is therefore seen as the potential for action (Giddens 1984). Giddens (1984) describes day-to-day life as a continuous flow of intentional action that, despite its intentionality, may result in unintended consequences that could become the unacknowledged conditions of further acts.

Moving the focus from the acting agent to agency, Giddens (1984) rejects that agency is defined by the intentions of human action and argues that agency refers to the capability of agents to achieve the action. Thus, agency for Giddens incorporates the element of power, in the form of transformative capacity to reach the intended outcome. Agents choose a course of action instead of another and through their actions they employ their capability to make a difference to *'a pre-existing state of affairs or course of events'* (Giddens 1984). An agent that lacks any sort of transformative capability ceases to be an agent as, for Giddens, agency is intrinsically linked to power. Power in social interaction is characterised by relations of autonomy and dependence between actors and is exercised through the use of resources. The relational view of power is expressed by the concept of the 'dialectic of control' according to which *'all forms of dependence offer some resources whereby those who are subordinate can influence the activities of their superiors'* (Giddens 1984, p. 16). Power is therefore always observed as two-way relations, even if the autonomy of one actor is minimal compared to another actor in the context of a social interaction (Giddens 1979). This view enables the analysis of power to consider both top down as well as bottom up approaches in a complementary manner (Cohen 1989).

5.4.2 Structure, structuration and the duality of structure

Structure is conceptualised as a set of rules and resources that are drawn upon by actors during the reproduction of social practices. Giddens (1984) rejects the notion that structure is something external to human action. Structure exists in the instantiation of social practices and in the memory traces of knowledgeable agents. It forms and shapes social life, but it is not itself the form and shape.

Social systems are reproduced social practices that don't 'have' structures but show structural properties that enable their 'binding' in time and space. As such, structure is not situated within time and space boundaries, but operates recursively within social systems, which are reproduced across time and space. The reproduction of social systems involves the process of structuration, which is expressed as the conditions involved in the continuity or transformation of structures. Fundamental to the structuration process is the notion of the duality of structure, according to which, structure is both the medium and the outcome of the social practices (Giddens 1984). The duality of structure rejects the notion that structural properties are solely constraining and views structure as both enabling and constraining. Giddens states that one of the tasks of social theory is the study of the structuring conditions of social systems that affect the manifestation of structure as enabling or constraining in the system reproduction (Giddens 1979).

For analytical purposes, Giddens distinguishes three dimensions as 'Structures', 'Modalities' and 'Interaction' (Figure 5.1). Considering the structure dimensions, 'Signification' refers to the constitution of meaning through discursive and symbolic structures, 'Domination' refers to resources that can be drawn upon to exercise power and 'Legitimation' refers to normative structures that include formal obligations as well as informal rules and codes of conduct (Whittington 2010). The modalities of structuration are placed in the intermediate layer as they are both drawn by actors in interaction and at the same time form the media of structural component reproduction (Giddens 1979). The modalities are again distinguished by three dimensions, 'Interpretative scheme', 'Facility' and 'Norm'. Interpretative schemes are defined as the actor's stocks of knowledge that forms *'an accountable universe of meaning'* expressed in the process of interaction (Giddens 1979). Giddens (1984) defines norms as rules that concern the *'sanctioning of conduct'.* He distinguishes two types of rules involved in social conduct; those that relate to the constitution of meaning, and those that relate to sanctions that rule following. Facilities are resources or capabilities of reaching outcomes that actors draw upon to exercise power in their interactions. They are distinguished by two types, allocative resources that supply capabilities of control over material resources and authoritative resources that supply capabilities of control over non-material resources (Giddens 1984; Cohen 1989). Resources are the media through which power is instantiated in action and structures of domination are reproduced (Giddens 1979).

Although Giddens presents structures, modalities and interaction in three dimensions, it is stressed that this distinction is purely analytical and that, in social practices, the dimensions are always intertwined (Giddens 1979; Whittington 2010). This is expressed by the horizontal double headed arrows between the three structure and interaction dimensions in Figure 5.1. The vertical double headed arrows between structures, modalities and interaction denotes the recursiveness of the duality of structure (Cohen 1989).

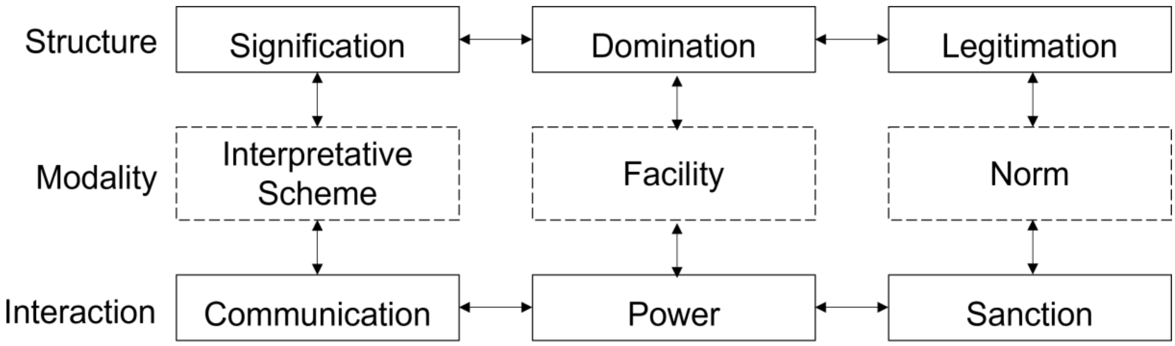

Figure 5.1 The dimensions of the Duality of Structure. Source Giddens (1984).

5.4.3 Structuration theory in sociological research

For the application of structuration theory in social study and empirical research, Giddens suggests two types of methodological bracketing: institutional analysis and the analysis of strategic conduct. The two types of analyses present different approaches in studying system properties across space and time. In institutional analysis, structural properties such as rules and resources are considered as *'chronically reproduced features of social systems'* (Giddens 1984, p. 288). In the analysis of strategic conduct, social systems are examined through analysing the ways agents draw on the social system's rules and resources in their social activities. The focus is placed upon how actors mobilise discursive and practical consciousness in their interactions within defined contextual boundaries whose institutionalised components are considered methodologically 'given'. This assumption does not mean however that human agency does not contribute to the production and reproduction of these institutionalised components. This bracketing is purely methodological and aims to place the focus of the analysis on *'contextually situated activities of definite groups of actors'* (Giddens 1984, p. 288). For the analysis of strategic conduct, Giddens (1984) emphasises three tenets: a thorough description of agents' knowledgeability, an interpretation of motivation and an understanding of the dialectic of control.

Another important aspect discussed by Giddens is that of social positions and position practice relations. Social positions are defined as social identities that pertain a range of prerogatives and obligations that the actor in this position may carry out. This range of prerogatives and obligations are defined by the role prescriptions related to that position. Role prescriptions however are regarded as normative elements which can have a wide range of interpretations when enacted in specific contexts resulting in different power relations. Therefore, it is essential that role prescriptions are considered alongside the actual practices as there may be discrepancies between what the role prescription entails and what the actors do within the social positions they occupy (Giddens 1979). Considering this, Giddens rejects that social systems consist of roles, and regards social practices as the *'points of articulation'* between actors and structures (Giddens 1979). According to Cohen (1989), social practices as presented by Giddens can be conceptualised as position practice relations, which affect the structuring of interaction whilst at the same time constitute the main 'building blocks' of institutional system integration. Through this concept, Giddens gives an institutional link between structure and agency (Cohen 1989).

Cohen (1989) (informed by Giddens' concepts) distinguishes three modes of system organisation based on their intentional or unintentional coordination and control. 'Homeostatic' systems are defined by unintentional coordination and control, 'reflexively regulated' systems by intentional coordination and unintentional control and 'self-reflexively regulated' or 'administered' systems by intentional coordination and control. Administered systems are intentionally controlled and coordinated by a group of leaders and administrators who act as 'administrative power-holders'. Administrative power refers to capabilities of coordination and control that relate to the timing and spacing of human activities. By exercising administrative power,

power-holders can affect the day to day lives of subordinate agents and thus form distinctive power relations between the two agentic groups. Cohen (1989) may distinguish these three modes of system organisation but stresses that this distinction is conceptual and that hybrid combinations of these three modes are encountered in real life contexts.

5.5 Structuration Theory application in Construction Research

Structuration theory has been used in construction research on a range of topics that relate to construction and supply chain management, defect problem solving, housing challenges and the digitisation of the construction sector.

Bresnen et al. (2005) used structuration theory to explore the relationship between structural conditions and managerial agency when trying to introduce new management initiatives in two UK construction firms. The study adopted a practice-based approach to explore the micro-processes of organisational change in the *‘under-researched’* context of construction project organisation. The analysis and findings were presented in relation to interpretative and normative rules, and power resources mobilised in the two cases. McCann (2017) used structuration theory to explore the relevance of project management practice standards to the UK construction industry and propose recommendations to improve project management best practice. Structuration theory was used to substantiate a business model developed by Selberherr (2015) that aimed to promote sustainable development on a societal level through value creation and cooperation of construction service providers. Koch and Schultz (2019) studied the social practices of construction projects in relation to defect problem solving. Structuration theory was used to analyse the interrelations between the relevant project structures and agents, with a focus on the unintended consequences of routinized practices. The exploration of the relationship between structural conditions and agency when introducing new initiatives observed in these studies is particularly relevant to the introduction of EC considerations in BIM-enabled projects which the explanatory phase of this thesis aims to analyse.

Structuration theory was also used to analyse construction supply chain relationships and the value of trust (Xu 2019) and how supply chain management applies to the UK construction sector focusing on the relationship between context and practice (Fernie 2005). Supply chain management in relation to the process of change in UK construction organisations was also investigated by Fernie and Thorpe (2007) using structuration theory and new institutionalism. Contextual factors were identified influencing supply chain management application. Fernie et al. (2006) suggest structuration theory as a contextual approach to study the relationship between practice and performance to support an agenda for change in the UK construction sector. A contextual approach is significantly important when investigation of EC considerations and the use of BIM in construction projects, as found in the exploratory phase of this thesis. Structuration theory offers the possibility of taking into account contextual factors, and hence, is suitable for addressing the research objectives of the explanatory phase (see section **Error! Reference source not found.**).

Kavishe et al. (2018) used structuration theory amongst other theoretical perspectives such as contingency, relational and equity theory to analyse the delivery challenges influencing public private partnership housing in Tanzania. Through the use of structuration theory, the institutional structures and the agency of stakeholders involved in addressing these challenges were analysed. Challenges and enablers were also investigated for risk allocation in the Zambian construction industry by Tembo-Silungwe and Khatleli (2018) using structuration theory. Perera and Lee (2021) used structuration theory as a relational lens to study a large-scale housing development project in the UK with an aim to create a deeper understanding of housing affordability in the 21^{st} century and to inform housing policies and planning practices. A deeper understanding to reach to explanatory accounts of how EC considerations are set and addressed in BIM-enabled projects to inform practice and policy forms part of the objectives of this second phase of this research. As can be seen from the above studies, structuration theory is appropriate for addressing this objective.

Structuration theory has also been used in studies that focused on change in relation to the digitisation of the construction sector. Hasan et al. (2021) used the structuration model of technology as a theoretical framework to analyse the use of mobile devices by construction management professionals. Structuration theory was used by Brooks (1997) as a theoretical framework to study organizationally situated computer-aided design. Morgan (2019) studied the BIM adoption process of a design firm and used structuration theory to analyse the relationships between the levels of user, firm and institution. Orlikowski (2000) seminal work on the study of technology-in-practice through a structurational perspective informed the research of Montagi et al. (2017) which compares BIM implementation as a ‘technology-in-use’ in two different contexts, Finland and Quebec. BIM brings digitisation of building representation and information management and requires a process change within the construction industry (section 2.3.2). As this study considers the use of BIM to facilitate EC considerations in building design, the use of structuration theory by the above studies shows its appropriateness to study change in relation to digitisation.

5.6 Critiques and limitations of Structuration Theory

Giddens’ concept of structure has been criticised for excessive subjectivism by a number of scholars such as Callinicos (1985) and Clegg (1989). Thompson (1989) characterises it as loose and abstract in comparison to the structuralist tradition, whereas Archer (1996) warns of the risk of conflating action with structure and Layder (1987) argues that structure is so undermined that it can have no pre-constitution or autonomy over action. Whittington (1992), however, stresses that although Giddens’ structure is instantiated in practice, its continuity lies in ‘memory traces’ as mentioned by Giddens (1984). Conflation can therefore be avoided as structural properties are not only the ones mobilised in agency, but also the ones that are left dormant residing in people’s minds.

Another criticism of Archer (1995) is that, because structure according to structuration theory is the outcome of practices, it can only have existence ‘here and now’. Stones (2005b) however rejects this criticism and stresses that, although Giddens focuses on human agency, he also recognises the contextual boundaries of human action and how they can limit the available options for human agents. Structural constraint and how it is addressed in structuration theory has received criticism from several scholars including Archer (1982), Layder (1987) and Thompson (1989). Cohen (1989) identifies two weaknesses in Giddens’ work that contribute to these criticisms, first, the absence of an in-depth interpretation of the agents’ motive development and second, a neglect of the distribution of structural options. Although he defers addressing the first weakness to future development, for the second, he proposes that the concept of position-practice relations that is introduced by Giddens and further elaborated by Cohen (1989) can be used to identify and compare structural option distribution.

In relation to methodological limits of structuration theory, Gregson (1989) considers that the theory is too generalised and lacks guidance on how it can be used empirically. Giddens (1984) however has addressed this by presenting a comprehensive list of aspects in structuration theory that relate to empirical research in the social sciences. Stones (2005a) supports that structuration, can indeed contribute to situated analyses. Bernstein (1989) criticises the lack of a conceptual foundation to develop a critical stance and means to generate solutions for critical problems. Cohen (1997) contends that Giddens reply to Bernstein’s critique gives a categorisation of types of critique and places Bernstein’s view as relevant to a moral critique category. He then states that a moral stance is assumed in all social inquiries, but moral critique is not part of the main concepts concerning structuration theory.

Some criticisms have focused on specific themes in relation to structuration theory. Stinchcombe (1990) questions how structuration theory sets the basis to explain historical change. Archer (1996) adds to this questioning by saying that whilst structuration theory aims to explain conceptually the reproduction of social structure, it does not give a basis to understand why some forms of social reproduction are successful in becoming institutionalised and others do not. Murgatroyd (1989) also stresses structuration theory’s neglect of the consideration of gender, leaving feminist sociological concerns unaddressed.

Structuration theory has also been criticised with regards to its limited attention to technology. In one of his few mentions of technology, Giddens states that he views technology just as he views other allocative resources that gain existence through they’re implication in human action (Giddens and Pierson 1998). As such, according to Giddens, technology does not embed structures, and can be an enabler or constraint to action depending on its use of human agents. Structuration theory however has extensively been used in Information System (IS) research, where technology and its use have a central role (Pozzebon and Pinsonneault 2005; Jones and Karsten 2008). DeSanctis and Poole (1994) suggested an adaptation of structuration theory, Adaptive Structuration Theory (AST) to study the technology use as an appropriation of structures embedded in technology. Orlikowski (1992), proposes the concept of 'the duality of technology' for the study of technology use in organisations. Although the 'duality of technology' considers technology as an artefact, it acknowledges its recursive notion according to which, technology is created and changed by human action. Orlikowski (2000) further expands the structurational analysis of technology by introducing a "practice lens" that distinguishes between technology considered as an artefact and the enactment of technologies, 'technology in practice', where structural properties of technologies are conceptualised as emergent rather than embedded.

As discussed in section 5.5, structuration theory has been considered an appropriate theory to inform the analysis of the explanatory phase of this research. Some of the criticisms described above such as its inappropriateness to study topics such as historic change and the lack of gender consideration do not hinder its use for this study as none of the above are relevant to the focus of this thesis. Other criticisms that relate to the lack of guidance in the empirical application of the theory aim to be addressed through the use of the Exploratory phase findings for the development of the Explanatory phase analytical framework. As part of the operationalisation of the theory, the concept of position-practice relations is used to address the criticism that relates to the neglect of the distribution of structural options.

5.7 Synthesis: Explanatory phase analytical framework

The Explanatory phase analytical framework draws on theoretical concepts from Structuration theory and is informed by findings from the Exploratory Phase. The basic structure of the framework is described and the rationale of how these concepts were synthesised to address the requirements of this research are explained below.

From the Exploratory phase analysis two basic requirements emerged; the need to further understand the relationship between conditions that affected the project outcomes and the need to understand the relationship between the identified conditions and the project outcomes. As such, two levels of analysis were required:

one level to create a deeper understanding of the relationship between the conditions (Conditions Analysis), and another to analyse the relationship between conditions and the project outcomes (Analysis of Strategic Conduct).

According to the duality of structure, there is a '*mutual dependence of structure and agency'* where structure is considered as *'both enabling and constraining'.* Giddens stresses the importance of studying the social system conditions that affect the relationship between structure and agency (Giddens 1979). Following this principle of structuration and to analyse the relationship between contextual structures and agency as observed in the case study project outcomes, a **Conditions Analysis** was conducted as a first step during the analysis of the case studies. The intermediate layer of modalities (interpretative scheme, facility, norm) which is situated between structure and agency in Giddens' duality of structure diagram (see Figure 5.1) was used to categorise the case study conditions. The definitions of these three modalities have been presented earlier in this chapter and can be summarised as the knowledge, resources and rules that actors draw upon in social conduct. For this study, interpretative scheme is not restricted to the actor's knowledge, but has been extended based on Rerup and Feldman (2011) to also incorporate other frames of reference that actors draw meaning upon, such as assumptions, ambitions and values. Norms relate to both the constitution of meaning as well as sanctions and are not restricted to rules, and have been extended based on Orlikowski (2000) to include codes of conduct and project approaches.

During the exploratory phase two layers of structures were identified: 1) an industry-wide layer, which included structures that related to the UK construction industry at the time that the project was being developed, and 2) a project-wide layer, which included structures that were relevant to the specific project case study. Therefore, the conditions were also divided into outer and inner conditions, with the former referring to industry-wide structures and the latter to project-wide structures. A note needs to be made in relation to this 'outer/ inner' division of conditions. 'Outer' conditions were not considered external to the social system being analysed. They were external to the project case study, but as they were relevant to the industry context that the project took place, 'outer' conditions remained a part of the social system that was being analysed. This is in line with Giddens' view that structures are not external to human action but rather are part of what shape social life (Giddens

1989). Another note to be made is that ‘interpretative scheme’ is only considered as an inner condition, since it refers to actors that are considered at project level. This is in line with the Orlikowski’s duality of structure adaptation, where structural properties of social systems consider rules and resources instantiated in practice, whereas interpretative schemes are considered for situated human agency (Orlikowski 2000), which would be at project level for the study.

Upon completion of the Conditions analysis, the analysis of the case studies moved to consider how the contextual conditions affected project outcomes through the **Analysis of Strategic Conduct**. The focus was on agency that related to EC considerations in a BIM-enabled project, which was conceptualised in this study as the human action affecting project outcomes. Giddens (1984) states that in the analysis of strategic conduct *‘the focus is placed upon modes in which actors draw upon structural properties in the constitution of social relations’* where the analysis draws on ‘*contextually situated activities’* of actors.

The analytical framework that consists of the two levels of analysis described above (the Conditions Analysis and the Analysis of Strategic Conduct) is presented in Figure 5.2.

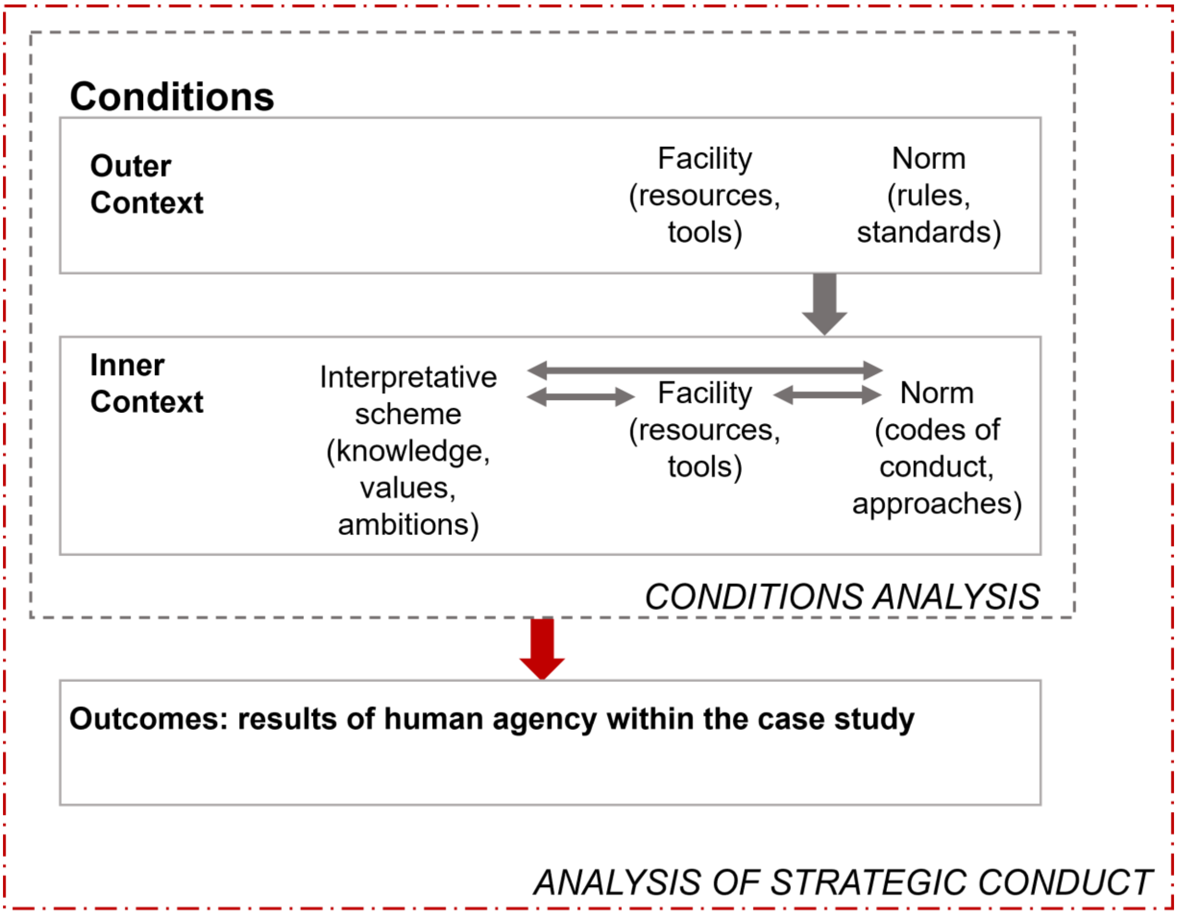

Figure 5.2 Explanatory phase analytical framework

In the Analysis of Strategic Conduct, the duality of structure is expressed by contextualised conditions and the outcomes of situated action. Structure is *'both the medium and outcome of conduct'* so whilst the contextual conditions are the medium of situated agency, the project outcomes contribute to the recursive nature of the structuration process (Giddens 1984). To capture this recursive nature of the structuration process, apart from project outcomes this study also considers contextual outcomes, which refer to the relation of the project outcome to the industry's status quo. Further elaboration on this is included in section 5.7.1.4.

Two basic concepts of structuration theory were used to analyse the structuration processes of the project outcomes: 'the dialectic of control' and 'position-practice relations'. The 'dialectic of control' was identified as an important tenet in the analysis of strategic conduct and 'position-practice relations' were listed in the aspects of structuration theory that are useful to operationalise structuration theory empirically (Giddens 1984). These two theoretical aspects of structuration theory are used at the final stage of analysis of strategic conduct as theoretically informed mechanisms that contribute to the explanation of the observed outcomes.

The conditions and outcomes that were considered for the analysis were informed by the Exploratory Phase results of this study. Further theoretical explanations and the Exploratory Phase analytical elements that informed the conditions and outcomes categories are described in the sections below.

5.7.1 Specifying elements of the Explanatory Phase framework using Exploratory Phase results

The Explanatory Phase analytical framework was developed based on theoretical concepts of structuration theory as described in the previous section. The framework was informed by empirical findings from the Exploratory Phase analysis. Exploratory Phase results were used to populate the conditions categories ‘Interpretative Scheme’, ‘Facility’ and ‘Norm’.

5.7.1.1 Specifying project Conditions

As described in the previous chapter (Chapter 4), Exploratory Phase findings were conceptualised and presented in three themes, ‘People’, ‘Process’ and ‘Tools’. Within the ‘People’ theme two main agent groups that can hold **interpretative schemes** were identified: the Client and the Design team. The findings that related to the client expressed the client ambitions for the project, therefore, they were conceptualised as ‘Client Ambitions’ in Explanatory Phase analysis. For the Design team however, some of the findings related to the design team knowledge and skills, whereas others related to initiatives they took to influence project outcomes. Therefore, interpretative schemes for the design team were conceptualised into two separate categories: ‘Professional knowledge/ skills’ and ‘Professional Leadership’.

There is a variety of definitions for the term ‘Leadership’ given by scholars throughout the last decades (Winston and Patterson 2006; Silva 2016). In this study, Stogdill (1950) the definition of leadership as cited by Silva (2016) is used, *‘the process (act) of influencing the activities of an organized group in its efforts toward goal setting and goal achievement’.* According to this definition and considering the focus of the thesis, ‘Professional leadership’ is conceptualised as any process or act made by the design team professionals to influence activities toward EC target setting and realisation through BIM application in the project case study.

Within the 'People' theme there were findings related to project resources and project approaches that the agent groups affected. These findings were conceptualised as 'Facilities' or 'Norms' during the Explanatory Phase analysis and according to the theoretical definitions presented in the previous sections of this chapter. More specifically, 'team appointments' were conceptualised as inner facility because they are used as project resources that create capabilities of control and can affect project outcomes. Both approaches to Sustainability and BIM have been conceptualised as inner norms as they are approaches that relate to constitution of meaning for the production of agency within the project.

During the Explanatory Phase it was made clear that the 'Process' theme referred to structures rather than processes and included both project level and Industry level structures. These were conceptualised as Inner and Outer 'Facilities' or 'Norms'. More specifically, BIM standards were conceptualised as an Industry-wide (outer) norm, as it is a code of conduct available at industry level. Employers Information Requirements (EIRs) are included within the Industry BIM standards; therefore, they were incorporated into this outer norm. Sustainability rating systems and regulations are also industry-wide codes of conduct and were separated into two outer norms: 'Sustainability Rating Systems' and 'Regulation OC focus' as this is the part of regulations that affected project outcomes. The project contract was conceptualised as an inner norm, as it is a code of conduct that relates specifically to the project. 'Cost' and 'Scheduling' were conceptualised as inner facilities, as they are both project resources.

The 'Tools' theme included findings related to BIM software and EC information. As these structures are industry wide and relate to resources that agents can draw upon, they were conceptualised as outer facilities: 'Complexity of BIM model data', 'Secondary data reliability' and 'Lack of EC benchmarks'.

5.7.1.2 Analysing project Conditions

During the analysis of the three case studies, the impact of conditions on project outcomes was investigated in detail through the consideration of the interrelations between conditions. This was enabled through visualisation and social network analysis, which is further elaborated in section 5.7.3. Some conditions directly affected project outcomes, whereas others had an indirect impact because they affected the conditions that directly affected the outcomes. To express this distinction between conditions in the analysis of the case studies, the conditions were categorised into 'direct' and 'indirect'. Indirect conditions were further divided into two sub-categories, primary and secondary, where the former are indirect conditions that are not affected by other conditions and the latter are indirect conditions that are affected by other conditions. Further elaboration on this is made in section 5.7.3.

During the cross-case comparison of the case studies, the aim was the investigation of the impact of context on the project outcomes. As such, a broader 'zoomed-out' approach was adopted to reach explanatory accounts of the impact of conditions on project outcomes. As such, during the cross-case comparison, conditions were categorised as driver or barrier and enabling or constraining. A condition is identified as a 'driver' or 'barrier' when it is the initiating condition for the outcome (who or what influenced this outcome to be), whereas conditions that facilitated or hindered the outcome are identified as 'enabling' or 'constraining' respectively (how this outcome came to be).

5.7.1.3 Specifying project Outcomes

As mentioned previously in the chapter, the 'project outcomes' were conceptualised as the results of agency that related to the focus of this study, which is EC considerations within a BIM-enabled building project. As this study investigates how EC considerations are set and realised in a BIM-enabled project, the project outcomes' categorisation was guided by the research objectives and formed two main categories:

- How EC considerations were set and communicated
- How EC conditions were addressed

The Exploratory Phase results informed these two project outcome categories with specific project elements that relate to both EC considerations and BIM application.

How EC considerations are set and communicated:

- EC target: a specific quantifiable target for the building project EC.
- EIR (Employers Information Requirements): a means to establish information requirements that would enable building assessment in relation to its EC.

- BEP (BIM Execution Plan): communicates how the EIRs are going to be provided.

How EC considerations were addressed:

- Carbon Approach/ Assessment: The approach taken to the project's carbon assessment
- BIM model data input: The EC data that is added to the BIM model
- BIM model data use: How the BIM model is used in the project design development

5.7.1.4 Analysing the project outcomes

To capture how project outcomes contribute to the recursive nature of the structuration process, the project outcomes relation to the industry-wide practices (status quo) was considered to derive the contextual outcomes. The industry status quo was established through literature review which identified the lack of EC considerations for building projects and BIM level 2 for BIM application (see sections 2.4.2 and 2.3.2 respectively). The contextual outcomes categorisation followed the work of Orlikowski (2000) that considered technologies-in-practice in relation to institutionalised practice. In this study, institutionalisation of enacted technologies is presented in relation to their types of enactment, conditions and structural consequences. The structural consequences refer to the relation of technologies-in-practice to the industry status quo, which can present preservation, enhancement or change. These three categories are used in this thesis to define the contextual outcomes as follows:

- Preserve status quo:
    - EC: no life cycle assessment of the whole building has been performed during the design stage
    - BIM-level 2
- Enhance status quo:
    - EC: LCA has been performed in the form of reporting and/ or comparison of options during the design stage
    - BIM: used for EC information management, but BIM model not used for LCA
- Transform status quo:

- EC: LCA has been performed during the design stage with an aim to reduce the project's EC.
- BIM: BIM used for EC information management and BIM model used for LCA

5.7.2 Summary of conceptual and empirical elements of analytical framework

Figure 5.3 presents the Explanatory phase analytical framework as informed by the findings of the Exploratory Phase for the condition and outcome elements.

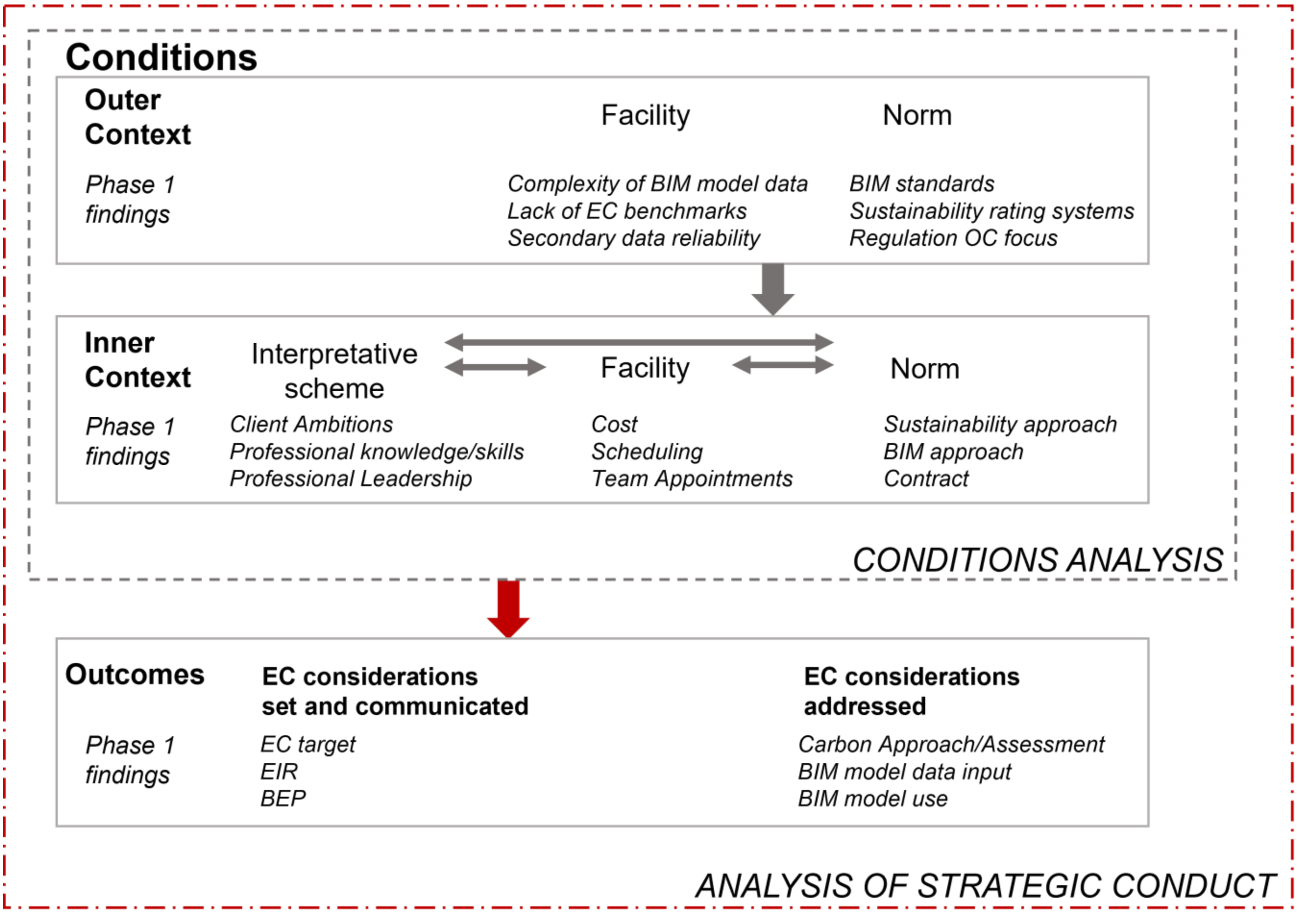

Figure 5.3 Explanatory phase analytical framework informed by Exploratory phase (Phase 1) findings.

As explained above and presented in Figure 5.3, the Explanatory Phase analytical framework was synthesised by theoretical concepts from the theory of structuration and was informed by empirical findings of the first analytical phase of this research study. Table 5.1, Table 5.2 and Table 5.3 list the analytical concepts that were used in the Explanatory phase and presents their theoretical and empirical explanations as they were used for this study.

Table 5.1 Theoretical concept definition and their empirical application in analysis - Conditions.

	Theoretical definition	**Empirical application in analysis**
Conditions	Structural properties of social system that mediate social action (Orlikowski 2000).	Contextual conditions categorised in the modality dimensions of interpretative scheme, facility and norm.
Outer Conditions	Industry level structural properties.	Contextual conditions categorised in the modality dimensions of facility and norm.
Inner Conditions	Project level structural properties.	Contextual conditions categorised in the modality dimensions of facility and norm.
Interpretative scheme	Stocks of knowledge applied by actors in the production of interaction (Giddens 1979) and frames of reference that actors draw meaning upon (Rerup and Feldman 2011).	Project actors' knowledge, values and ambitions: • Client Ambitions: Client ambitions for the project that relate to sustainability and BIM application. • Professional Knowledge and skills: Design team knowledge and skills that relate to sustainability and BIM application. • Professional leadership: any process or act made by the design team professionals to influence activities toward EC target setting and realisation through BIM application in the project case study.
Facility	Resources or capabilities of reaching outcomes that actors draw upon to exercise power in their interactions (Giddens 1979).	Industry level (outer) and project level (inner) resources: **Outer:** • Secondary data reliability: Databases for material EC • BIM model data: Complexity relating to the information stored within the BIM model • EC benchmarks: the lack of EC benchmarks available to the construction industry **Inner:** • Team appointments: Professional appointments that make up the project's design team • Scheduling: The project's timetable • Cost: Financial cost as part of the project budget
Norm	Rules, protocols and codes of conduct that actors draw upon in social conduct (Orlikowski 2000).	Industry level (outer) and project level (inner) rules, codes of conduct, approaches: **Outer:** • Regulations OC focus: Construction industry regulations and their focus on OC • BIM standards: Standards available that relate to BIM use in the UK construction industry • Sustainability rating systems: Rating systems that assess the environmental impact of buildings **Inner:** • Sustainability approach: the approach to sustainability taken in the project with a focus on carbon • BIM approach: the application of BIM in the project in relation to information management, with a focus on EC information • Contract: the project contractual agreement

Table 5.2 Theoretical concepts definitions and their empirical application in analysis - Outcomes.

	Theoretical definition	Empirical application in analysis
Project Outcomes	The result of human agency (Orlikowski 1992)	Outcomes observed in the project in relation to EC considerations and BIM use. Two main categories of outcomes were informed by the study's research objectives.
		EC consideration setting and communicating includes: • EC target: a specific quantifiable target for the building project EC. • EIR: Employers Information Requirements that have been identified as a means to establish information requirements that would enable building assessment in relation to its EC. • BEP: BIM Execution plan communicates how the EIRs are going to be provided.
		EC consideration addressing includes: • Carbon Approach/ Assessment: The approach taken to the project's carbon assessment • BIM model data input: The EC data that is added to the BIM model • BIM model data use: How the BIM model is used in the project design development
Contextual Outcomes	Structural consequences that refer to transformations in structures of the social system as enacted by situated agents (Orlikowski 2000)	The relation of the project outcomes to industry-wide practices (status quo).
		Three contextual outcomes are considered in relation to the industry's status quo: • Preservation • Enhancement • Transformation

Table 5.3 Theoretical concepts definitions and their empirical application in analysis - Mechanisms.

	Theoretical definition	**Empirical application in analysis**
Mechanisms	Causal structures that generate or trigger observable events that we may observe (Archer et al. 2020)	The mechanisms were informed by structuration theory's concepts: 'Position-practice relations' and 'Dialectic of control'. Mechanisms are considered in relation to the two main categories of outcomes: 'How EC considerations are set and communicated' and 'How EC considerations are addressed'.
		Position-practice relations refers to the relations between the client and the design team and the relations amongst the design team professionals as observed through their practice in the case study.
		Dialectic of control refers to the relations of autonomy and dependence between actors as exercised through the use of resources.

5.7.3 Untangling Complexity: Reflections on making complexity transparent during Phase 2 analysis

During the explanatory phase (phase 2), the development of the analytical framework and its application during phase 2 analysis entailed the researcher acting as a research instrument; the researcher acted both as the composer and conductor of the analytical phase ‘orchestra’. As described in section 5.7.1 the elements of the explanatory phase analytical framework were specified using results of the exploratory phase. This specification required populating the conditions and outcomes categories with themes that emerged during the first phase of the research. This required the critical interpretation of the researcher as themes didn’t always neatly fall into a category. The researcher addressed this through delving into structuration theory in an iterative manner to thoroughly comprehend how each category is conceptualised. The theoretical and empirical definitions as used in this research study are presented in Table 5.1, Table 5.2 and Table 5.3 with an aim to create a transparent elaboration of how empirical findings were categorised through the use of theoretical concepts.

Another aspect of complexity occurred during the use of the framework to analyse the case studies and involved the impact of conditions on project outcomes. During the analysis the researcher found that a condition may impact an outcome directly or indirectly through its impact on another condition. Demonstrating these intricate relations of impact was resolved by further categorisation of conditions as direct or indirect and establishing sub-categories of indirect conditions as primary and secondary depending on whether they were affected by other conditions (secondary) or not (primary). During the cross-case comparison that aimed to reach to explanatory accounts, complexity related to the way conditions impacted outcomes, and whether they instigated the outcome or impacted the way the outcome was delivered. As such, a new set of categorisations was established by the researcher in an effort to unpack this complexity. Conditions were categorised as a driver or barrier when they initiated an outcome and as enabling or constraining when they influenced how the outcome came to be. All the above formed part of sense-making by the researcher and bears a level of subjectivity that is inherent to the type of research that was carried out. Striving for transparency has enabled the researcher to communicate the decisions made during the analytical process and the process of sense-making.

5.7.4 Visualisation and social network analysis

Studying and representing the relationships between conditions and outcomes was facilitated through their visualisation on a social network map. Using visualisation to support the description of *‘complex orderings and re-presentations of relationships’* creates a powerful extension to text description of the analysis (Bazeley 2003; Dunleavy 2003). The social network map creation was based on the Explanatory phase analytical framework. Its elements were divided into ‘Conditions’ and ‘Outcomes’ and were colour-coded in order to portray the different categories of conditions and outcomes as presented in the analytical framework. Figure 5.4 shows the social network element types and their respective colour-coding. As there are some outcomes that relate to EC considerations that may not have been reached within the case studies, this has been expressed through a hollow circle on the respective outcome elements. Links between the network elements represent the relationship between conditions and outcomes.

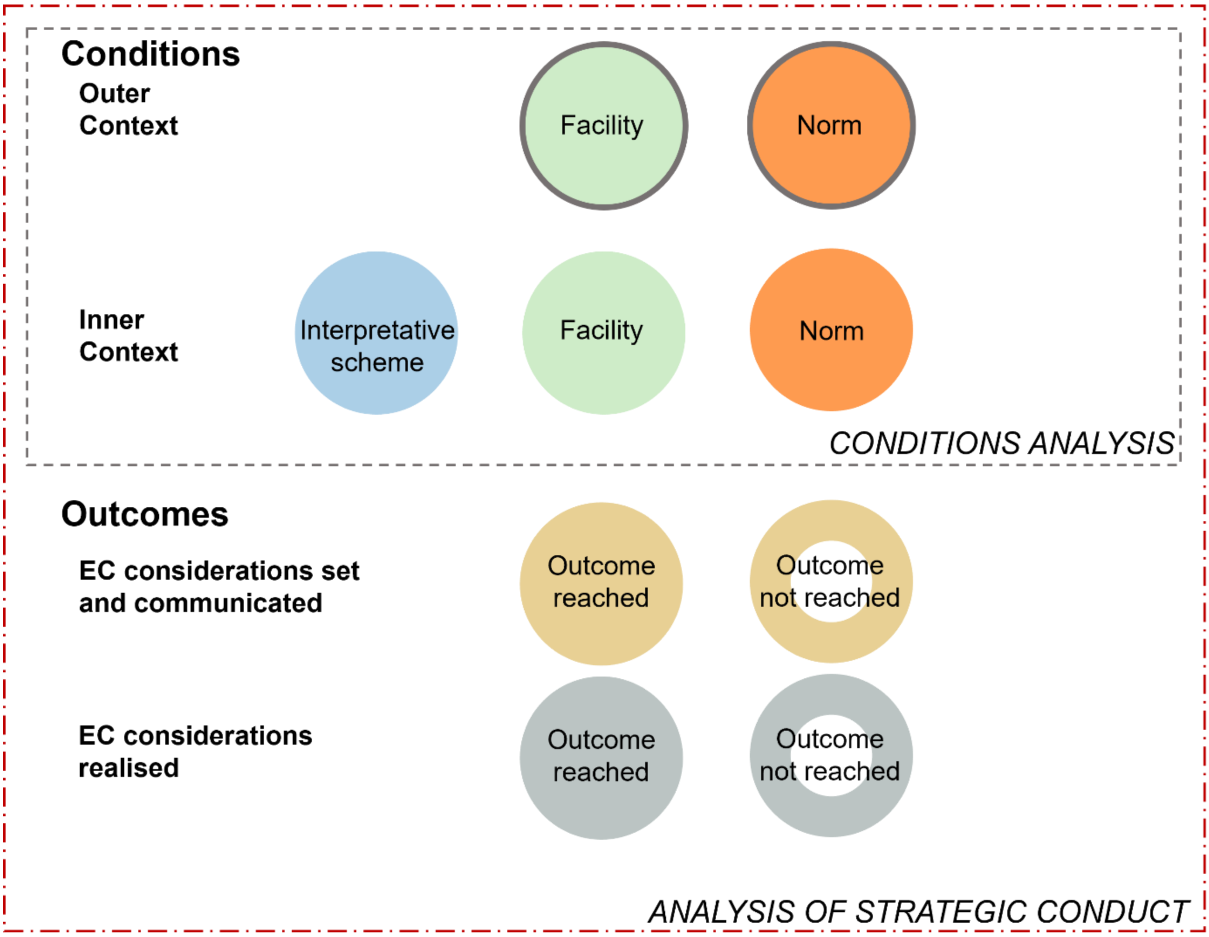

Figure 5.4 Conditions and Outcomes representation as elements of the social network map.

Apart from visualisation, use of the social network map enabled some basic social networks analytics to be performed. This highlighted attention points with an aim to address the network complexity and enabled further theoretical understanding of the relationship between conditions. The two analytics that were used were the 'Outdegree' of conditions, which indicated the number of outgoing links each condition had, and the 'Indegree' of conditions, which indicated the number of incoming links each condition had (Stokman 2001). This enabled identification of the conditions that affected the most other conditions and the conditions that were affected the most by other conditions respectively. The Strategic Conduct analysis considered the Conditions analysis to reveal hidden patterns of relationships, as some conditions directly impact project outcomes, whereas other conditions affect and shape these conditions, and therefore affect the outcomes in an indirect way. To express this distinction between conditions that directly affected outcomes and conditions that indirectly affected outcomes, the conditions were categorised into ‘direct’ and ‘indirect’. Indirect conditions were further divided into two sub-categories, primary and secondary, where the former are indirect conditions that are not affected by other conditions and the latter are indirect conditions that are affected by other conditions. This primary and secondary ordering of indirect conditions resonates with the way Giddens (1984) divides structural contradictions into primary and secondary, with the latter being contradictions that *‘are dependent upon, or brought into being by, primary contradictions’.* This categorisation of conditions enabled a deeper understanding of the complexity of relationships between conditions and outcomes.

To visualise the relationships between the different types of conditions and the project outcomes in the social network map, the links between conditions and outcomes were colour coded accordingly to reflect direct (red), indirect primary (grey) and indirect secondary (light and thin grey) conditions affecting project outcomes, as demonstrated in Figure 5.5.

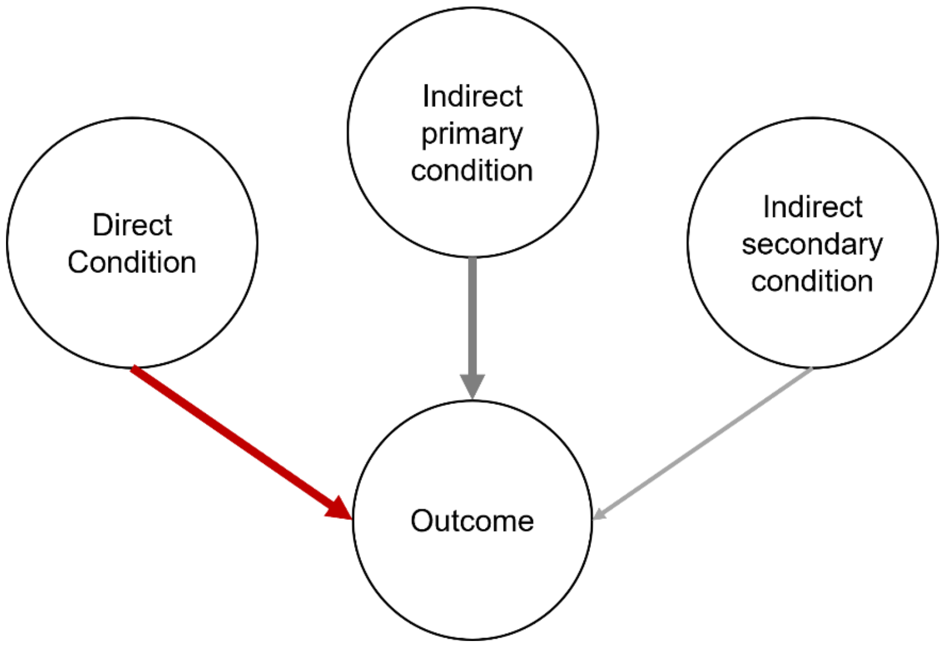

Figure 5.5 Direct and indirect condition links to outcomes

5.8 Summary and Contribution to thesis

This chapter started with an overview of socio-technical systems. Structuration theory was identified as the most appropriate theory to inform the theoretical underpinnings of the Explanatory phase. An extended overview of the theory of structuration followed where the key elements of the theory were discussed to enable a deeper conceptual understanding of structure, agency and their mutual dependence that constitutes the duality of structure. It considered how structuration theory has been used in construction research and discussed the critiques and limitations of structuration theory. The deeper conceptual understanding of the key elements of the theory along with an understanding of empirical applications and its limitations contributed to the synthesis of the analytical framework development for Explanatory phase analysis. The findings from the Exploratory phase informed the theoretical concepts of the framework with specific empirical elements. The contribution of this chapter to the thesis enabled a theoretically informed analysis of the case studies (Chapter 6) and formed the basis of the cross-case comparison (Chapter 7).

Chapter 6 Explanatory phase results and analysis

6.1 Chapter Introduction

The previous chapter presented the key elements of structuration theory and introduced the theoretical framework for the Explanatory phase (Phase 2) analysis. The framework uses key concepts of structuration theory, and its elements are empirically informed by the Exploratory phase (Phase 1) findings (Figure 5.3). Using this theoretical framework, this chapter presents the *Conditions analysis* and the *Analysis of strategic conduct* for three case studies.

The analysis of each case study is presented using the following structure:

- **Case Description**
- **Conditions analysis:** Studies the relationship amongst the case study contextual conditions. Structuration theory concepts of *Interpretative Scheme, Facility* and *Norm* are used to categorise the project's outer (industry-wide) and inner (project-wide) conditions.
- **Analysis of strategic conduct:** Studies how the conditions affected agency in the case study and the resulting outcomes. The outcomes are divided into two main categories according to the research focus. Each outcome category considers elements established through Phase 1 analysis:
    - o How EC considerations are set and communicated in a BIM-enabled project: This section considers the project's *EC target*, and BIM information management through the *Employers Information Requirements (EIR)* and *BIM Execution Plan (BEP).* These are included as sub-headings of this section.
    - o How EC considerations are addressed in a BIM-enabled: This section considers the project's *Carbon Approach/ Assessment, BIM model data input* and *BIM model use.*
- **Conditions, Mechanisms and Outcomes:** Summarises the contextual conditions that enabled/ constrained the project outcomes, establishes causal mechanisms that contributed to the project outcomes and presents the project and contextual outcomes.

As mentioned in the previous chapter, social network mapping is used to represent the project outer conditions, inner conditions, and outcomes (Figure 5.4). These are presented as elements of the social network and the relationships between them are expressed as links between different elements.

6.2 Case Study 1

6.2.1 Case Description

The first case study refers to the same building project analysed during the Exploratory phase (Phase 1). During the Explanatory phase, the Explanatory phase analytical framework is used to bring new insights through the theoretical lens of structuration. An extensive description of this case study was included in Chapter 4 which presented the Exploratory phase (Phase 1) results (section 4.3). As such, a case description is not repeated in this chapter. As the primary data of this case study has also been presented in Phase 1 results, no excerpts of interviews or document analysis were included in this chapter.

6.2.2 Conditions Analysis

All conditions and the links that show their relationships are represented in Figure 6.1. Looking first into how industry-wide outer conditions affect inner (project) conditions, it can be seen that outer context Facility conditions had no impact on the project inner conditions.

Outer context Norm conditions had an impact on inner norms. More specifically, the current industry focus on OC by sustainability rating systems and regulations had an impact on shaping the project's Sustainability Approach. Similarly, BIM standards appeared to have an impact on the project's approach to BIM. The variety of approaches to BIM level 2 that is observed in practice was identified during Phase 1 results as a result of the BIM standards' flexibility in the way BIM level 2 is applied in practice. This was manifested in the case study by a poor BIM level 2 approach.

Moving to the analysis of inner conditions, an outdegree[10] analysis was performed to identify the number of outgoing links each condition has. This enabled the identification of the number of conditions each condition affects, and hence, the conditions that had the most impact on affecting other inner project conditions. It was found that interpretative scheme 'Client ambitions' had the highest outdegree (5),

[10] Social network analytic that indicates the number of outgoing links of an element in a social network.

followed by interpretative scheme ‘Professional leadership’ (2), and facility ‘Cost’ (2). An indegree analysis[11] on conditions was also performed to identify the number of incoming links each condition has. This enabled to identify the conditions that are affected the most by other conditions. Mostly affected was inner norm ‘Sustainability approach’ (4), inner facility ‘Team appointments’ (3) and inner norm ‘BIM approach’ (2). The outdegree and indegree of conditions helped identify quantitatively the relationships of conditions and highlight focus points. A deeper understanding of the relationships between conditions is given through qualitative analysis on conditions.

[11] Social network analytic that indicates the number of incoming links of an element in a social network.

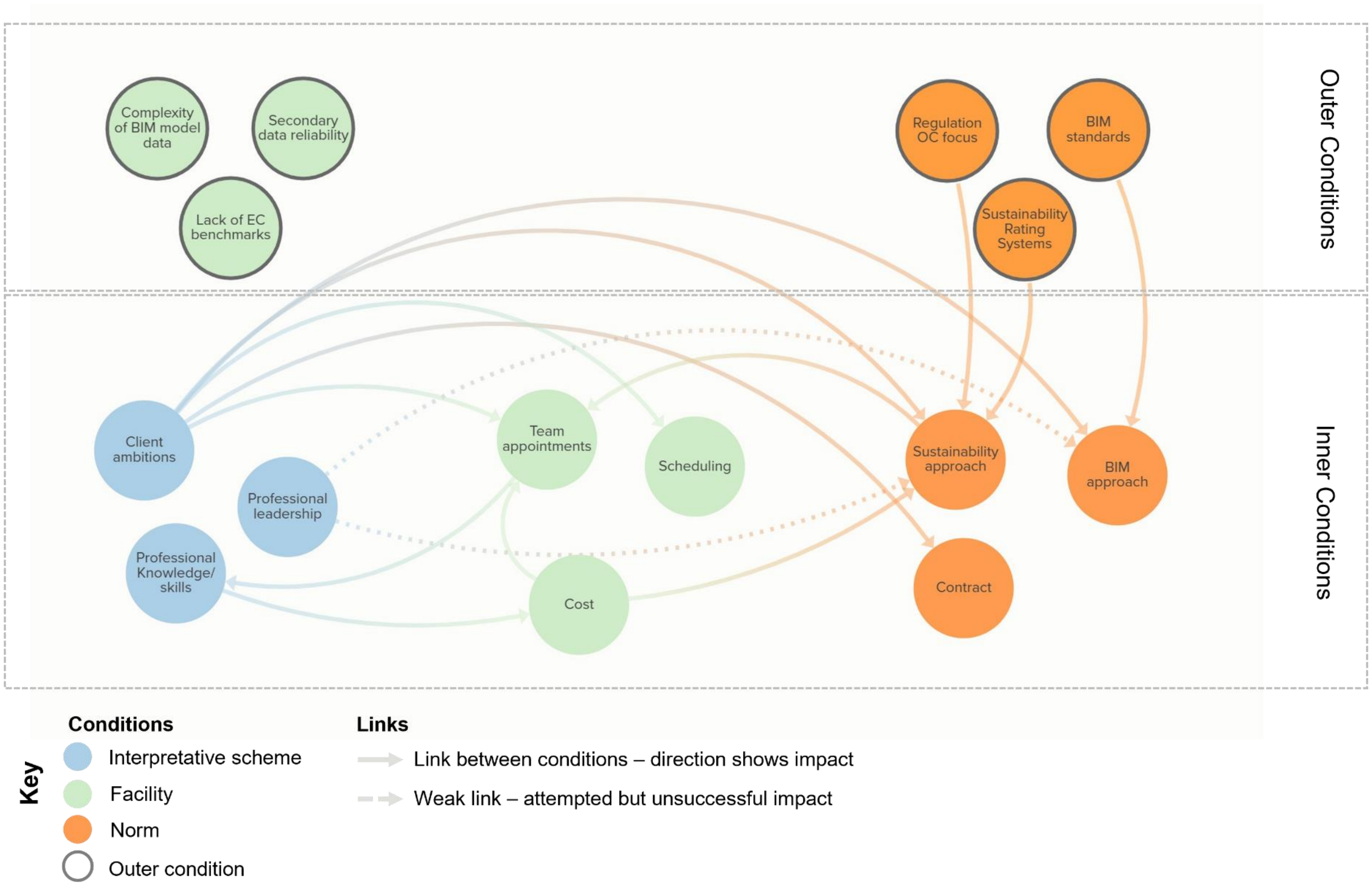

Figure 6.1 Case study 1 Conditions and their relationships.

The ‘Client ambitions’ appear to affect almost all other conditions at project level as can be seen in Figure 6.2. They affect all inner norms: ‘Sustainability approach’, ‘BIM approach’ and ‘Contract’ and affect two out of three facilities: ‘Team appointments’ and ‘Scheduling’. ‘Scheduling’ and ‘Contract’ are an authoritative resource and an inner norm respectively and don’t affect other conditions but have an impact on the outcomes of the project. This will be shown in section 6.2.3, the Strategic Conduct Analysis. Team appointments affect the knowledge and skills that the design team have, as there are practices that are more or less skilled in low carbon design and BIM use, therefore the selection of the practice defined by ‘Team appointments’ also affects the knowledge and skills that the design team bring to the project. The design team knowledge and skills can also be enhanced by the appointment of experts or consultants in LCA and BIM. Since the client is responsible for the team appointments, ‘Client ambitions’ affect the selection of the design team in relation to the skills and knowledge the latter need to possess to fulfil the client ambitions. Therefore, the inner interpretative scheme ‘Client ambitions’ indirectly also affects the inner interpretative scheme of ‘Professional Knowledge/skills’.

‘Team appointments’ of this project were mostly based on the ‘Sustainability approach’ of the project, which was affected by the ‘Client ambitions’. The ambition to achieve a BREEAM Excellent rating for the project appeared as the main driver and influence of the project’s sustainability approach. To facilitate the achievement of the BREEAM target, a Sustainability Consultant was appointed from the start of the design stage (RIBA Stage 0) and the design team was appointed in relation to their ability to deliver a BREEAM Excellent project.

‘Cost’ affected ‘Team appointments’ and ‘Sustainability Approach’ as seen in Figure 6.3. More specifically, additional cost hindered the appointments of LCA and BIM Information lead experts, even though these appointments were requested by the design team. The BREEAM target was the main ‘Sustainability Approach’ driver. However, as the project followed a “lowest capital cost” approach to achieving the BREEAM Excellent target, ‘Cost’ limited the approach to sustainability to just the fulfilment of the BREEAM target requirement.

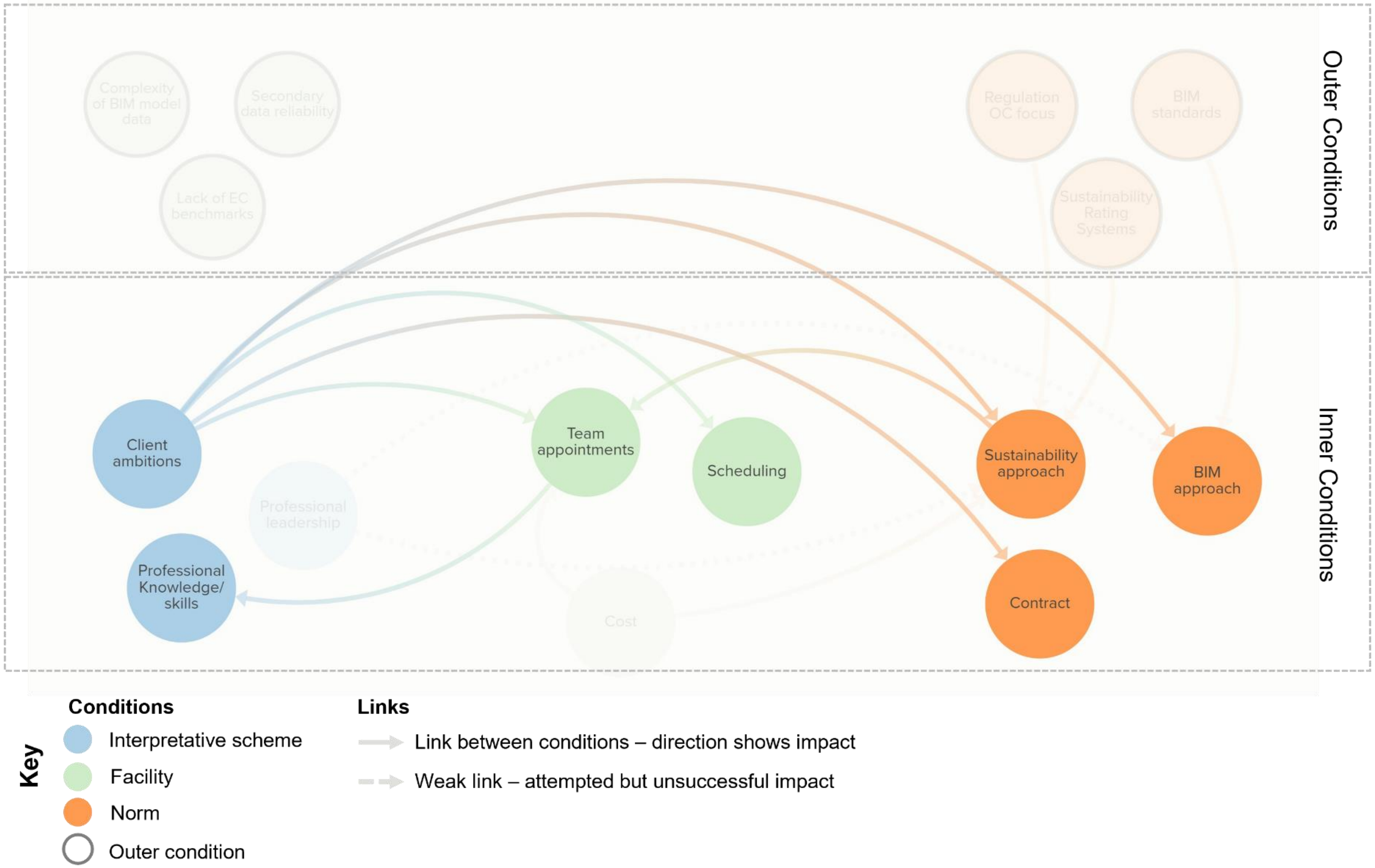

Figure 6.2 Case study 1 Client Ambitions relationships with other conditions.

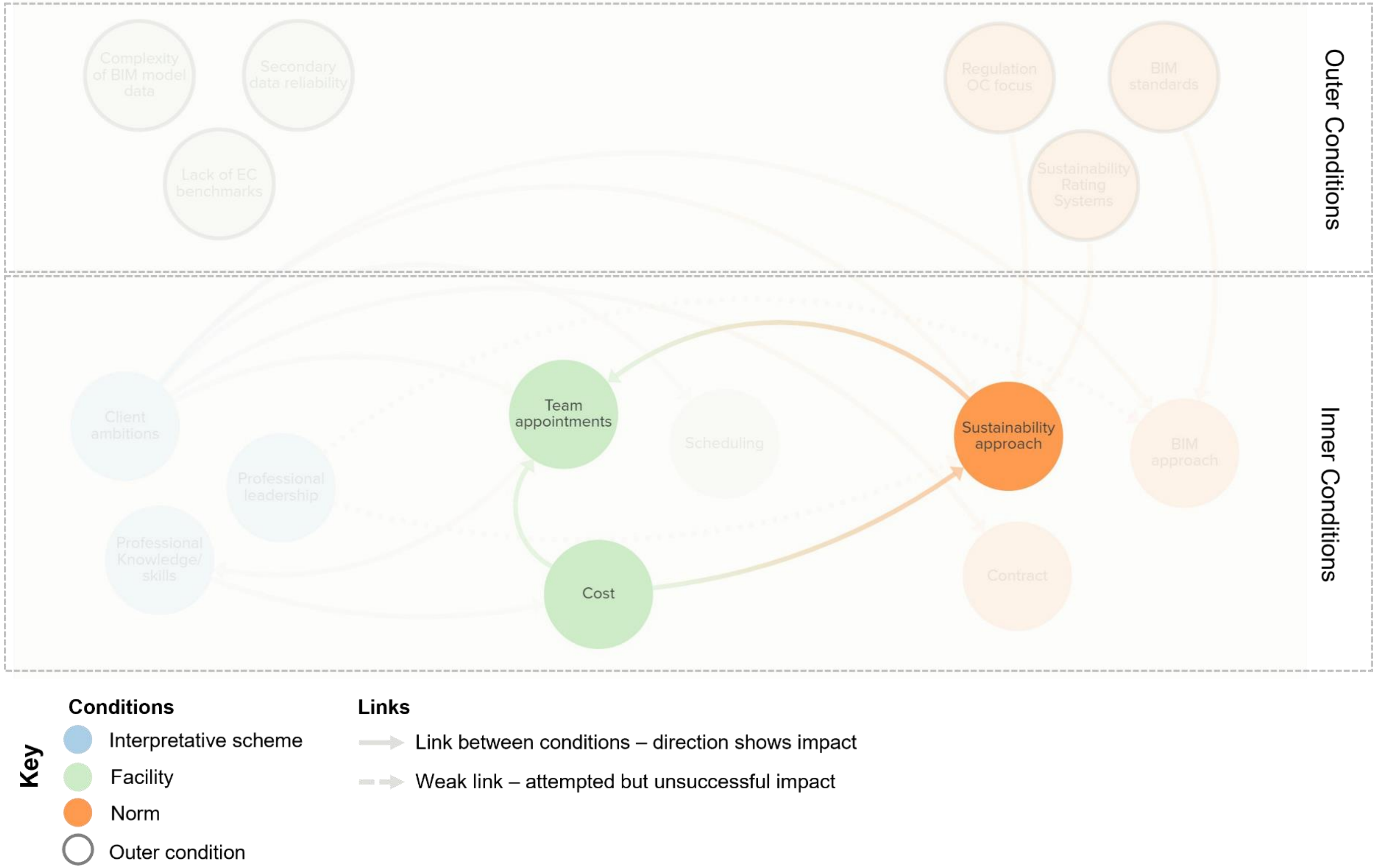

Figure 6.3 Case study 1 Cost relationship with other conditions.

‘Professional leadership’ was expressed in this project through the design team’s request to appoint experts on LCA and a BIM Information Lead for the project, which would ensure the whole building life-cycle assessment and enhance the project’s information management. However, these appointments were not made due to the additional cost that they would incur and hence they didn’t manage to affect the sustainability approach of the project to include whole life cycle assessment as part of the carbon reduction assessment processes and a stronger BIM approach to be taken. The project’s BIM approach followed a very basic BIM application with the potential of enhanced information management not realised. This is shown in the Strategic Conduct Analysis in section 6.2.3, which considers the project outcomes. The ‘Professional leadership’ links to ‘Sustainability approach’ and ‘BIM approach’ are considered ‘weak’ and are shown in dashed line in Figure 6.4. Through this dashed representation, it is aimed to show that there was an effort of the ‘Professional leadership’ condition to affect the project’s ‘Sustainability approach’ and ‘BIM approach’ norm conditions, but this effort was not successful.

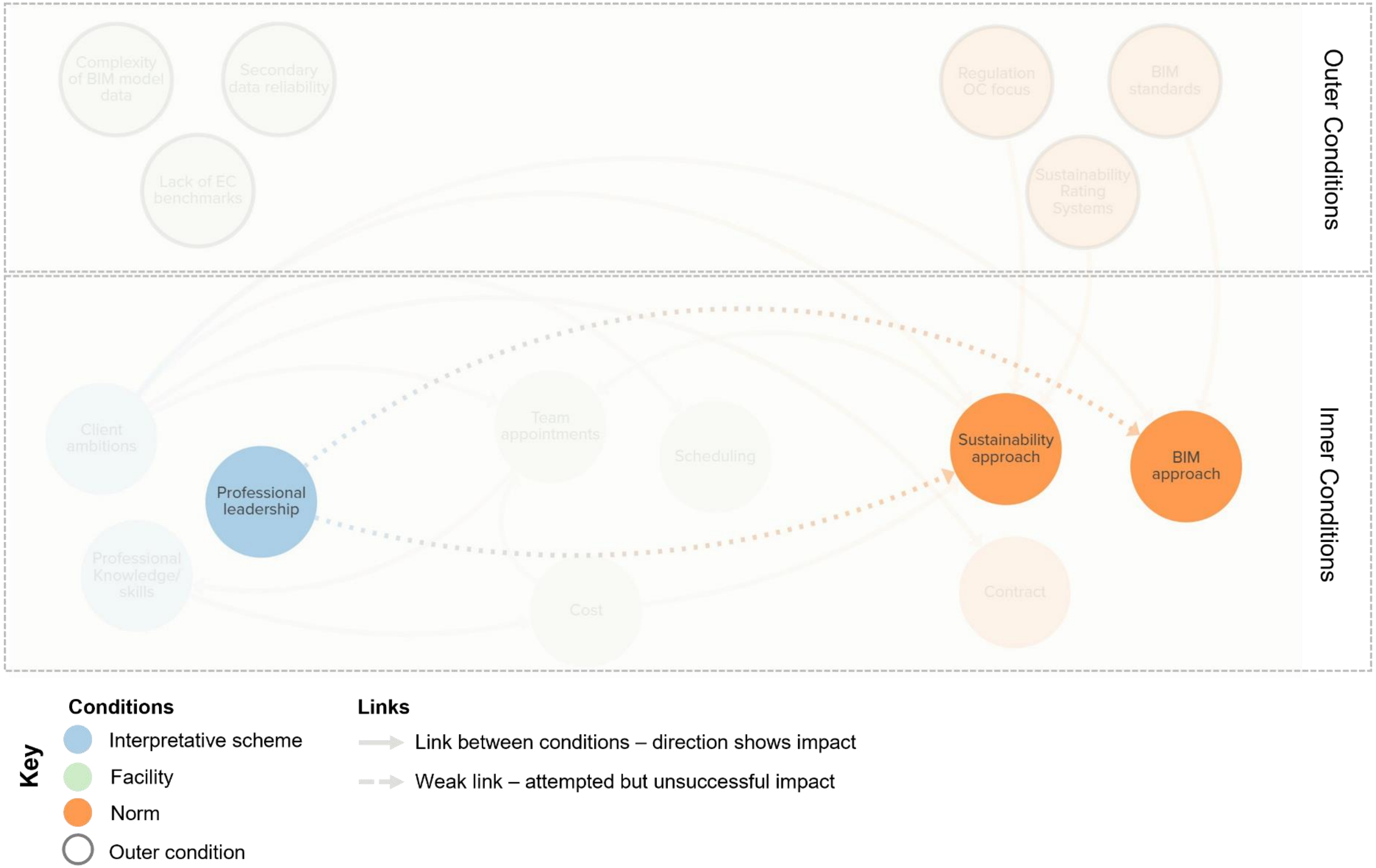

Figure 6.4 Case study 1 Professional leadership relationships with other conditions.

6.2.3 Analysis of Strategic Conduct

Strategic Conduct Analysis aims to understand how the relationships of the conditions affected the project outcomes that relate to how EC considerations were set, communicated, and addressed. The application of BIM in relation to EC considerations is also explored.

As a first step, the conditions that directly affected the outcomes are identified and presented in red lines in the social network diagram as presented in Figure 6.5. Then, through considering the conditions analysis presented in section 6.2.2, a deeper understanding is reached by considering how direct conditions are affected by other conditions to identify the indirect conditions that affect the outcomes. As mentioned in the previous chapter (section 5.8.1.2), indirect conditions are divided into two categories, primary and secondary, where the former are indirect conditions that are not affected by other conditions and the latter are indirect conditions that are affected by other conditions. The primary and secondary indirect conditions that affect the project outcomes are presented in Figure 6.6.

In the following sections the two outcome categories ‘How EC considerations are set and communicated’ and ‘How EC considerations are addressed’ are analysed in more detail and the outcomes within each category are discussed and presented in separate figures for more clarity.

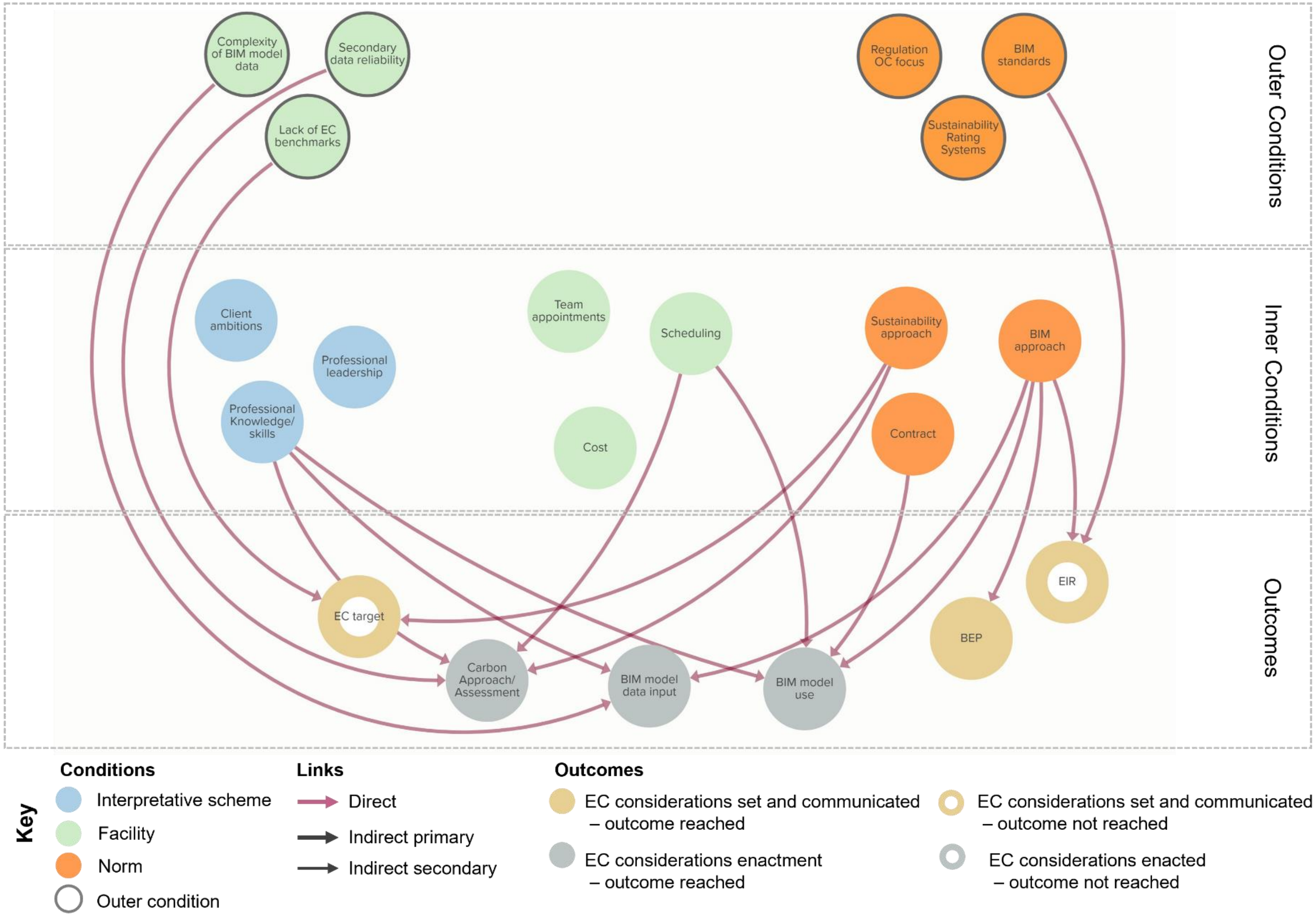

Figure 6.5 Case study 1 - All outcomes and the direct conditions affecting them.

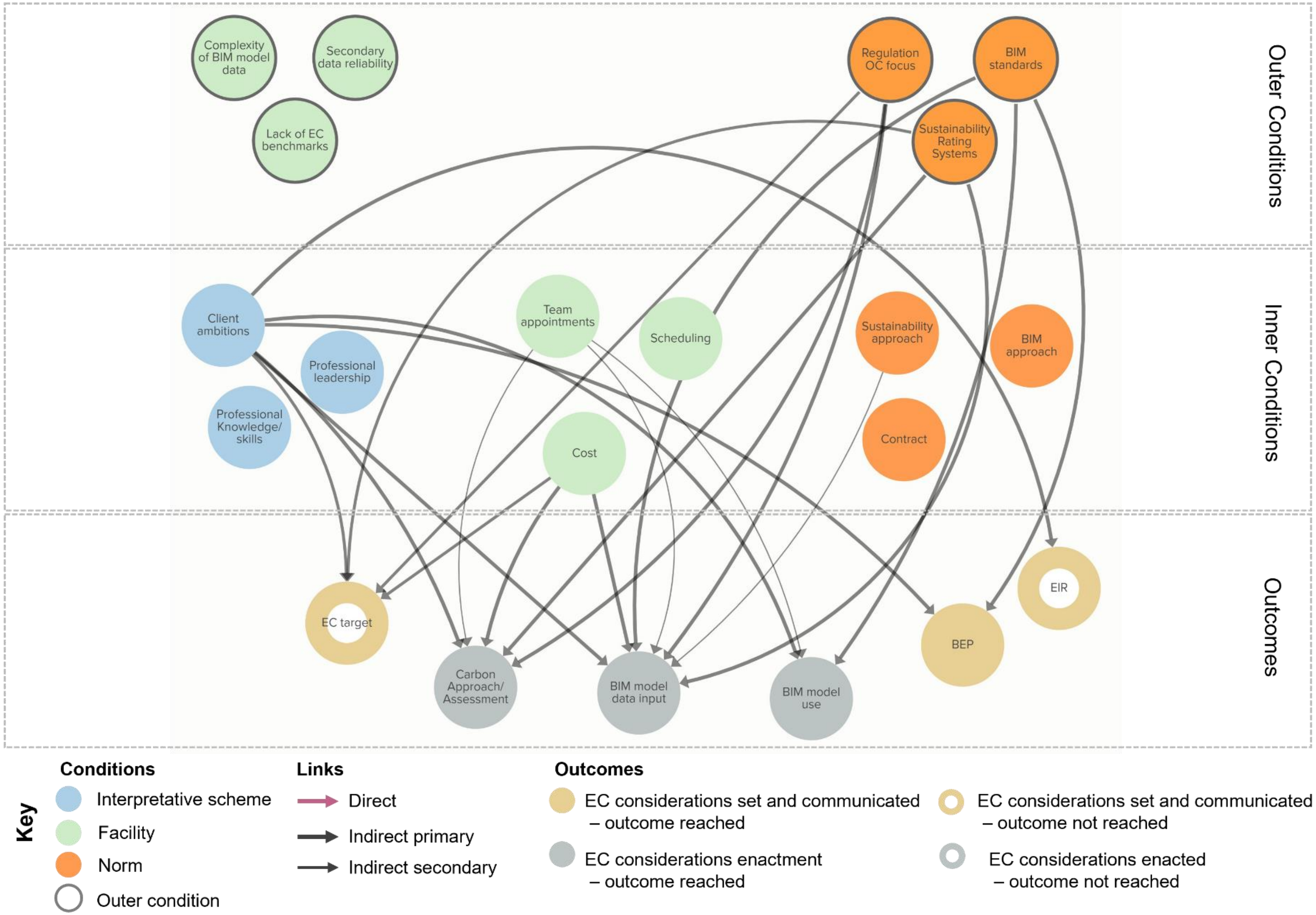

Figure 6.6 Case study 1 All outcomes and the indirect conditions affecting them.

6.2.3.1 How EC considerations are set and communicated

The outcomes that relate to how EC considerations are set and communicated are the project's 'EC target', 'EIR' and 'BEP'. The direct and indirect inner and outer conditions that affected these outcomes are presented in Figure 6.7 and Figure 6.8 respectively and summarised in Table 6.1. All the outcomes in this category are directly affected by inner norms of 'Sustainability Approach' and 'BIM Approach', whereas the outer conditions that affect them are the 'Lack of EC benchmarks' and the construction industry's 'BIM standards'.

Through the conditions analysis presented in section 6.2.2, the relationships of conditions are considered and the indirect conditions that affect these outcomes are identified. The indirect primary inner conditions that affected outcomes that relate to how EC considerations are set and communicated are 'Client ambition' and 'Cost', and indirect primary outer conditions are Regulation focus on EC, Sustainability Rating Systems and BIM Standards.

Table 6.1 Case study 1 - The direct and indirect primary conditions that affected how EC considerations are set and communicated.

	Direct Conditions		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
EC Target	Sustainability Approach	Lack of EC Benchmarks	Client ambitions Cost	Regulation OC focus Sustainability Rating Systems
EIR	BIM Approach	BIM Standards	Client ambitions	BIM Standards
BEP	BIM Approach		Client ambitions	BIM Standards

Further elaboration on the way direct and indirect conditions affected how EC considerations are set and communicated are presented for each outcome of this outcome category below.

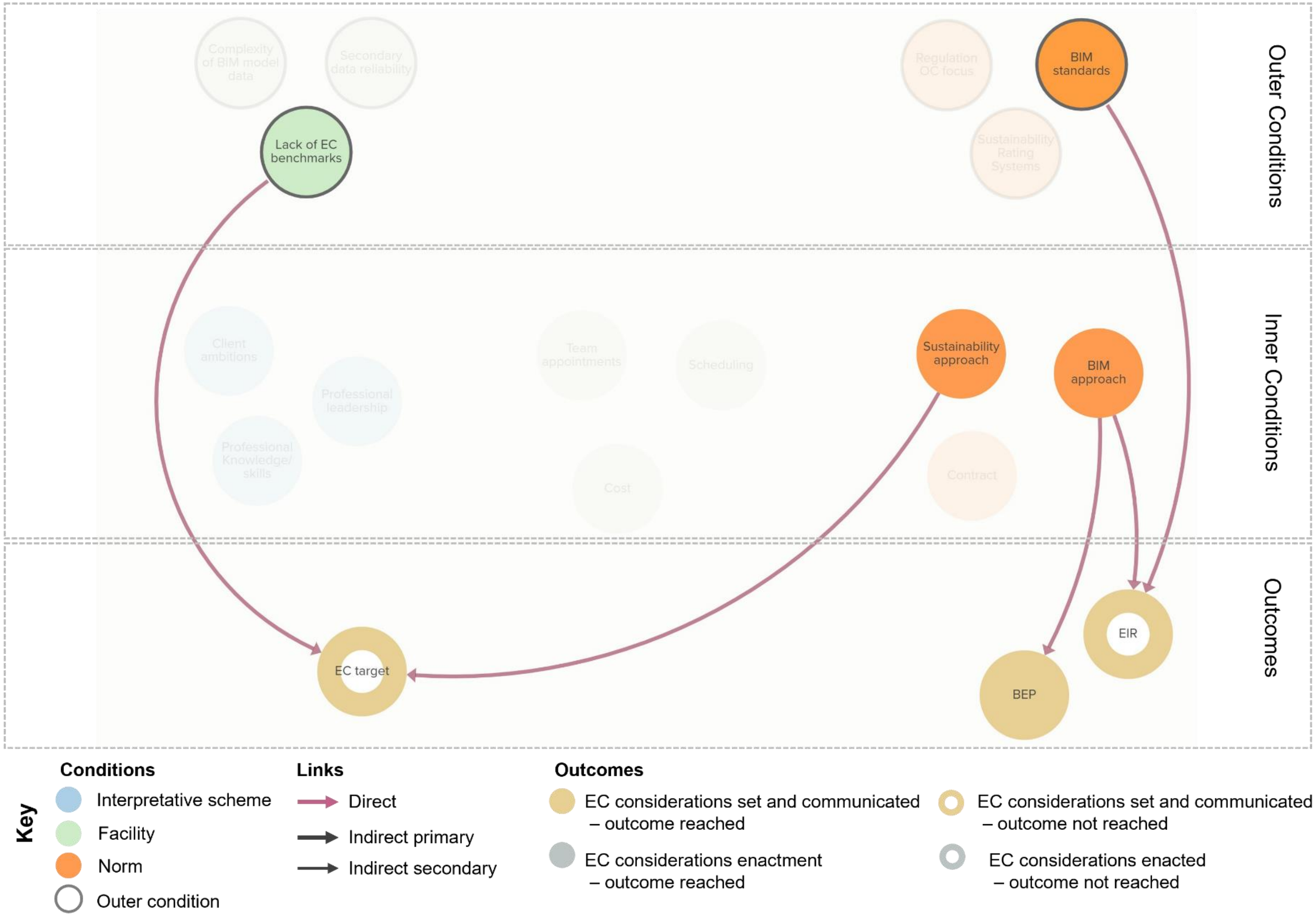

Figure 6.7 Case study 1 - How EC considerations are set and communicated outcomes and the direct conditions affecting them.

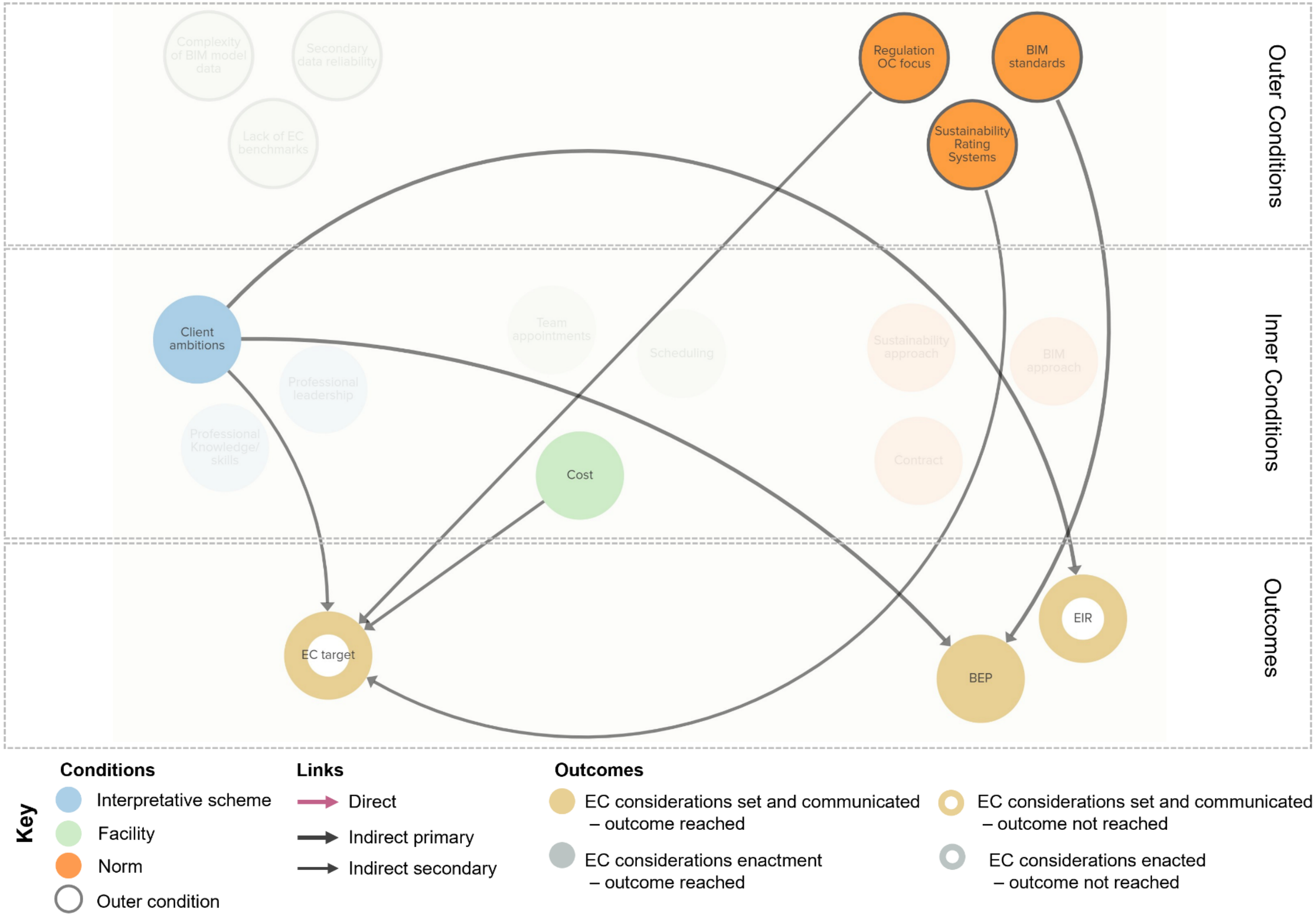

Figure 6.8 Case study 1 - How EC considerations are set and communicated outcomes and the indirect conditions affecting them.

6.2.3.1.1 EC Target

The conditions that directly affected EC target setting were the inner norm 'Sustainability Approach' and the 'Lack of EC benchmarks' external facility. The indirect primary conditions that affect this outcome were inner 'Client ambitions', 'Cost' and outer 'Regulation OC focus' and 'Sustainability Rating Systems'. The conditions that affected the EC target outcome are presented in Table 6.2 and in Figure 6.9.

Table 6.2 Case study 1 - The direct and indirect primary conditions that affected the EC target outcome (Excerpt from Table 6.1).

	Direct Conditions		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
EC Target	Sustainability Approach	Lack of EC Benchmarks	Client ambitions Cost	Regulation OC focus Sustainability Rating Systems

The Sustainability approach of the project, which is the direct condition that affected the EC target outcome was heavily based on the BREEAM target that the project was set to achieve. The current regulation focus on OC also affected the project's sustainability approach toward not establishing an EC target for the project. The lack of industry wide EC benchmarks available posed a challenge in setting a specific EC target for the building. The lack of external top-down push for setting an EC target made the client ambitions become the main deciding factor for setting an EC target. The additional cost that setting and trying to achieve the EC target would incur affected the sustainability approach of the project to not include a specific EC target for the project. Looking at the direct conditions, external facility and internal norm appear to be affecting the EC target setting. However, when considering the conditions analysis and how conditions affect each other, it can be seen that the interpretative scheme of the 'client ambitions' and 'cost' facility, along with external norms 'Regulation OC focus and 'Sustainability rating systems' affect the outcome of EC target setting, and in the case of this case study, the result was the lack of a specific EC target for the project. In Figure 6.9, the hollow circle for the EC target outcome represents the fact that an EC target was not set for the project.

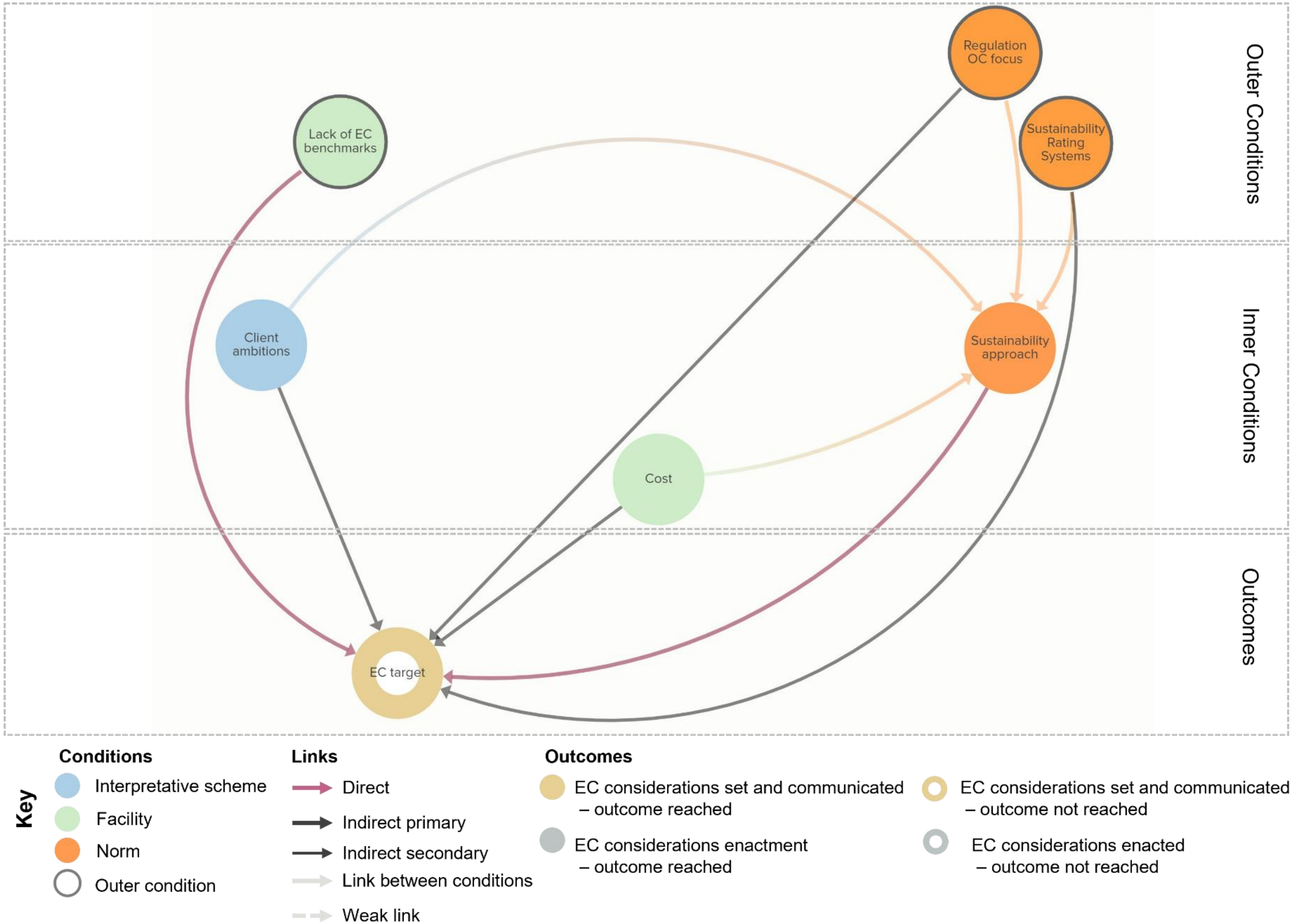

Figure 6.9 Case study 1 - The conditions that affected the EC target.

6.2.3.1.2 Employers Information Requirements (EIR)

The EIR is directly affected by the inner norm 'BIM Approach' of the project and the outer norm 'BIM Standards'. The indirect primary condition that affects this outcome is interpretative scheme 'Client ambitions'. The conditions that affected the EIR outcome are presented in Table 6.3 and in Figure 6.10.

Table 6.3 Case study 1 - The direct and indirect primary conditions that affected the EIR outcome (Excerpt from Table 6.1).

	Direct Conditions		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
EIR	BIM Approach	BIM Standards	Client ambitions	n/a

The PAS 1192-2:2013 specification document presents the origin and content of the Employer's Information Requirements (EIR), which is the information that is required by the employer from the design team and suppliers for the development of a BIM level 2 project during the capital/ delivery phase (BSI 2013). Setting these requirements forms the start of the information management process. As mentioned in Phase 1 Results and analysis (Chapter 4), there are many levels within BIM level 2. Hence the BIM approach can significantly vary from one BIM Level 2 project to another, depending on the BIM approach of the project. Through the conditions analysis, it was identified that in this case study the project's BIM approach was affected by the 'Client ambitions', so the EIR indirect primary condition is the 'Client ambition' interpretative scheme as it affects the 'BIM approach' inner norm. The client didn't demonstrate an ambition to establish a strong BIM Level 2 approach and this was reflected in the lack of setting the EIR for the project. The design team showed professional leadership by suggesting the appointment of a BIM information lead for the project to push for a stronger BIM approach, but this appointment did not take place. In Figure 6.10, the hollow circle for the EIR outcome represents the fact that an EIR document was not produced for the project.

Setting the EIRs for a project is the responsibility of the client, who may not have the ambition to establish strong information management through BIM. Furthermore, clients may also lack the expertise to describe the information requirements in the level of detail that would make them useful for the project's development. The design team professionals would be much better skilled to establish the information requirements of the project. They have the expertise to cover the information requirement contents listed in the PAS 1192-2:2013 specification, such as a schedule of EC specific information to be included in information models (BSI 2013). Placing the responsibility of the EIR on the client reduces opportunity for professionals to influence information requirements and enhance the potential of EC information to be included as part of the BIM information management and BIM model data.

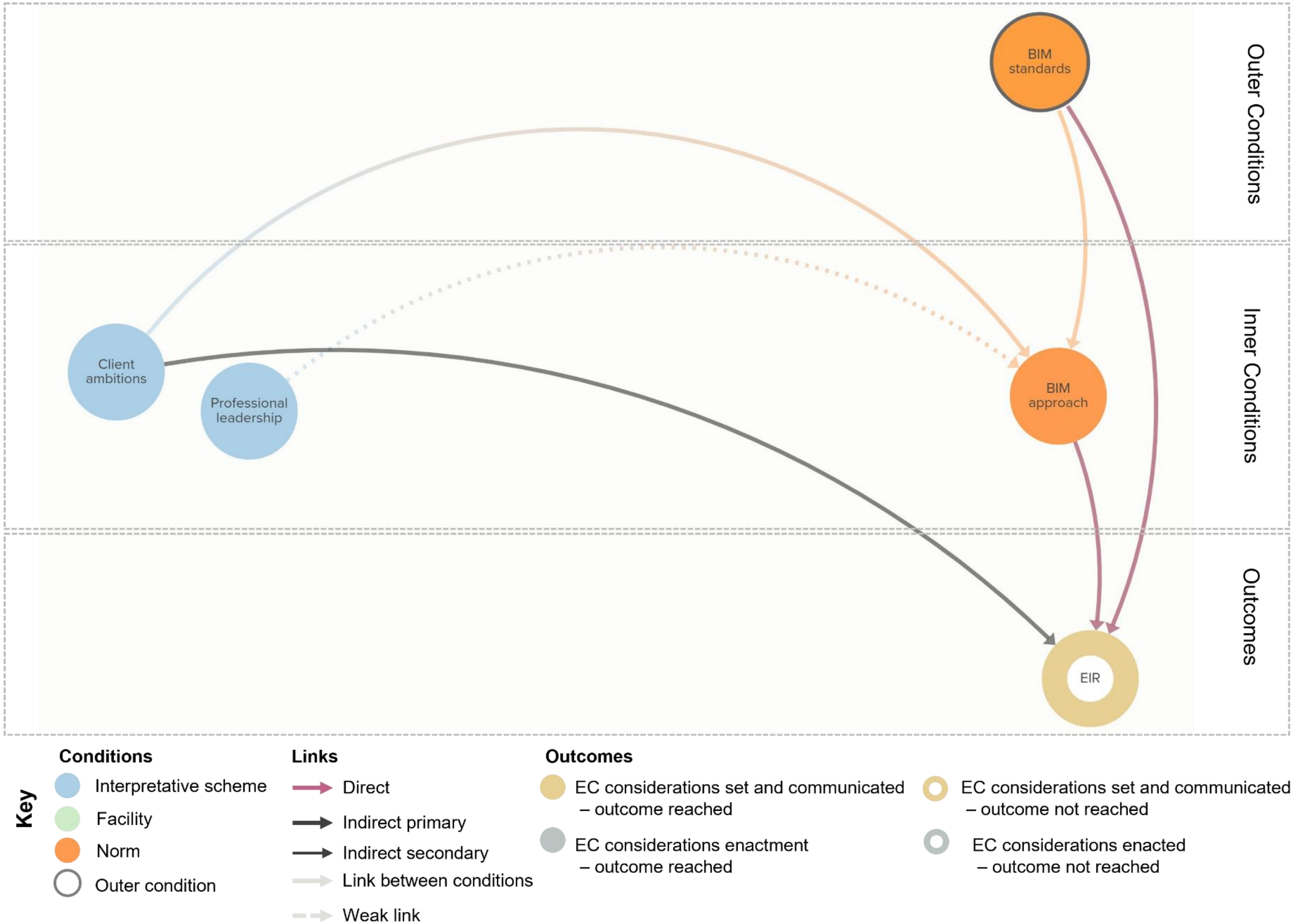

Figure 6.10 Case study 1 - The conditions that affected the EIR.

6.2.3.1.3 BIM Execution Plan (BEP)

The BIM Execution Plan (BEP) is directly affected by the inner norm 'BIM Approach' of the project. The indirect primary conditions that affected this outcome are interpretative scheme 'Client ambitions' and outer norm 'BIM Standards'. The conditions that affected the BEP outcome are presented in Table 6.4 and in Figure 6.11.

Table 6.4 Case study 1 - The direct and indirect primary conditions that affected the BEP outcome. (Excerpt from Table 6.1).

	Direct Conditions		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
BEP	BIM Approach	n/a	Client	BIM Standards

According to the PAS 1192-2:2013 specification document, the BEP is a direct response to the project's EIRs (BSI 2013). Even though there were no EIRs set for the project, a BEP was established. However, as mentioned in Phase 1 results (Chapter 4), the BEP wasn't established until RIBA Stage 3, when information exchanges through BIM model sharing had already started from RIBA Stage 2. The delay in establishing the project BEP highlights the weak BIM approach of the project. With regards to EC considerations of the project, while the EIR would be where EC related information requirements would be communicated, the BEP would establish how this information would be provided. In the case of this case study where no EIRs were established and an EC target was not set, the BEP did not include EC information delivery processes.

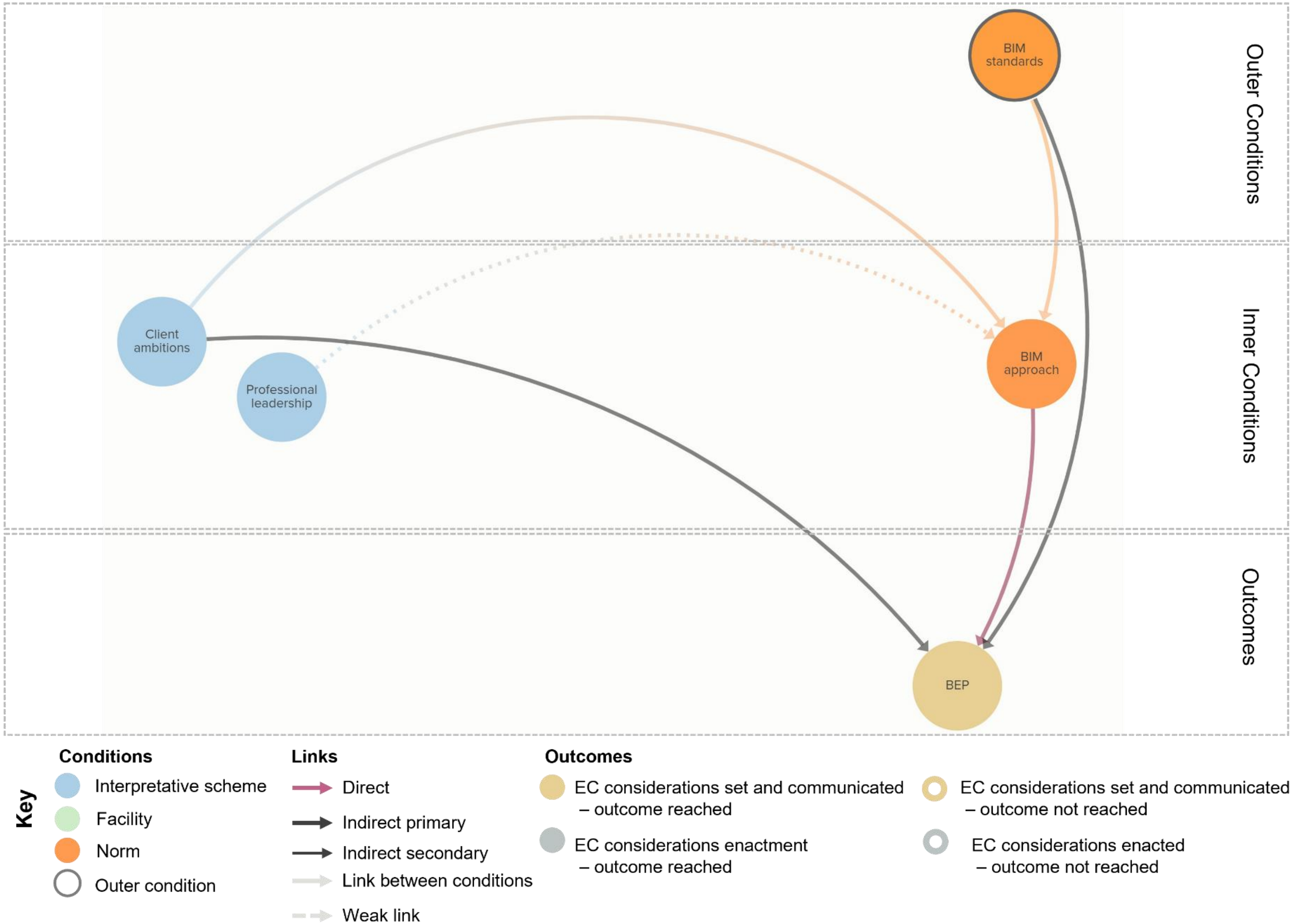

Figure 6.11 Case study 1 - The conditions that affected the BEP.

6.2.3.2 How EC considerations are addressed

The outcomes that relate to how EC considerations are addressed are the project's 'Carbon Approach/Assessment', 'BIM model data input' and 'BIM model use'. The direct and indirect inner and outer conditions that affected these outcomes are presented in Figure 6.12 and Figure 6.13 respectively and summarised in Table 6.5. Compared to the outcomes that related to how EC considerations are set and communicated, this set of outcomes was affected by a wider range of conditions. The outcomes that relate to how EC considerations are addressed were directly affected by all inner norms, 'Sustainability approach', 'BIM approach' and 'Contract', the interpretative scheme 'Professional knowledge/skills' and the inner facility 'Scheduling'. The outer conditions that directly affect this set of outcomes are facilities 'Complexity of BIM model data' and 'Secondary data reliability'. Interestingly, through various indirect secondary conditions, the indirect primary conditions that affected this set of outcomes were the same as the indirect primary conditions that affect the outcomes that relate to how EC considerations are set and communicated: the inner conditions 'Client ambition' and 'Cost' and outer conditions 'Regulation OC focus', 'Sustainability Rating Systems' and 'BIM Standards'.

Table 6.5 Case study 1 - The direct and indirect primary conditions that affected how EC considerations are addressed.

	Direct Conditions		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
Carbon Approach/ Assessment	Sustainability Approach Professional knowledge/Skills Scheduling	Secondary data reliability	Client ambitions Cost	Regulation OC focus Sustainability Rating Systems
BIM model data input	Professional knowledge/Skills BIM Approach	Complexity of BIM model data	Client ambitions Cost	BIM Standards Regulation OC focus Sustainability Rating Systems
BIM model use	Professional knowledge/Skills Scheduling Contract BIM Approach	n/a	Client ambitions	BIM Standards

Further elaboration on the way direct and indirect conditions affected how EC considerations are addressed are presented for each outcome of this outcome category below.

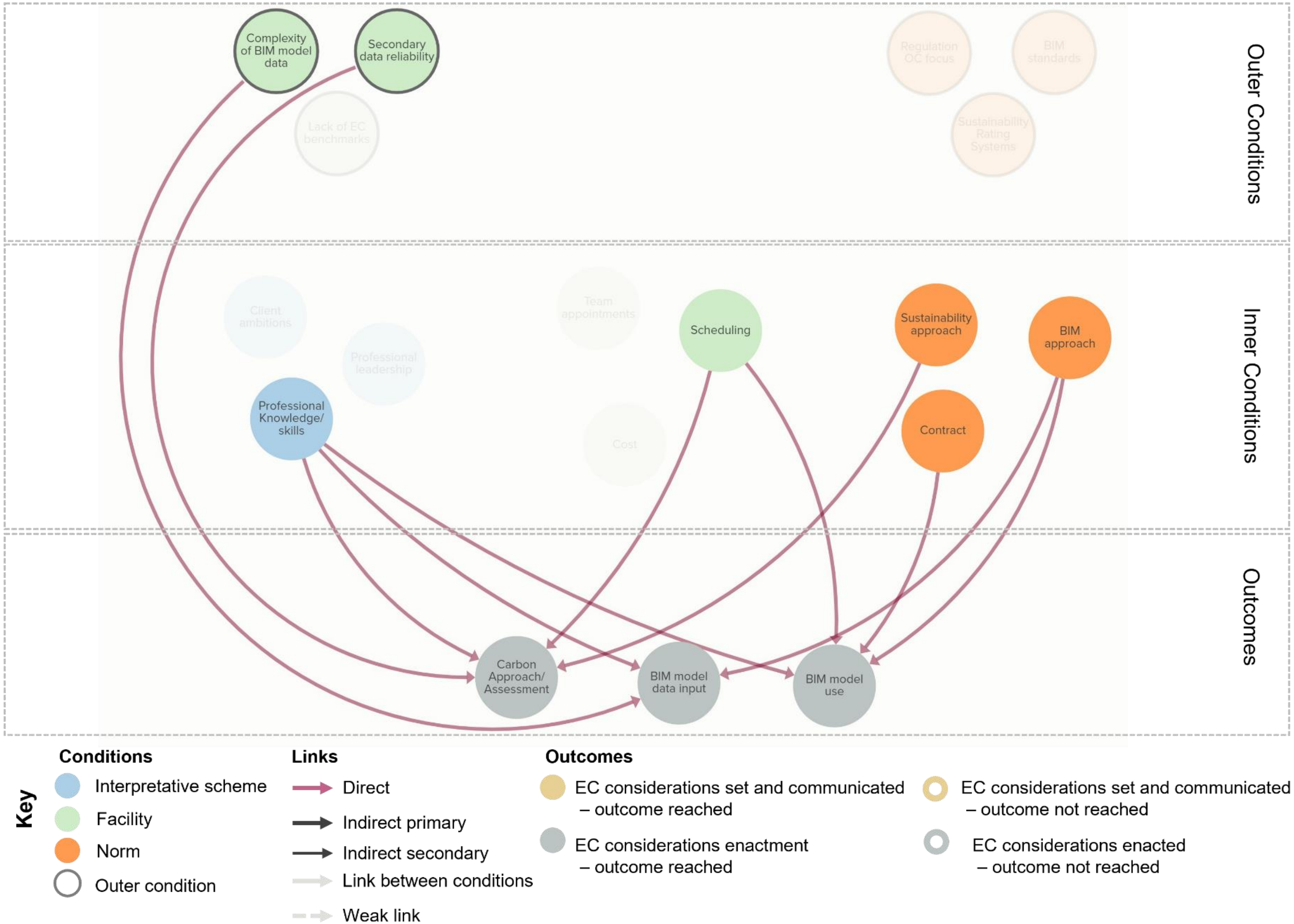

Figure 6.12 Case study 1 - How EC considerations are addressed outcomes and the direct conditions affecting them.

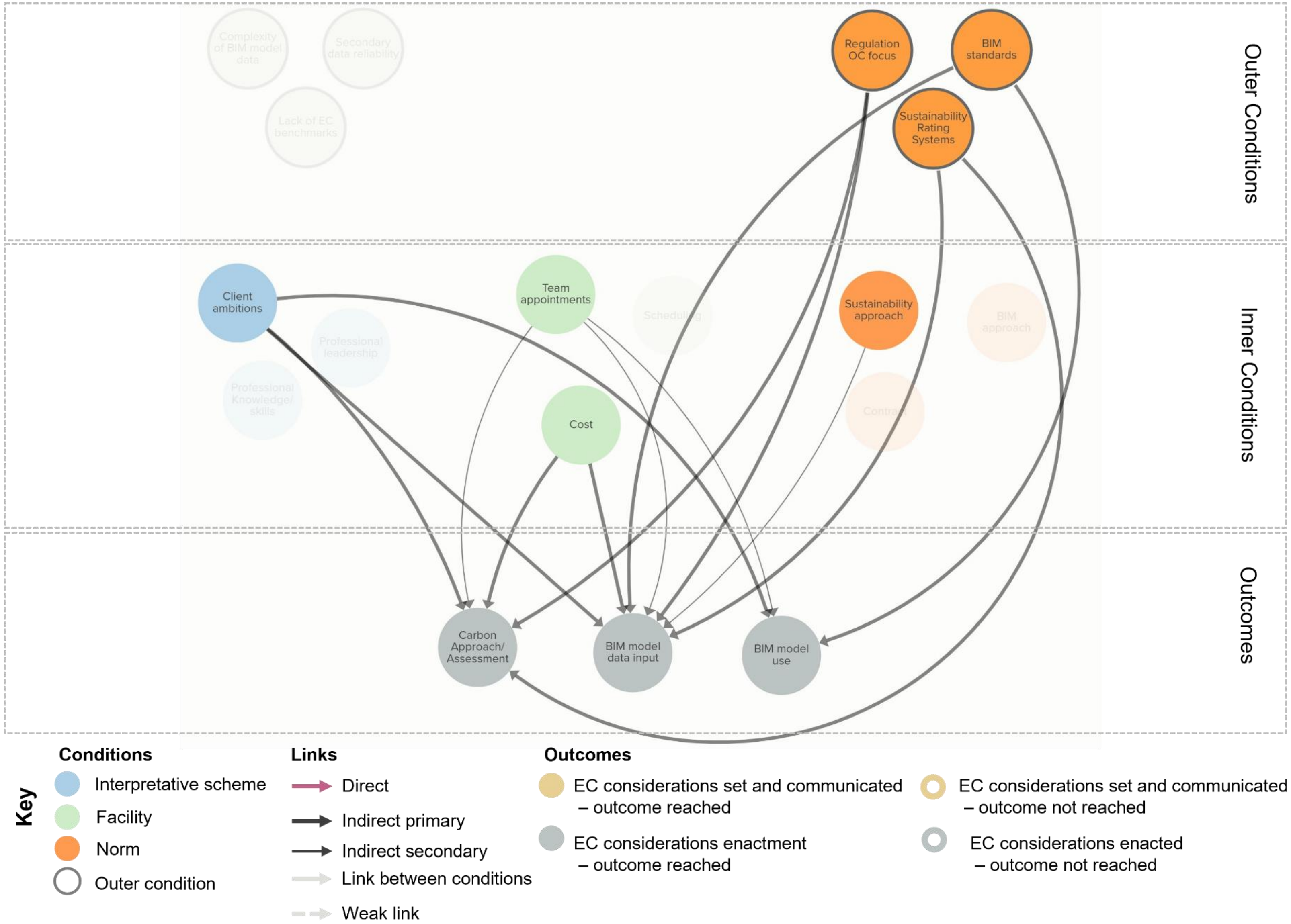

Figure 6.13 Case study 1 - How EC considerations are addressed outcomes and the indirect conditions affecting them.

6.2.3.2.1 Carbon Approach/ Assessment

The conditions that directly affected the project's 'Carbon Approach/Assessment' were the inner norm 'Sustainability Approach', interpretative scheme 'Professional Knowledge/Skills', inner facility 'Scheduling' and the 'Secondary data reliability' outer facility. The indirect primary conditions that affected this outcome were inner 'Client ambitions', 'Cost' and outer 'Regulation OC focus' and 'Sustainability Rating Systems'. The conditions that affected the 'Carbon Approach/Assessment' outcome are presented in Table 6.6 and in Figure 6.14.

Table 6.6 Case study 1 - The direct and indirect primary conditions that affected the Carbon approach/assessment outcome. (Excerpt from Table 6.5).

	Direct Conditions		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
Carbon Approach/ Assessment	Sustainability Approach Professional knowledge/Skills Scheduling	Secondary data reliability	Client Ambitions Cost	Regulation OC focus Sustainability Rating Systems

The project Sustainability approach, as discussed in the conditions analysis, did not include a whole-life cycle approach to carbon. Embodied carbon considerations were handled separately by each the relevant professional team and during different stages, and the approach of each team was affected by their respective knowledge and skills in assessing the anticipated EC of the material choices they made. Alternative material option assessment was hindered by the project's tight schedule. The Sustainability Consultant stressed that the secondary EC data reliability created a challenge in assessing the EC carbon of the project. An LCA expert appointment was suggested to facilitate the process which demonstrated professional leadership as an effort to expand the sustainability approach of the project and to assess the life-cycle carbon of the building. However, this appointment did not take place due to the additional cost that it would incur to the project. Therefore, professional leadership didn't succeed in affecting the norm of sustainability approach of the project and enable an LCA assessment. The interpretative scheme 'Client ambition' and 'Cost' facility prevailed, resulting in the lack of such an expert appointment to perform the LCA assessment. The current focus of regulations and rating systems on OC also affected the project’s sustainability approach, hindered whole-life carbon assessment to take place and resulted in a fragmented carbon approach by the different professional teams.

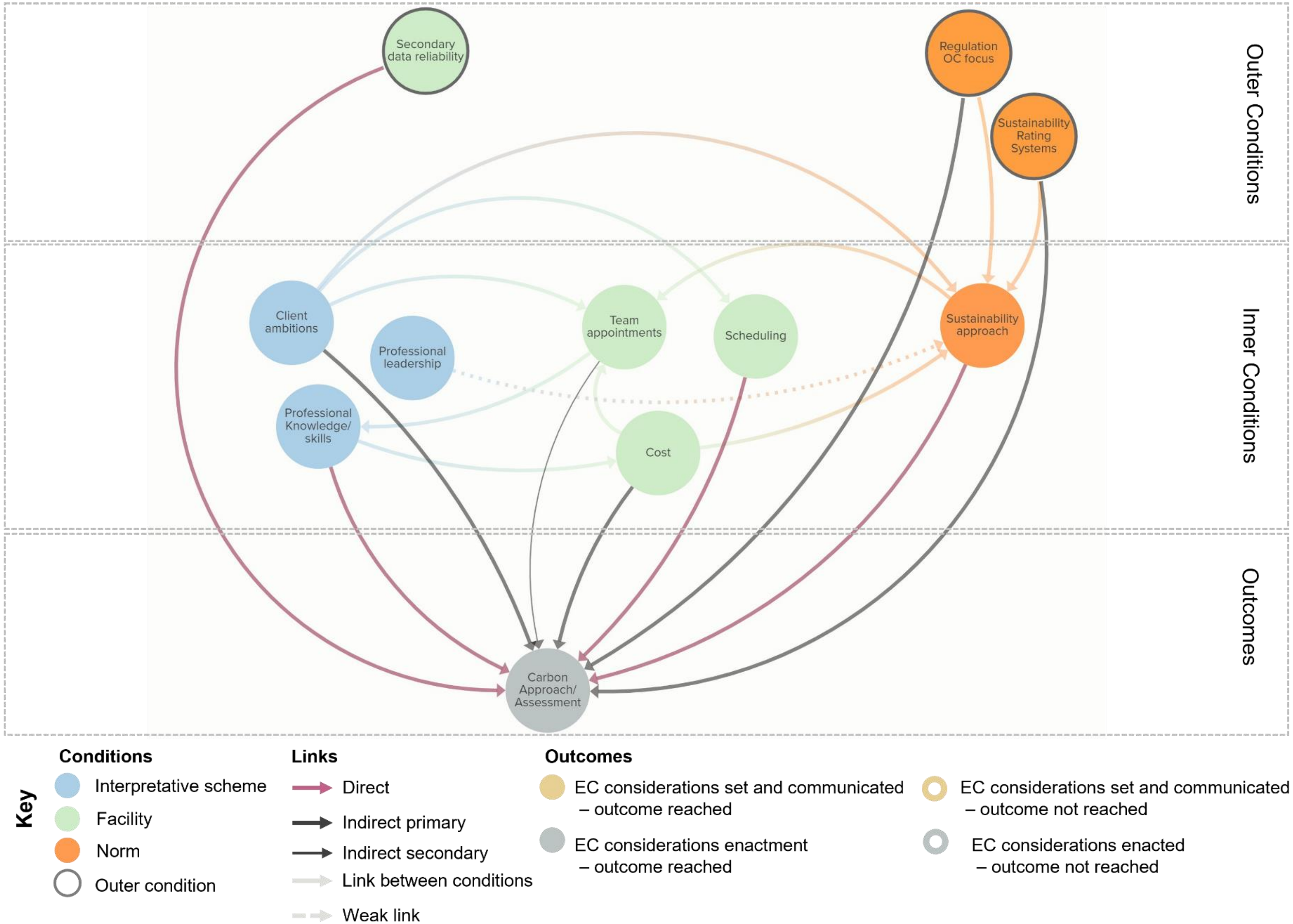

Figure 6.14 Case study 1 - The conditions that affected the Carbon Approach/ Assessment.

6.2.3.2.2 BIM model data input

The conditions that directly affected the project's BIM model data input were the inner norm 'BIM approach', interpretative scheme 'Professional Knowledge/Skills', and outer facility 'Complexity of BIM model data'. The indirect primary conditions that affect this outcome were inner interpretative scheme 'Client ambitions', inner facility 'Cost' and outer norms 'Regulation OC focus', 'Sustainability Rating Systems' and 'BIM Standards'. The conditions that affected the BIM model data input outcome are presented in Table 6.7 and in Figure 6.15.

Table 6.7 Case study 1 - The direct and indirect primary conditions that affected the BIM model data input outcome. (Excerpt from Table 6.5).

	Direct Conditions		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
BIM model data input	Professional Knowledge/Skills BIM Approach	Complexity of BIM model data	Client ambitions Cost	BIM Standards Regulation OC focus Sustainability Rating Systems

BIM model data input is directly affected by the inner interpretative scheme 'Professional knowledge/skills', inner norm 'BIM Approach' and external facility 'Complexity of BIM model data'. Adding data in the BIM model is not intuitive for data that relates to EC, therefore the complexity of adding EC data is presenting a challenge to professionals lacking the expert professional skills. The professional team suggested the appointment of a BIM information lead and an LCA expert to expand the expertise in both BIM information management as well as the sustainability approach in relation to carbon, however, these appointments did not take place. This highlights the impact 'Team appointments' have on establishing the available skills of the design team. As mentioned in the conditions analysis, 'Team appointments' were affected by 'Client ambitions' and were informed by the project's 'Sustainability approach'. The sustainability approach of the project was driven by the client's ambition to achieve a BREEAM Excellent rating, and was therefore influenced by the outer norms 'Sustainability rating systems' and 'Regulation OC focus'. The 'BIM approach', which is also affected by the client, was weak for this project and presents a challenge for this outcome. As mentioned above, there was no EIRs established and the BEP, which was not introduced until RIBA Stage 3, did not include BIM model parametric data requirements relating to EC.

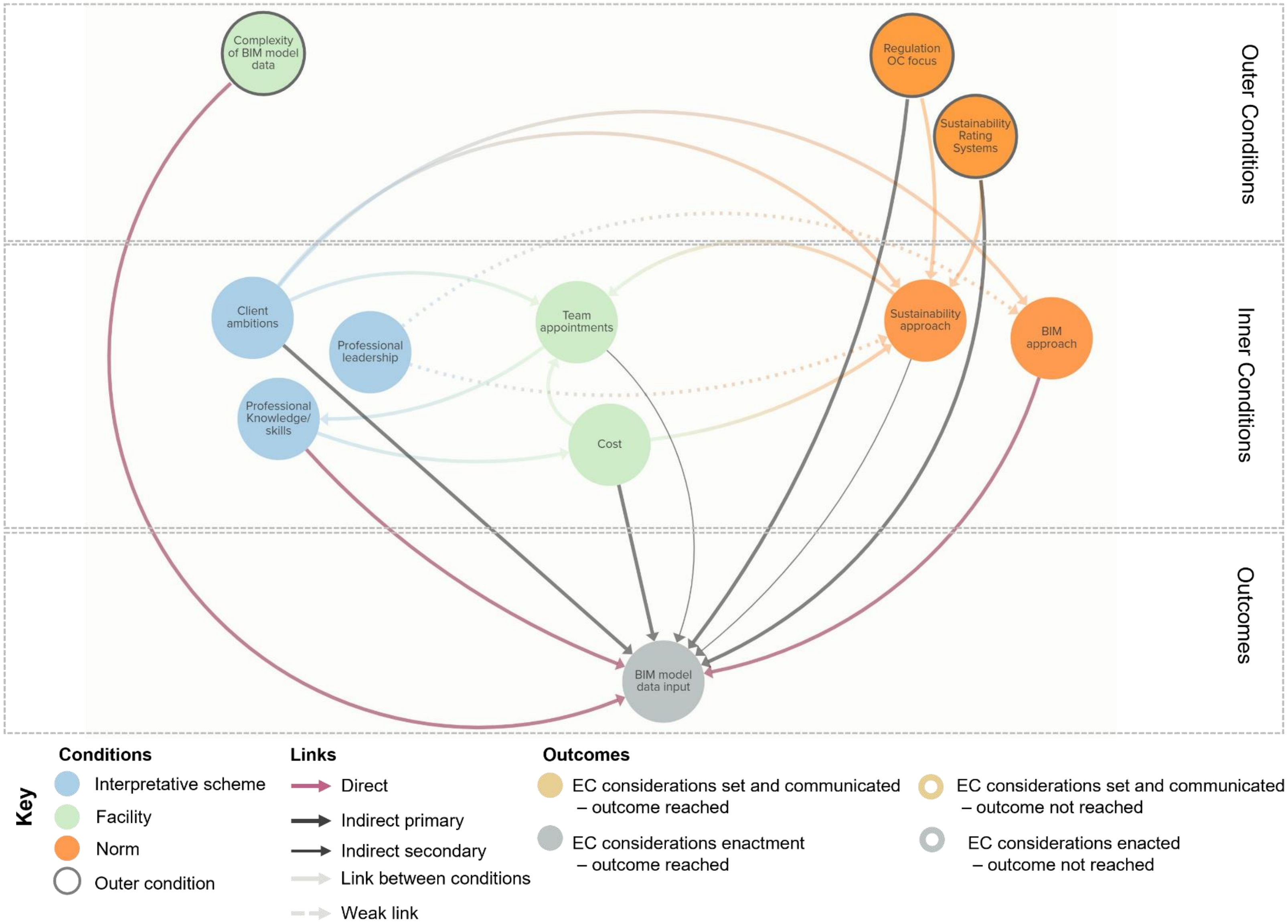

Figure 6.15 Case study 1 - The conditions that affected the BIM model data input.

6.2.3.2.3 BIM model use

The conditions that directly affected the project's 'BIM model use' were interpretative scheme 'Professional Knowledge/Skills', and inner norms 'BIM approach' and 'Contract'. The indirect primary conditions that affect this outcome were inner interpretative scheme 'Client ambitions' and outer norm 'BIM Standards'. The conditions that affected the 'BIM model use' outcome are presented in Table 6.8 and in Figure 6.16.

Table 6.8 Case study 1 - The direct and indirect primary conditions that affected the BIM model use outcome. (Excerpt from Table 6.5).

	Direct Conditions		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
BIM model use	Professional Knowledge/ Skills Scheduling Contract BIM Approach	n/a	Client	BIM Standards

The 'BIM model use' followed the BIM Level 2 guidance according to which a managed 3D data bearing environment is created in separate discipline-based models. These models were coordinated by the architectural team to form a federated model for collaboration. Although the PAS 1192-2:2013 specification document includes EC information as part of the parametric information of the model level definition (BSI 2013), as mentioned in the BIM model data input outcome section, EC information was not included in the project's BIM model. This lack of EC data in the model and material quantity related data input of the model resulted in lack of trust by the sustainability consultant to use the BIM model for material quantity information and EC impact calculation. The BIM model was also not used by the quantity surveyor (QS) team for material quantity extraction for cost calculations. However, this was due to the lack of familiarity of the QS team with the BIM software. 'Professional knowledge/skills' therefore resulted in limited the BIM model use for the project. For QS team, this was due to their own lack of BIM skills, whereas for the sustainability consultant, it was due to the lack of model data input by the principal design team. The use of the BIM model in this case study was restricted to spatial coordination of the building amongst the principal design team different professions and this was not always successfully achieved during the design stage, which is indicative of the project's weak BIM approach. The project tight scheduling also hindered the coordination of the design team through the use of the BIM model. It caused delays of BIM model sharing between the different design team professions which in turn resulted in discrepancies of the building design between the different teams. The project contract is also a condition that affects the use of the BIM model, particularly during the novation phase of Design and Build contracts. Liability issues hinder the sharing of the BIM model created during the design stage with the contractor team. Although this is relevant to the BIM model use after the design phase is completed which is not within the scope of this research, this finding was mentioned during the Phase 1 interviews as a significant challenge to BIM model use.

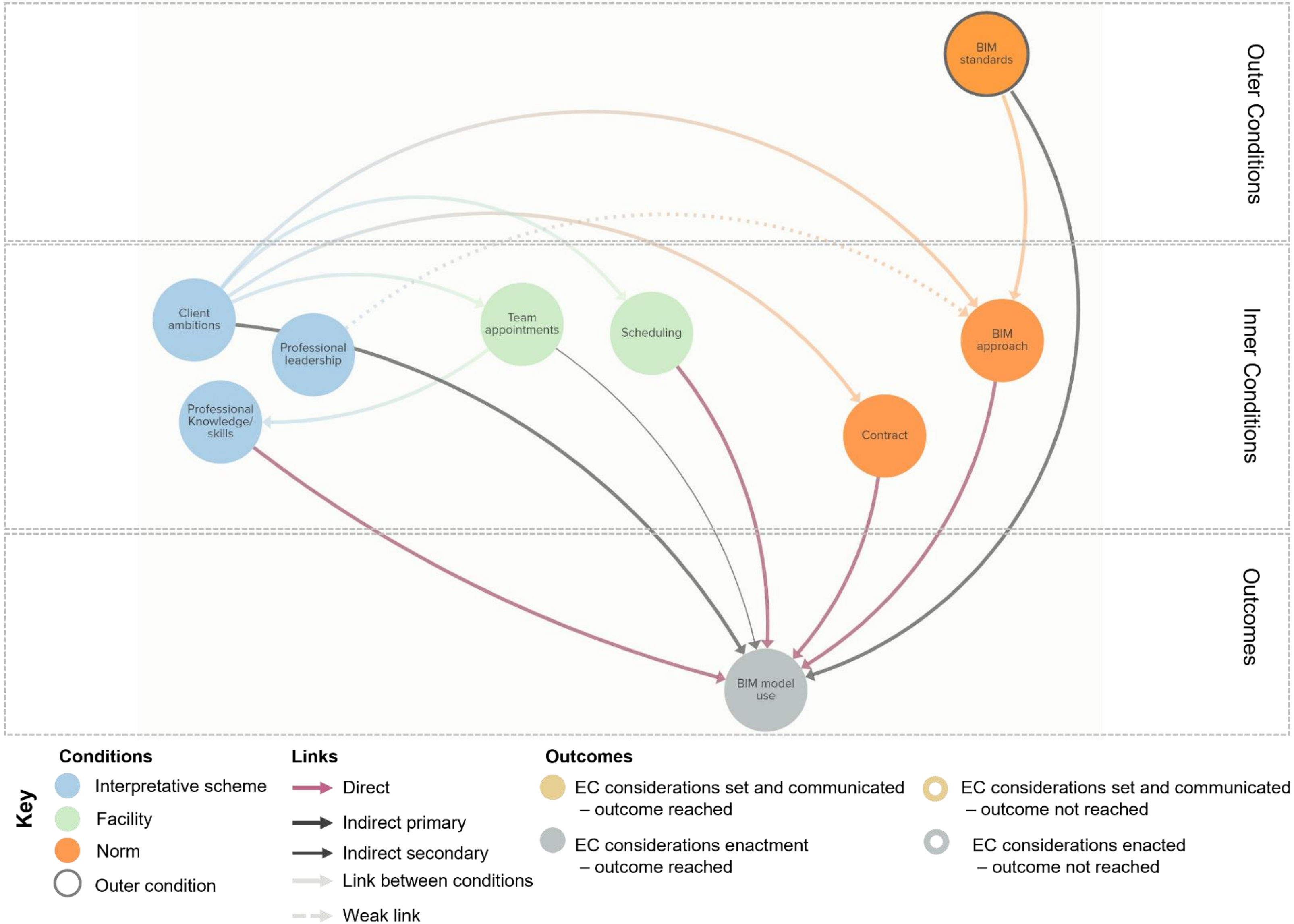

Figure 6.16 Case study 1 - The conditions that affected the BIM model use.

6.2.4 Conclusions

6.2.4.1 Conclusions from Conditions Analysis and Analysis of Strategic Conduct

The conditions that affected directly the EC consideration outcomes for this case study were primarily inner project conditions, with the project's 'BIM approach' affecting four out of six outcomes and 'Professional Knowledge/skills' affecting three out of the six outcomes. Together they affect all outcomes apart from the EC target, which is directly affected by the project's 'Sustainability apporach' and 'Lack of EC benchmarks'. All direct conditions affecting the project outcomes are shown in Figure 6.17.

Figure 6.17 Case study 1 - Quantitative representation of direct conditions affecting project outcomes.

Through the Conditions Analysis, the indirect primary conditions affecting the outcomes were identified. 'Client ambitions' was the condition that was identified to indirectly affect all six EC consideration outcomes. 'Cost' and all outer norms affected three out of six outcomes respectively. All indirect conditions affecting outcomes is shown in Figure 6.18.

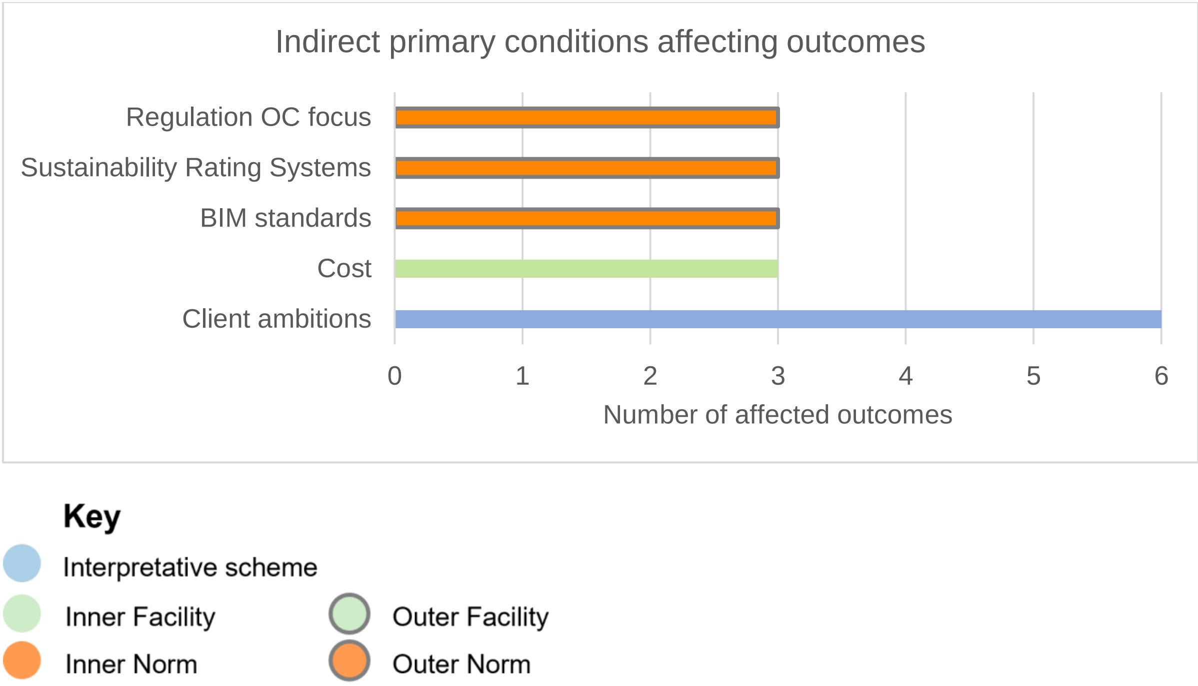

Figure 6.18 Case study 1 - Indirect primary conditions affecting project outcomes.

For this case study, when considering direct conditions, outcomes appeared to be affected by the project's inner norms and the professional team knowledge and skills interpretative scheme. However, when considering the indirect conditions, it is made clear that outer norms and the client ambitions had a much more dominant impact on affecting outcomes.

6.2.4.2 Conditions, Mechanisms and Outcomes

The heavy focus of regulation and rating systems on OC hindered EC considerations to be set and addressed in the project. The BIM standards placing responsibility on client to create the project's EIR resulted in lack of EIR setting and the BEP being introduced late during the design process. This shows that outer norms as top down approaches are not facilitating EC considerations to be set as a project target and EC information to be required as part of the project information that is to be generated and communicated amongst the design team. Outer norms appeared as **constraining conditions** to EC target setting and empowered the client in relation to project information requirements.

Although it is the design team's role to apply their knowledge and create a design that is (in some cases more and some less) distilled with sustainability principles and it is the design team that enacts BIM during the course of a project, for this case study it has been the client who had more power over affecting these aspects of the project. **Position practice relations** can portray structural properties of social systems as specific interactions of signification, domination and legitimation through the typification of agents (Giddens 1984). Indeed, for this case study, the client ambitions as a structure of signification legitimised the approach to sustainability and the BIM approach of the project. The position-practice relations observed between the client and the design team has overridden the role of the design team in relation to *how EC considerations are set and communicated through BIM.* This resulted in lack of whole building considerations to be set for the project and poor information management through BIM. According to the duality of structure perspective, structure is both the medium and outcome of social practices. As such, through considering the relationship of the project outcomes to the industry-wide practice (see section 5.8.1.4), the contextual outcomes of the project outcomes can be defined as preserving the status quo. The direct and indirect primary conditions, mechanisms and outcome that relate to this outcome category are summarised in Table 6.9.

Table 6.9 Case Study 1 - How EC considerations are set and communicated: Conditions, Mechanisms and Outcomes.

Conditions	**Mechanisms**	**Outcome**	
Direct & Indirect Primary	**Position-practice Dialectic of control**	**EC considerations Set and communicated**	**Contextual**
Direct: Outer: BIM Standards and Lack of EC benchmarks Inner: Sustainability and BIM Approach. **Indirect Primary:** All outer norms, inner Client ambitions and Cost	**Position practice relations:** Client legitimising inner norms of sustainability and BIM approach. Design team role overridden by client.	No EC considerations set. No communication of EC information requirements through BIM.	Preserves status quo.

Outer facilities that relate to the complexity of BIM model data and EC secondary data reliability constrained the capabilities of the principal design team. However, the design team showed professional leadership by making an effort to expand the project's inner norms that related to sustainability and BIM approach. Acknowledging their lack of expert skills, they requested experts to be appointed for LCA and BIM information lead roles. This request however was not facilitated by the client due to additional cost that these appointments would incur. The project tight scheduling was also a constraining condition for the coordination of the design team through the use of the BIM model.

According to Giddens (1979, p. 91), *'resources are the media through which power is exercised, and structures of domination reproduced'* . Cohen (1989, p. 158) mentions that *'administrative power refers capabilities of coordination and control over timing and spacing of human activities'* and adds that through the use of resources, administrative power holders can exercise control over sub-ordinate agents. For this case study, the client appears in the project as the administrative powerholder by exercising administrative power through the control of authoritative resources of scheduling and team appointments. Although agents access to resources may be asymmetric, and administrative powerholders may have more control over resources than sub-ordinate agents, Giddens also introduces the concept of **'dialectic of control'** according to which all agents in a social system have some power over their agency (Giddens 1979; Giddens 1984). The design team appeared as 'agents in subordinate positions' that showed limited dialectic of control in their attempt to expand inner norms and the available expertise of the project. This resulted in limited EC considerations to be included to the building design, lack of LCA assessment and restricted BIM model use to merely spatial coordination. The unsuccessful attempt of professional leadership to affect the project's sustainability and BIM approach agrees with Cohen (1989) who mentions that courses of action are *'shaped by the limits of resource-based facilities agents do or do not possess to implement decisions'* (Cohen, p. 153). Considering the duality of structure perspective, the contextual outcome shows preservation of the industry status quo. The direct and indirect primary conditions, mechanisms and outcomes that relate to this outcome category are summarised in Table 6.10.

Table 6.10 Case Study 1 - How EC considerations are addressed: Conditions, Mechanisms and Outcomes.

Conditions	Mechanisms	Outcome	
Direct & Indirect Primary	**Position-practice Dialectic of control**	**EC consideration address**	**Contextual**
Direct: Outer facilities Complexity of BIM model data, Secondary data reliability Inner: All norms, Scheduling and Professional knowledge/skills **Indirect Primary:** All outer norms, inner Client ambitions and Cost	**Dialectic of Control:** Limited for the design team due to client administrative power over project's facilities and norms.	Limited EC considerations in building design, no whole building LCA. No use of BIM model for EC assessment.	Preserves status quo.

6.3 Case Study 2

This section presents the analysis of the second case study using the Explanatory phase analytical framework. Firstly, a description of the case study is presented. The analysis then follows the same structure as Case Study 1, presenting the Conditions analysis, Analysis of Strategic Conduct and then leading to the Conditions, Mechanisms and Outcomes of the case study.

6.3.1 Case Description

This case study considers the design stage of a commercial building project in South-Eastern England classified as E Commercial, Business and Services according to the Town and Country Planning (Use Classes) Order 1987.[12] The project includes retail and commercial office spaces and a public square. The client is a large commercial property development company, and the main building use is the headquarters of an international bank. Table 6.11 summarises basic information about the case study, such as the use, location and size of the project. The project aims to achieve a BREEAM 'Excellent' rating as a minimum and is registered under the BREEAM 2014 version. The project follows a Design and Build procurement route and includes a Pre-Construction Services Agreement (PCSA) whereby a contractor team was appointed to consult the design team during Stage 3 on buildability and ensure a smooth transition from design to construction stage. The procurement strategy follows the client's new project procurement and management process, according to which, key early supply chain is involved to improve design, coordination, and value certainty during the design stage. With regards to BIM application, the project can be considered as BIM Level 2 and an Information management team was appointed as BIM consultants to the client to ensure a thorough BIM Level 2 project delivery. Each professional team of the principal design team had their respective BIM Task Team Manager, who was responsible for the full inclusion of the BIM process from their organisation. The appointed BIM Information Manager for the project was responsible for progressively maintaining the Federated BIM model throughout the design stage.

[12] The Use Classes were last updated on 1 September 2020 and Class E more broadly covers uses previously defined in the revoked Classes A1/2/3, B1, D1(a-b) and 'indoor sport' from D2(e).

Table 6.11 Case Study 2 basic information.

Case Study	Building use/ Use Class*	Location	Area
	Commercial and retail / E Commercial, Business and Services	South-Eastern England	52,000 m^2

The team appointments of the project also reflected the project's high sustainability aspirations. The principal design team had high sustainability expertise and, to enable a holistic approach to sustainability, LCA consultants were appointed at RIBA Stage 2 for the EC assessment of the project. Table 6.12 includes information about the type and size of main project stakeholders, which are the client, and the principal design team. Their sustainability expertise, or in the case of the client sustainability aspirations, is also included in the table. Sustainability expertise information for the design team was gathered from companies' website information and the projects that they have delivered. Depending on whether sustainability was core to their practice, sustainability expertise was ranked as low/ medium and high. The rankings were colour-coded red (low), amber (medium) and green (high) respectively.

Table 6.12 Case Study 2 main stakeholder information.

	Client	**Architect (ARCH)**	**MEP Engineers (MEP)**	**Structural Engineers (STR)**	**Quantity Surveyor (QS)**
Type/ size	Private, commercial developer	One office in UK and two internationally	Global consultancy company with offices in 13 countries.	Global company with offices in 6 countries	Global consultancy with offices in 20 countries
Sustainability Expertise/ Aspirations (for client)	Environmental Sustainability Strategy for their projects	Sustainable design stated as principle and projects include sustainability.	Consultancy offers assessment on various environmental design and sustainability aspects.	Sustainable design stated as principle and projects include sustainability	Sustainability stated as part of the Property & Asset Management Services offered.

The data collection for the CS included interviews with the project stakeholders and project document analysis and forwarded emails (email communication between the client, the BIM consultant and the LCA consultant). The collected data for the CS are presented in detail in section 3.3.6.1.

Within the following sections, reference to empirical data is made using the code that refers to the data type as described below:

- Interview: Int. (number indicating RIBA stage the interview took place)-(profession code as presented in Table 6.12).

    Eg. Int.2-ARCH: Interview with architect during RIBA Stage 2.

- Project documents: (document title as presented in Table 3.6)-St.(number of RIBA stage if applicable)-(profession code if applicable).

    Eg. RIBAreport-St.1: RIBA Stage 1 report

- Forwarded emails: Email-St.(number of RIBA stage)-(professions included in the email communication).

    Eg. Email-St.2-Client-LCAconsultant-BIMlead

6.3.2 Conditions Analysis

All conditions and the links that show their relationships are presented in Figure 6.20. The analysis started with looking first into how industry wide (outer) conditions affected project (inner) conditions. It can be seen that outer context Facility conditions 'Complexity of BIM model data', 'Secondary data reliability' and 'Lack of EC benchmarks' had no impact on other conditions. Outer context Norms had an impact on inner norms. More specifically, the current industry focus on OC by sustainability rating systems and regulations had an impact in shaping the project's 'Sustainability Approach'. This has been evident throughout the project's RIBA reports, where sustainability sections only mention operational energy reduction ambitions, and meeting energy demands through decentralised and low/zero carbon technologies (RIBAreport-St.1,2,3). The only comment that relates to embodied carbon is in relation to material selection:

> *'Materials selected needs to have a high recycled content and be locally extracted and manufactured' (RIBAreport-St.1).*

In RIBA Stage 3, embodied carbon assessment is mentioned in the MEP stage report as a way to identify opportunities to reduce the project's embodied carbon through material selection (RIBAreport-St.3-MEP). During Stage 3 material selection is defined in more detail. The project reports included required U-values of building components as part of the required thermal performance of materials (RIBAreport-St.3- Consultants). There was however no quantifiable requirement in relation to building component EC values. This also suggests that the sustainability approach of the project is influenced by the current regulation focus on operational energy and carbon. Outer norm BIM standards had an impact on the project's BIM approach with members of the design team being required to follow a series of available standards to establish a consistent approach to collaboration (EIR). The list of standards mentioned in the EIR document is presented in Figure 6.19.

Standard Ref.	Title
BS 1192:2007+A2:2016	Collaborative production of architectural, engineering and construction information
PAS1192-2:2013	Specification for information management for the capital/delivery phase of construction projects using BIM
PAS1192-3:2014	Specification for information management
BS1192-4:2014	Collaborative production of information
PAS1192-5:2015	Specification for security minded building information modelling, digital built environments and smart asset management
CIC BIM Protocol	Standard Protocol for use in projects using Building Information Modelling
BSRIA Soft Landing	BSRIA Soft Landings Framework – BSRIA BG 4/2014
ISO12006-2:2015	Building construction -- Organization of information about construction works Part 2: Framework for classification of information
Project Specific BEP	Project Specific BIM Execution Plan

Figure 6.19 Case Study 2 - Extract of EIR document with list of standards to be followed by the design team.

Moving to the analysis of inner conditions, an outdegree analysis was made to identify the number of outgoing links each condition has. 'Client ambitions' had the highest outdegree (3) followed by 'BIM approach' (2). 'Professional knowledge/skills', 'Team appointments', 'Sustainability approach' and 'Contract' only had one outgoing link. An indegree analysis was also made to identify the incoming links each condition has. Mostly affected by other conditions was inner facility 'Team appointments' (3) followed by inner norm 'BIM approach' (2). 'Sustainability approach', 'Scheduling', 'Professional leadership' and 'Professional knowledge/ skills' only had one incoming link. The outdegree and indegree of conditions helped identify quantitatively the relationships of conditions and highlight focus points. A deeper understanding of the relationships between conditions is given through a qualitative analysis on conditions that follows below.

'Client ambitions' is the condition that affects most inner conditions of the project as can be seen in Figure 6.21. They affect inner norms 'Sustainability approach', 'BIM approach' and 'Team appointments'. The client had high aspirations for both sustainability and BIM use in the project. With regards to sustainability, the project is aiming to achieve high ratings in several sustainability rating systems, including BREEAM and LEED[13]. In interviews with the project's lead architect and the embodied carbon consultant, it was mentioned that the aim is to extend the sustainability approach further than the rating systems requirements. Therefore, in this case study, the sustainability approach is predominantly affected by the client ambitions, which extend further than the requirements to achieve the sustainability ratings. Similarly, the 'BIM approach' of the project is influenced by the 'Client ambitions' for a high level 2 BIM application which will facilitate collaboration.

[13] Leadership in Energy and Environmental Design (LEED) is a worldwide used green building rating system.

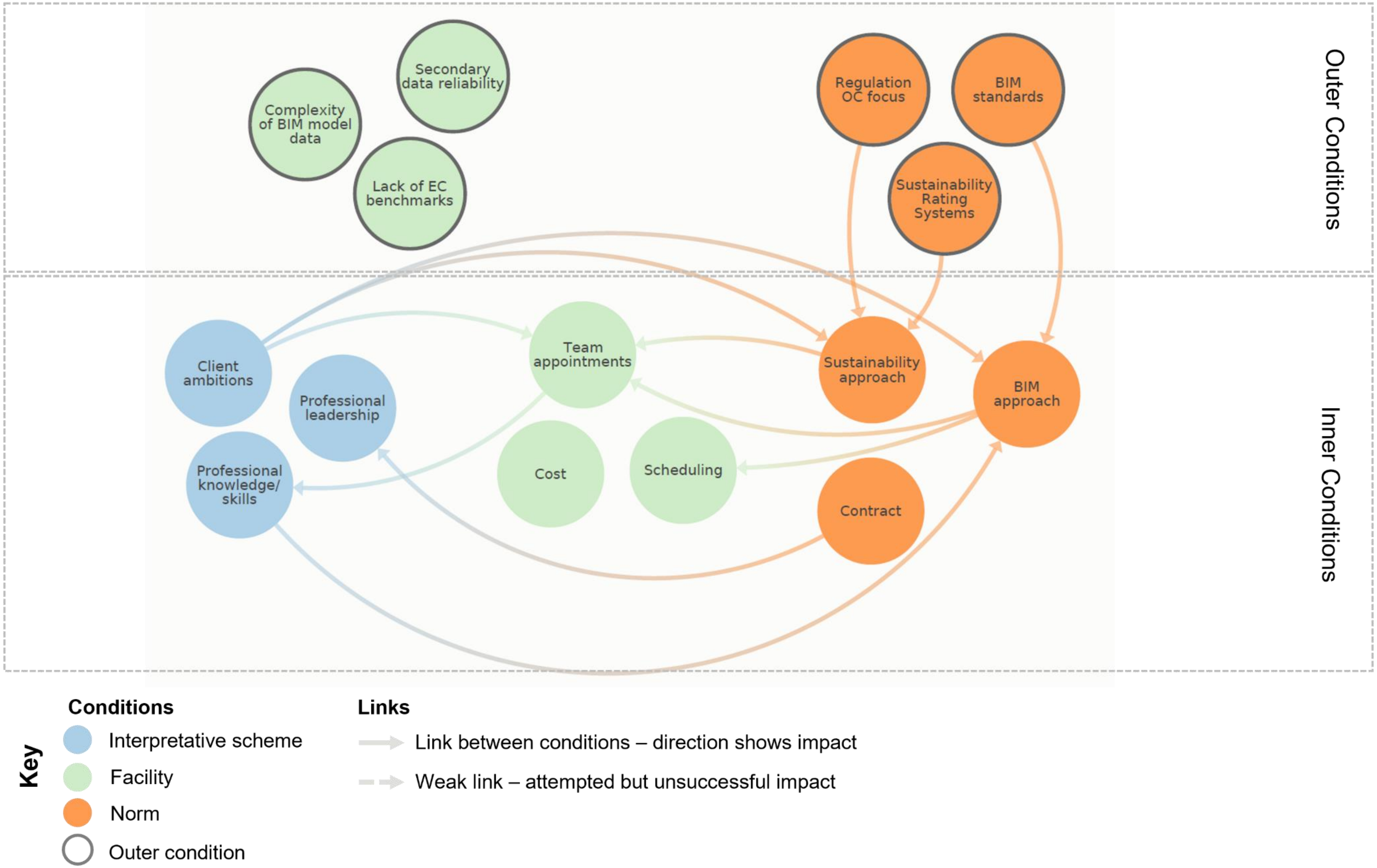

Figure 6.20 Case study 2 - Conditions and their relationships.

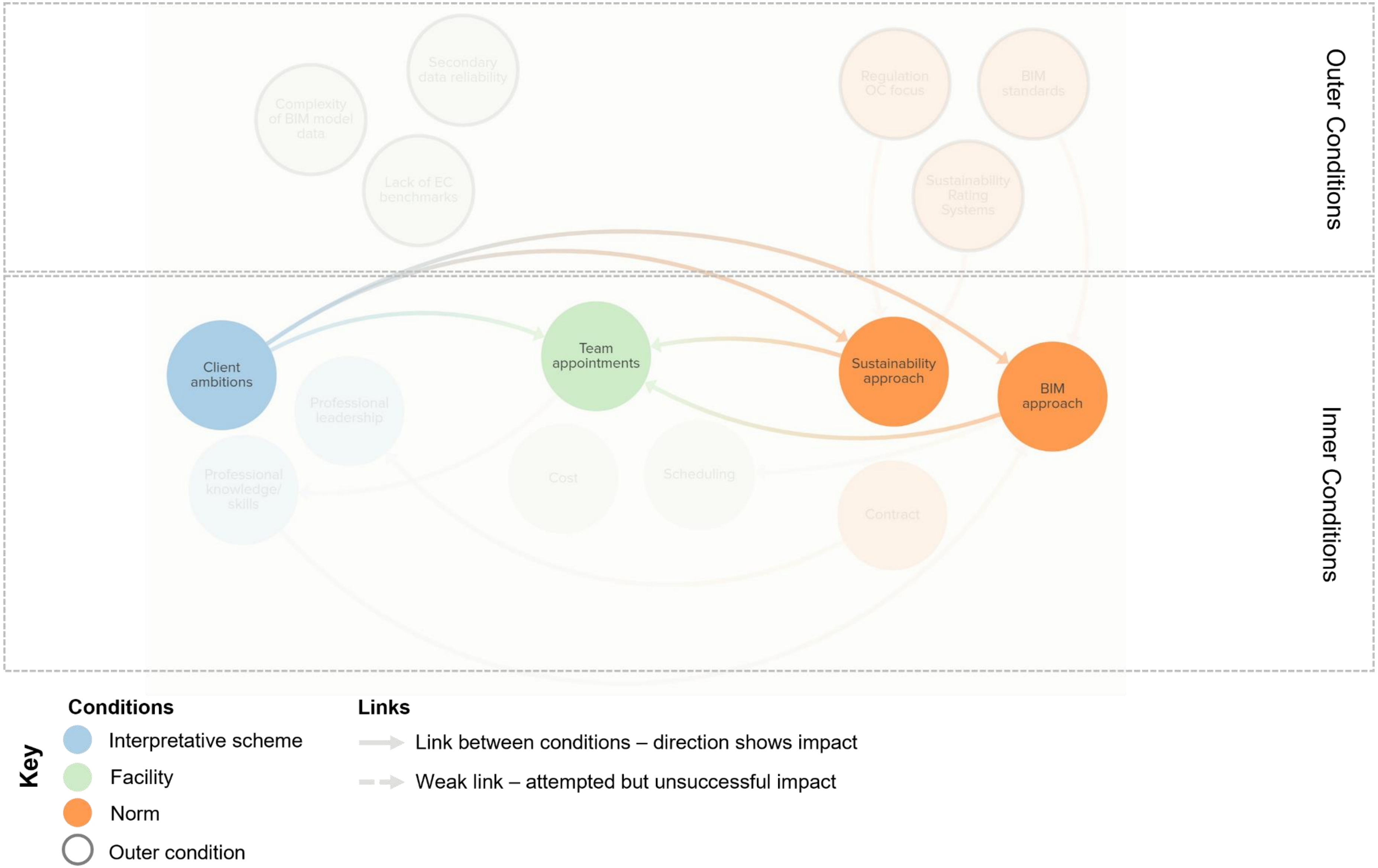

Figure 6.21 Case study 2 - Client ambitions relationships with other conditions.

‘Team appointments’ reflects the client ambitions for high sustainability aspirations and BIM application within the project. This is evident by the appointments of experts that joined the principal project team from the early design stages and gave consultation on BIM and Sustainability. With regards to sustainability, at the end of Stage 2/ beginning of Stage 3, LCA consultants were appointed to ensure EC assessment took place and EC reduction efforts were made. ‘Team appointments’ in turn affected the ‘Professional knowledge/skills’ of the project team and high expertise by both the principal design team and the appointed consultants was ensured. With regards to BIM application, each professional team within the design team had their own BIM team manager and a BIM information manager was also appointed for the project to ensure coordination and validation of the BIM federated model:

> *‘The Consultants will retain responsibility for the information the model is derived from throughout the BIM Model process, while the Information Manager is responsible for the management of the Federated BIM Model. The BIM Information Manager will support the Consultant Design Team and Specialist Trades with the BIM process to aid coordination and validation’ (BEP).*

The strong BIM approach is also reflected in the stage 3 MEP report where BIM model creation and drawing production is allocated to the different professional teams to ensure timely production of the models and facilitate collaboration. During RIBA stage 3, a Pre-Construction Services Agreement (PCSA) was made which included the appointment of a contractor team to act as advisors to the design team to ensure buildability and a smooth transition from the design to the construction stage. This reinforced the design team knowledge and skills in relation to technical aspects of the design development.

The links that relate ‘Team appointments’ to other conditions within the project are presented in Figure 6.22, and it can be seen that ‘Team appointments’ is a condition that is key in this case study for an enhanced sustainability and BIM approach.

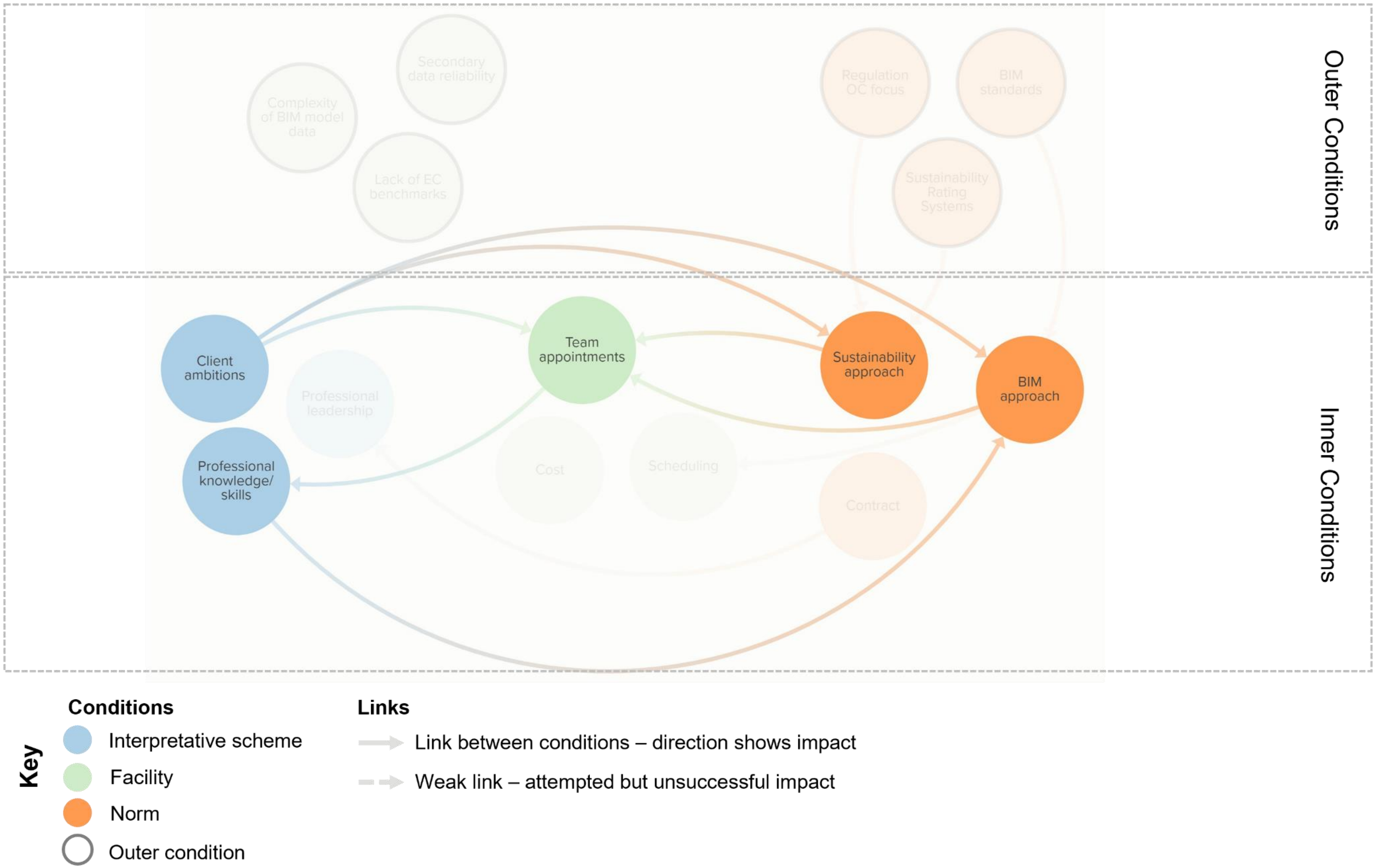

Figure 6.22 Case study 2 - Team appointments relationships with other conditions.

The strong ‘BIM approach’ of the project had an impact on ‘Scheduling’ to allow BIM models submitted by each team on agreed dates to be checked and federated:

> *‘On the agreed dates, all parties will submit their models which will be coordinated by the lead designer and clash detected. All data drops are to be fully checked and the information verified before issue. Actions will be disseminated by the Principal Designer to all parties via the Common Data Environment and errors or non-compliance will be corrected as a priority within agreed timescales.’ (EIR).*

The project reports showed that the project’s ‘Contract’ enabled the design team professionals to take leadership during the end of the design stage to ensure that material choices during the construction stage would be compatible with what the design team had specified. This is reflected in the structural report in relation to materials and component specifications that are mentioned as ‘or equivalent approved’:

> *‘Approval will only be granted where it can be documented that the alternative meets the performance specified in all aspects, including, but not limited to strength, stiffness, durability, robustness and buildability’ (RIBAreport-St.3-STR).*

Although EC is not mentioned in the aspects of performance listed, this gives some scope to engineers to reject a change in material that would increase the EC of the project.

Finally, ‘Cost’ didn’t appear to have an impact on other inner conditions in this case study, and ‘Team appointments’ that expanded the expertise of the design team were made despite the additional cost they incurred. During an interview with the project’s lead architect, it was mentioned that value engineering that aims at cost optimisation can have an impact on the project’s carbon, either positively by coincidentally reducing carbon through cost optimisation redesign or negatively by dropping the carbon assessment requirements due to the additional cost that carbon assessments incur. However, for this case study, the carbon assessment was enabled through the appointment of LCA consultants and carbon optimisation resulted in the reduction of the project’s capital cost. The capital cost savings were approximately six times greater than the cost of the fee related to carbon assessment and consultancy. This highlights that cost optimisation through carbon optimisation can be more significant than the cost of the experts' appointment to achieve the carbon reductions.

The relationships of Scheduling, Contract and Cost are highlighted in Figure 6.23.

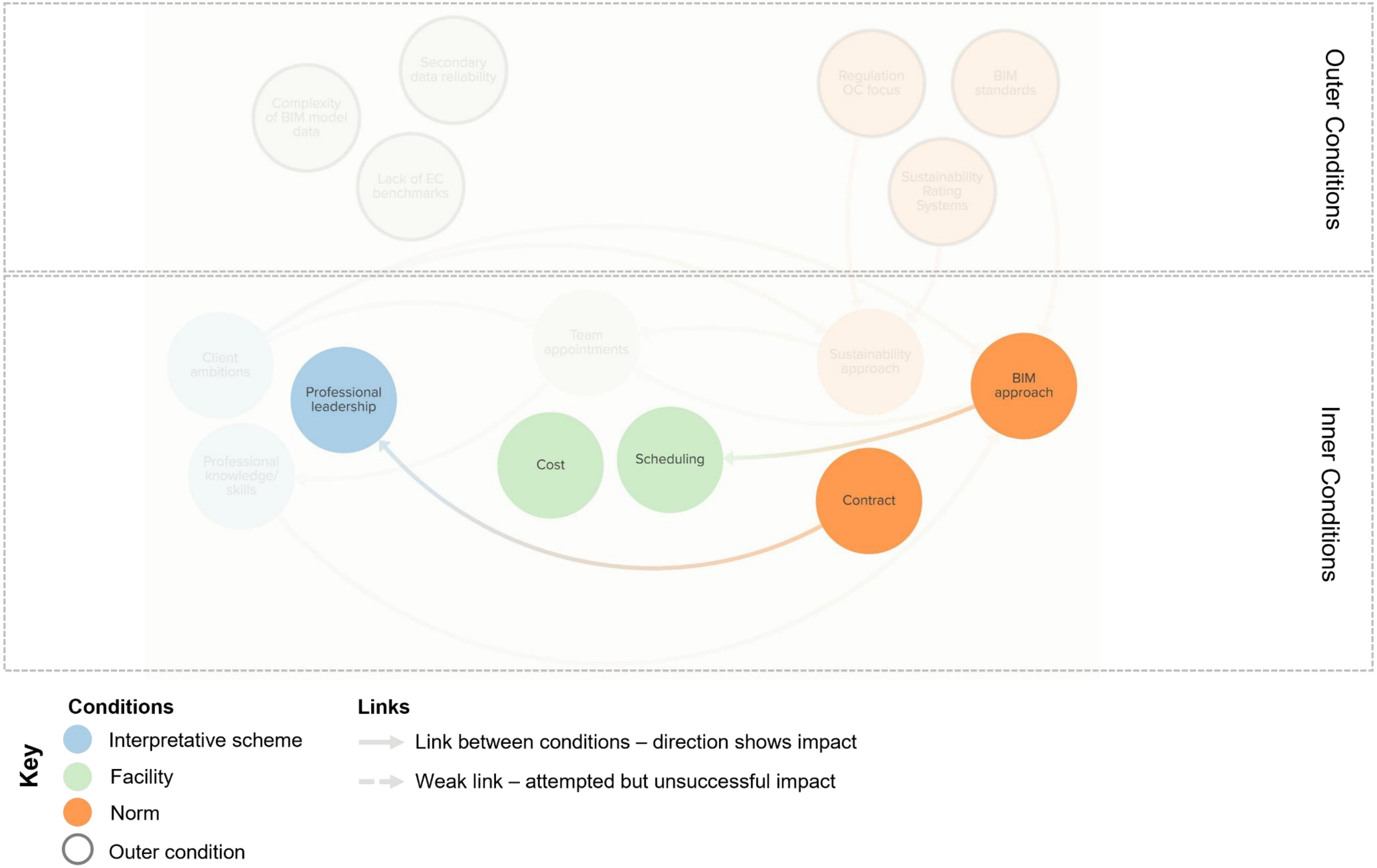

Figure 6.23 Case study 2 - Scheduling, Contract and Cost relationships with other conditions.

6.3.3 Analysis of Strategic Conduct

Strategic Conduct Analysis aims to understand the relationships of the conditions and the way they affected the project outcomes that relate to how EC considerations were set, communicated, and addressed. The application of BIM in relation to EC considerations is also explored. This part of the analysis starts with identifying the conditions that directly affected the project outcomes and are presented with red arrows in the diagrams. Then, considering the conditions analysis presented in section 6.3.2, the indirect conditions that affect the project outcomes enable a deeper understanding of how the project conditions affected the project outcomes. The indirect conditions are divided into primary and secondary and are presented in the diagrams with grey arrows. The direct and indirect conditions that affect the project outcomes are presented in Figure 6.24 and Figure 6.25 respectively.

In the following sections the two outcome categories ‘How EC considerations are set and communicated’ and ‘How EC considerations are addressed’ are analysed in more detail and the outcomes within each category are discussed and presented in separate figures for more clarity.

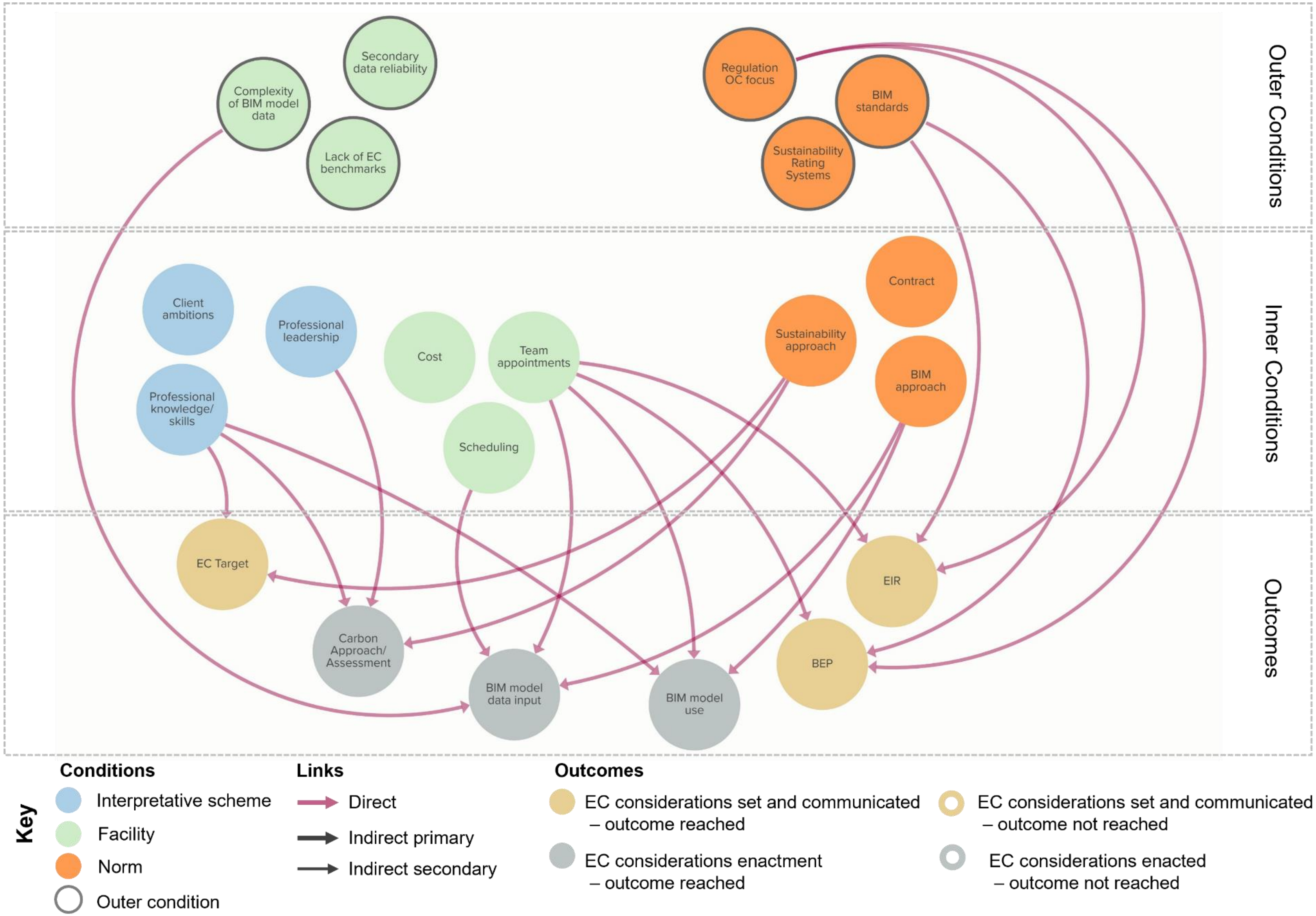

Figure 6.24 Case study 2 - All outcomes and the direct conditions affecting them.

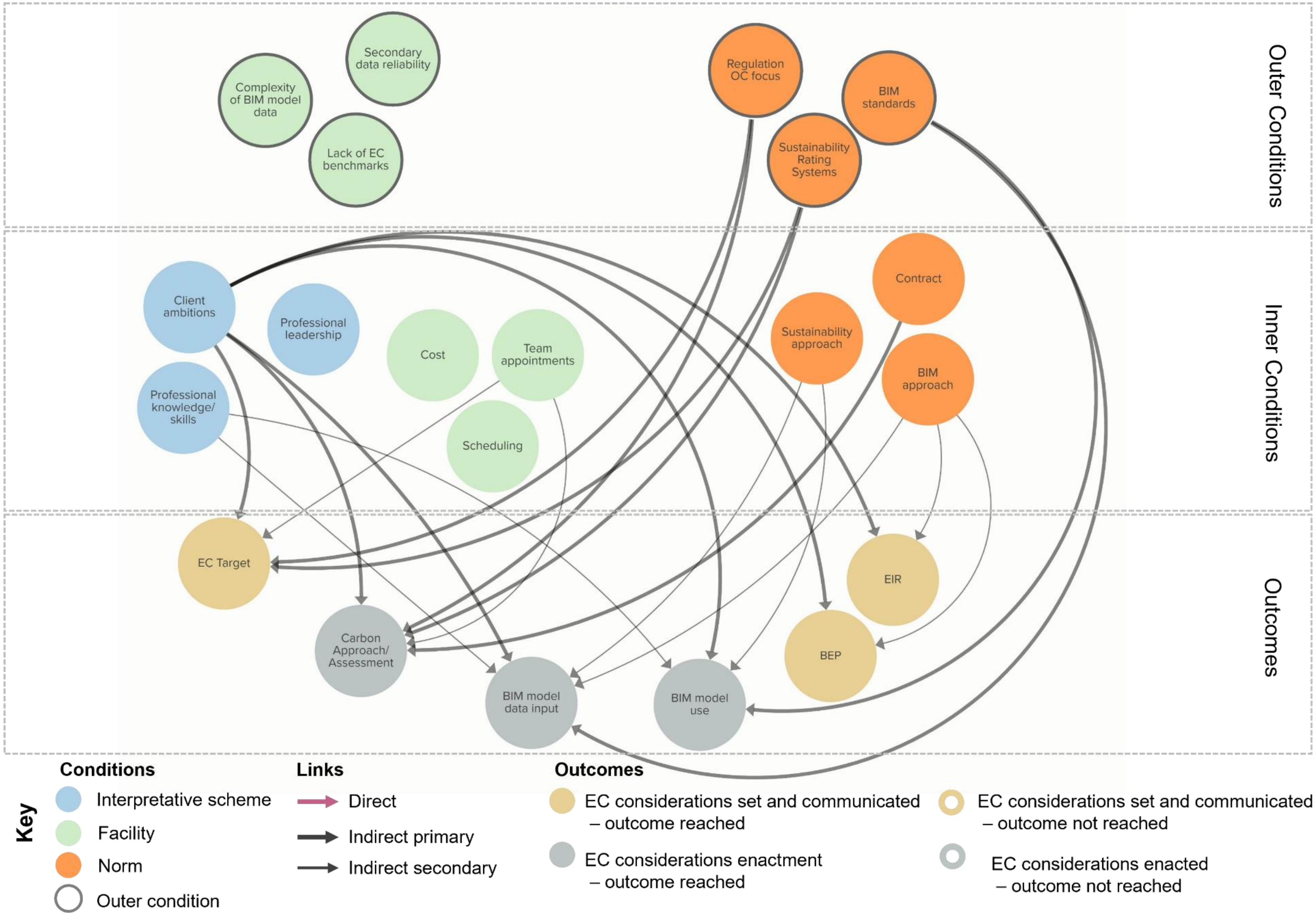

Figure 6.25 Case study 2 - All outcomes and the indirect conditions affecting them.

6.3.3.1 How EC considerations are set and communicated

The outcomes that relate to how EC considerations are set and communicated are the project's 'EC target', 'EIR' and 'BEP'. The direct and indirect inner and outer conditions that affected these outcomes are presented in Figure 6.26 and Figure 6.27 respectively and summarised in Table 6.13. Outcomes in this category are directly affected by inner norm of 'Sustainability approach', the 'Team appointments' facility and the 'Professional knowledge/skills' of the design team, which is an interpretative scheme. Outer conditions that affect them are the 'Lack of EC benchmarks' and the construction industry's 'BIM standards'.

Through the conditions analysis presented in section 6.3.2, the relationships of conditions are considered and the indirect conditions that affect these outcomes are identified. The indirect primary inner conditions that affected outcomes that relate to how EC considerations are set and communicated are 'Client ambitions', 'Team appointments' and 'BIM approach' which are an interpretative scheme, a facility and a norm respectively. Outer conditions that affected these outcomes are 'Regulation OC focus' and 'BIM Standards'.

Table 6.13 Case study 2 - The direct and indirect primary conditions that affected how EC considerations are set and communicated.

Outcomes	Direct Conditions		Indirect Primary Conditions	
	Inner	**Outer**	**Inner**	**Outer**
EC Target	Professional knowledge/ skills Sustainability Approach	n/a	Client ambitions	Regulation OC focus Sustainability Rating Systems
EIR	Team appointments	BIM Standards Regulation OC focus	Client ambitions	n/a
BEP	Team appointments	BIM Standards Regulation OC focus	Client ambitions	n/a

Further elaboration on the way direct and indirect conditions affected how EC considerations are set and communicated are presented for each outcome of this outcome category below.

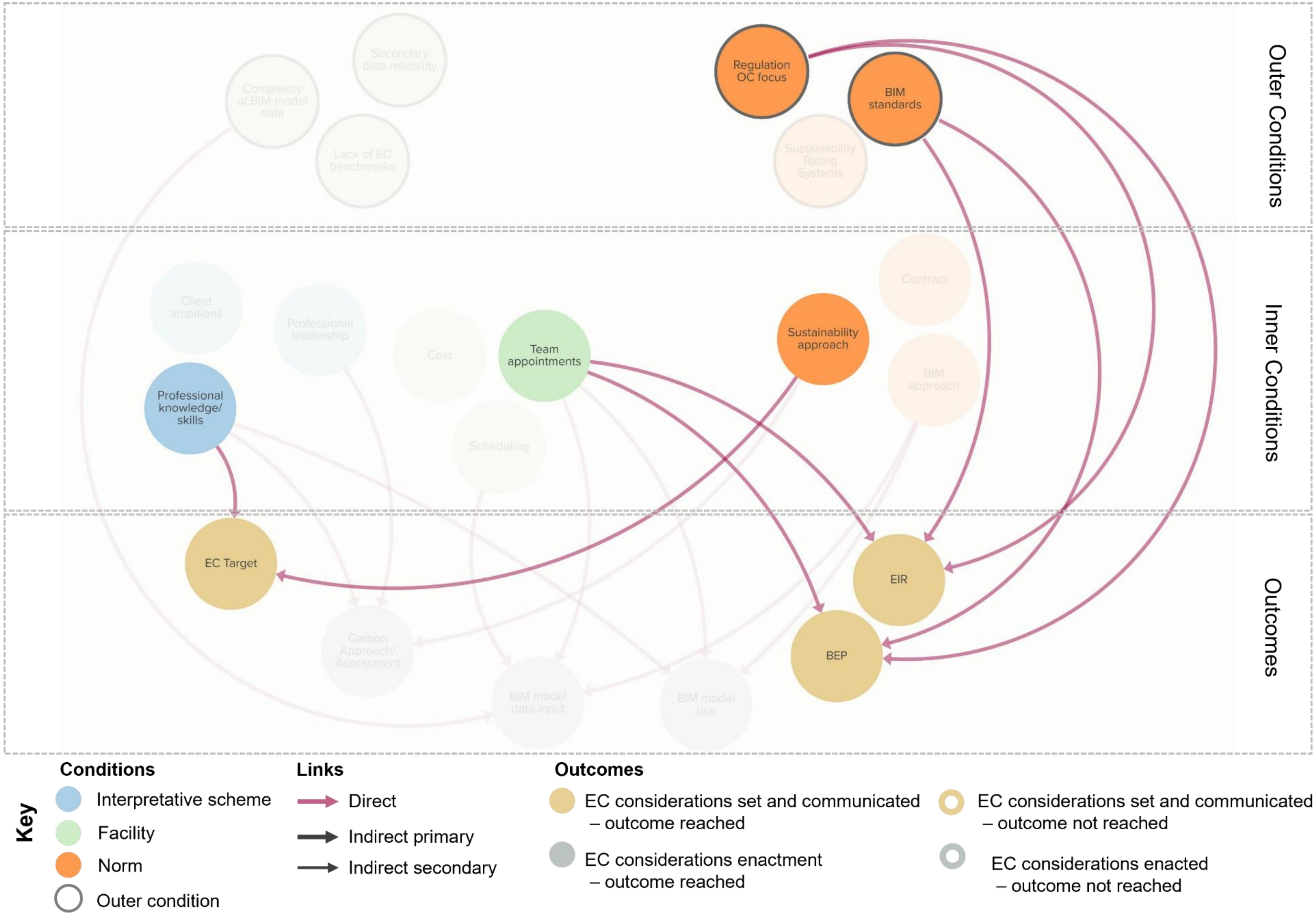

Figure 6.26 Case study 2 - How EC considerations are set and communicated outcomes and the direct conditions affecting them.

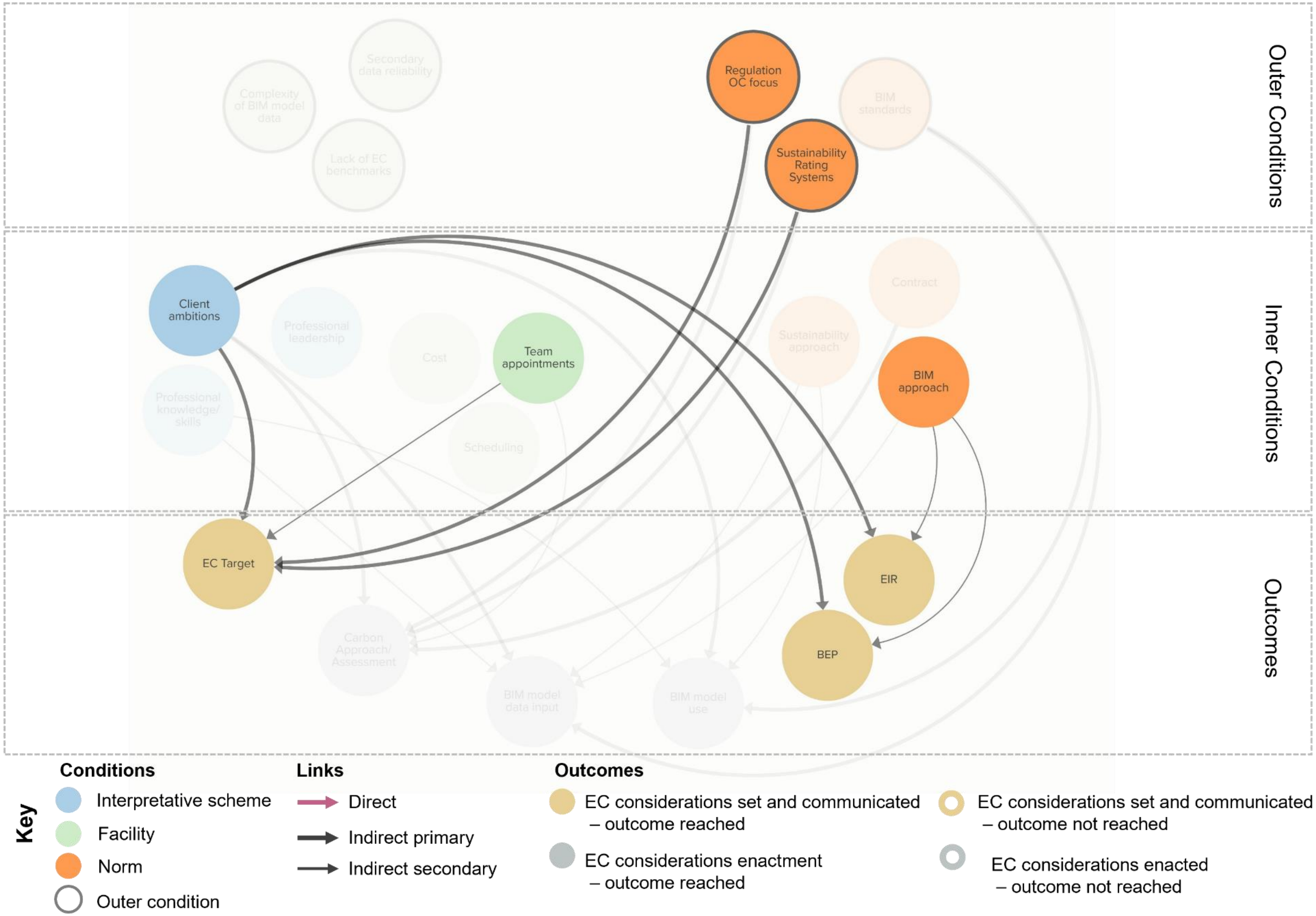

Figure 6.27 Case study 2 - How EC considerations are set and communicated outcomes and the indirect conditions affecting them.

6.3.3.1.1 EC Target

The lack of industry-wide available EC benchmarks did not have an impact on setting an EC target for the project. At the end of Stage 3, the upfront carbon target for the project was 900 kg CO_2e/m^2, however, during the interview with the client, it was acknowledged that the target was perceived as very ambitious by the client:

> *'we know we won't meet the target' (Int.3-Client).*

The target changed during the construction stage to 1,335 kg CO_2e/m^2 and its whole-life carbon was calculated at 193,785 tonne CO_2e for a 60-year lifespan. The project aimed to include whole life carbon benchmarking against other similar projects upon its completion. Target setting was enabled by the sustainability approach that the project took and the professional skills that the appointed LCA consultants brought to the project. The direct inner conditions therefore that affected this outcome were 'Sustainability approach' and 'Professional knowledge/skills'. 'Team appointments' indirectly affected this outcome by expanding the design team knowledge and skills to include LCA expertise. Both the project's 'Sustainability approach' and 'Team appointments' are affected by the client's high sustainability aspirations for the project, therefore, the indirect primary inner condition that affected this outcome is 'Client ambitions'. Although the sustainability approach was also affected by outer norms 'Regulation OC focus' and the 'Sustainability rating systems' which predominantly focus on OC carbon reduction, the client ambition to include EC considerations in the project and to reduce the project's embodied impacts prevailed in extending the sustainability approach to address this aspect of sustainability alongside OC impacts. The conditions that affected the EC target outcome are presented in Table 6.14 and Figure 6.28.

Table 6.14 Case study 2 - The direct and indirect primary conditions that affected the EC target outcome. (Excerpt from Table 6.13).

	Direct Conditions		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
EC Target	Professional knowledge/skills Sustainability Approach	n/a	Client ambitions	Regulation OC focus Sustainability Rating Systems

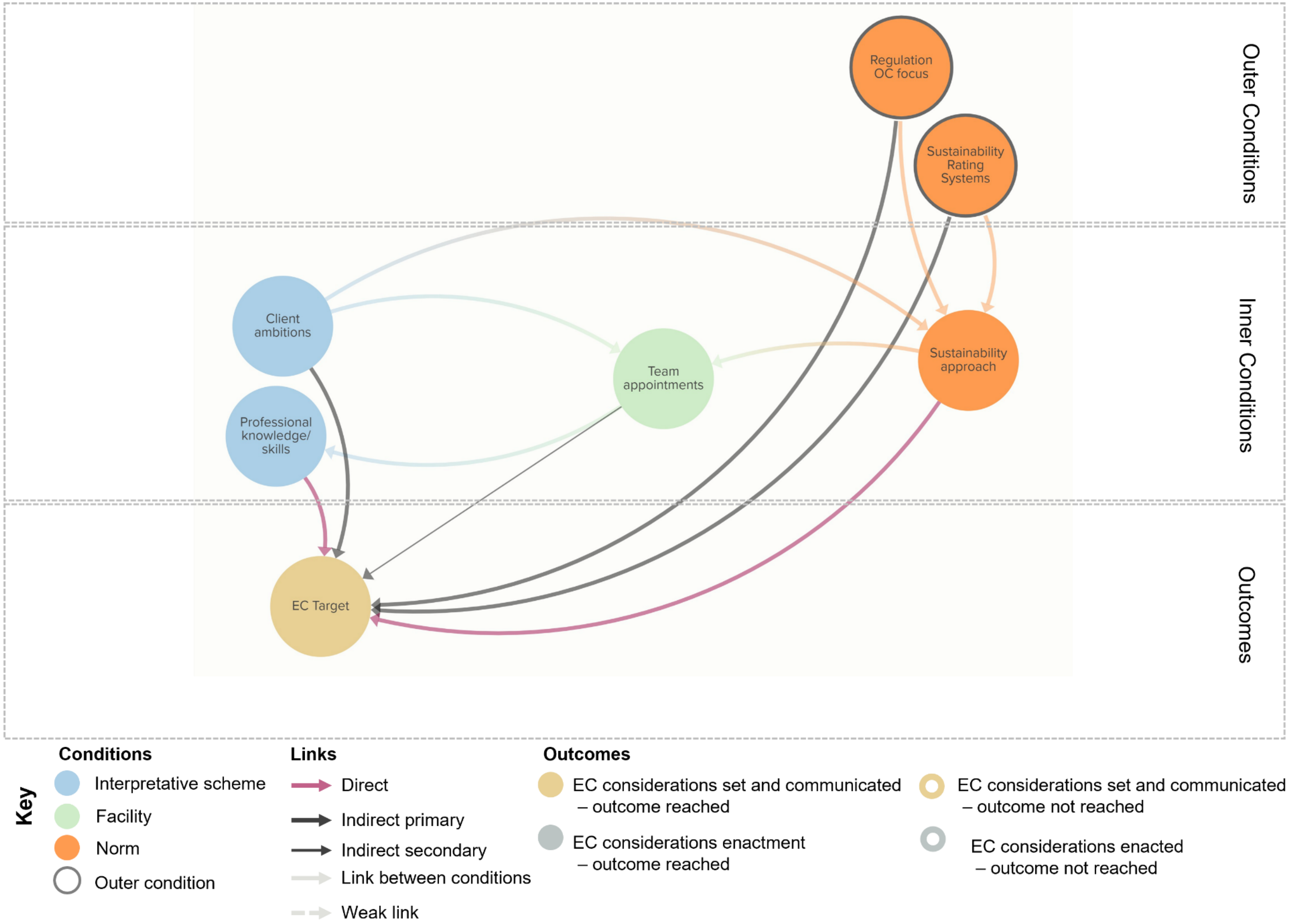

Figure 6.28 Case study 2 - The conditions that affected the EC target.

6.3.3.1.2 Employers Information Requirements (EIR)

The EIR document was prepared by the appointed Information Management team who provided consultation to the client in relation to BIM application. In Phase 1 results (chapter 4) it was identified that clients lack the expertise to create EIR documents, which commonly results in the architectural team drafting it, or in the complete lack of an EIR document for projects. Therefore, the inner facility 'Team appointments' that enhanced the professional team BIM expertise directly affected the creation of the EIR document for the project. 'Team appointments' are affected by the inner interpretative scheme 'Client ambitions', as such, 'Client ambitions' was the indirect primary condition affecting this outcome. The EIR document was based on industry-wide BIM standards, namely the Construction Industry Council (CIC) BIM Protocol and mentions other standards that need to be followed for the project development and BIM model use:

> *'Projects shall be delivered in accordance with the principles of BIM Level 2 as defined in PAS1192-2:2013. […] The PIM [Project Information Model] should be developed during design and construction to produce a data rich AIM [Asset Information Model] to comply with the principles defined in PAS1192-3:2014.' (EIR).*

The Levels of model definition in the EIR document were set as per PAS 1192-2:2013 document that specifies information management for the capital/delivery phase of construction projects using building information modelling (BSI 2013). As such, EC is included in the parametric information required at all stages of the project development. The EIR document lists specific BIM uses which include sustainability evaluation and energy analysis, with a note on the latter that:

> *'BIM allows teams to carry many of these analyses on early-stage concept models.' (EIR).*

Although the client pushed for the use of BIM to facilitate EC assessment (this will be explained further in the 'Carbon Approach/Assessment' outcome analysis), EC or whole-life carbon assessment is not mentioned in the list of the specific BIM uses. Therefore, it is evident that the current regulation OC focus had an impact on what is mentioned in the EIR document as required uses of BIM, with OC related assessments being mentioned whereas EC assessment being excluded from the list.

The conditions that affected the EIR outcome are presented in Table 6.15 and Figure 6.29.

Table 6.15 Case study 2 - The direct and indirect primary conditions that affected the EIR outcome. (Excerpt from Table 6.13).

	Direct Conditions		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
EIR	Team appointments	BIM Standards Regulation OC focus	Client ambitions	n/a

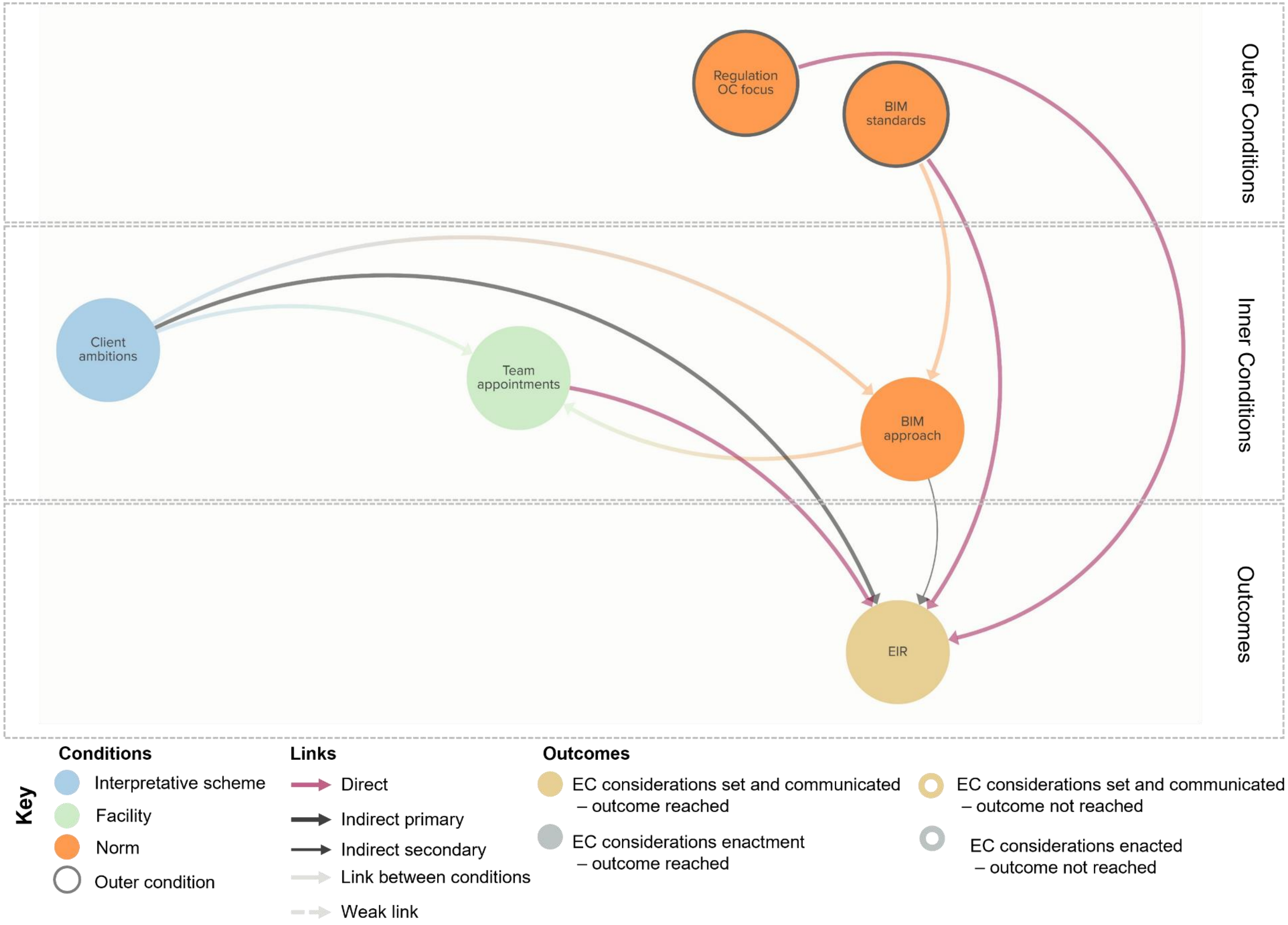

Figure 6.29 Case study 2 - The conditions that affected the EIR.

6.3.3.1.3 BIM Execution Plan (BEP)

Similar to the Employers Information Requirements (EIR), the BIM Execution plan (BEP) document was prepared by the appointed Information Management professional team. The inner facility 'Team appointments' that enhanced the professional team BIM expertise directly affected the creation of the BEP document for the project. 'Team appointments' are affected by the inner interpretative scheme 'Client ambitions'; as such, 'Client ambitions' was the indirect primary condition affecting this outcome. As the client of this project is a large development company, a template BEP was available by the client to inform the BEP document that the BIM consultants produced. This enabled the development of a very thorough BIM execution plan for the project that was in line with and reinforces the project's strong BIM approach. In the BEP, responsibility of the information model is described:

> *'The Consultants will retain responsibility for the information the model is derived from throughout the BIM Model process, while the Information Manager is responsible for the management of the Federated BIM Model. The BIM Information Manager will support the Consultant Design Team and Specialist Trades with the BIM process to aid coordination and validation.' (BEP).*

Similar to the EIR document, the uses of BIM listed in the BEP document all relate to assessments that relate to OC carbon, whereas EC is not included in the list of BIM uses. This shows the impact of industry-wide regulation OC focus that results in formally mentioning aspects that relate to OC and neglecting EC as part of the BIM use for the project's carbon assessment. The conditions that affected the BEP outcome are presented in Table 6.16 and Figure 6.30.

Table 6.16 Case study 2 - The direct and indirect primary conditions that affected the BEP outcome (Excerpt from Table 6.13).

	Direct Conditions		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
BEP	Team appointments	BIM Standards Regulation OC focus	Client ambitions	n/a

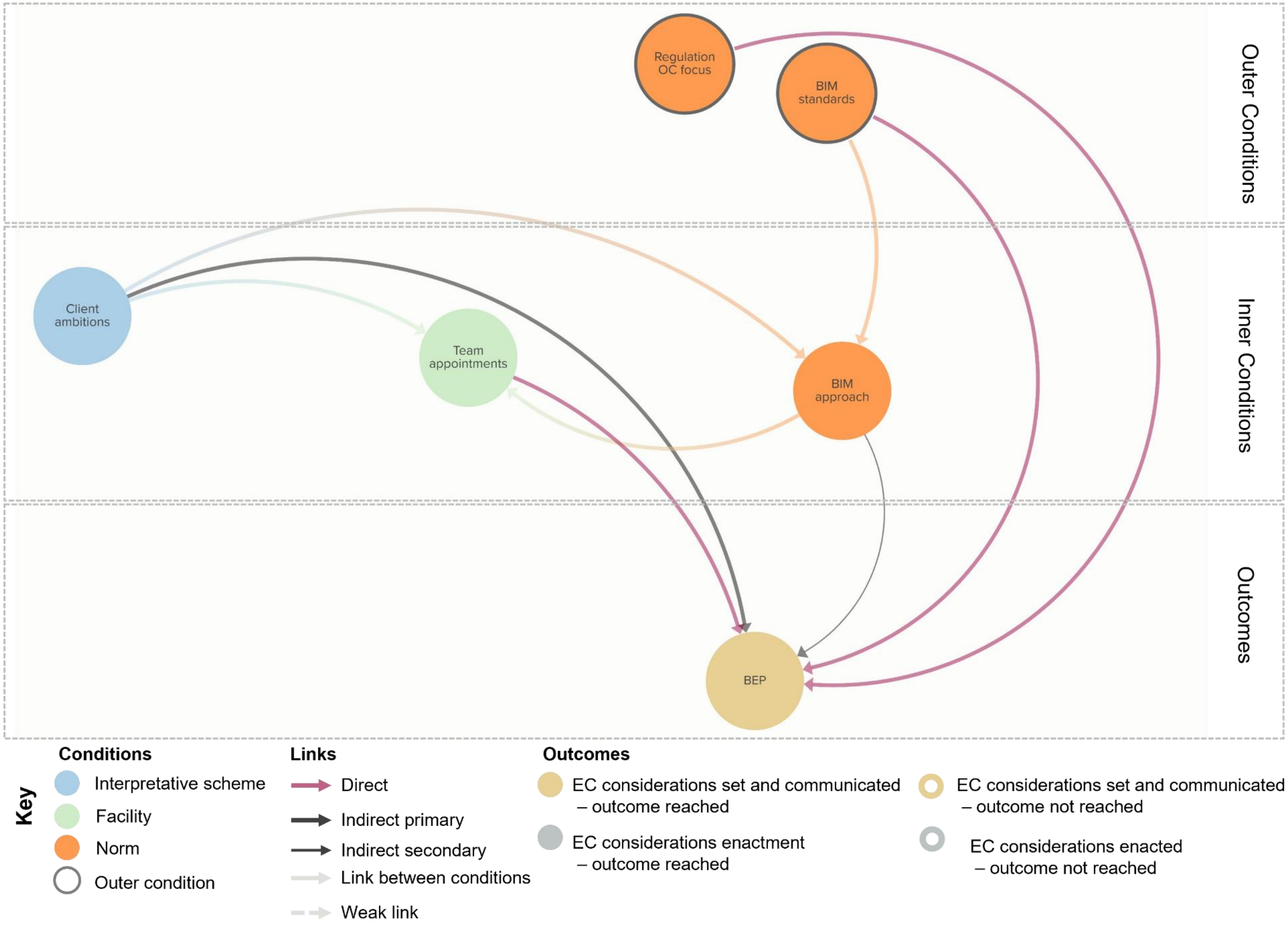

Figure 6.30 Case study 2 - The conditions that affected the BEP.

6.3.3.2 How EC considerations are addressed

The outcomes that relate to addressing EC considerations are the project's 'Carbon Approach/Assessment', 'BIM model data input' and 'BIM model use'. The direct and indirect inner and outer conditions that affected these outcomes are presented in Figure 6.31 and Figure 6.32 respectively and summarised in Table 6.17. Compared to the outcomes that related to how EC considerations are set and communicated, this set of outcomes was affected by a wider range of conditions. The outcomes that relate to how EC considerations are addressed were directly affected by the project's inner norms 'Sustainability approach' and 'BIM approach', inner facilities 'Team appointments' and 'Scheduling' and interpretative schemes 'Professional knowledge/skills' and 'Professional leadership'. The only outer condition that directly affected this set of outcomes was 'Complexity of BIM model data', whereas all outer norms affected these outcomes indirectly.

Table 6.17 Case study 2 - The direct and indirect primary conditions that affected how EC considerations are addressed.

	Direct Conditions		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
Carbon Approach/ Assessment	Sustainability Approach Professional knowledge/ Skills Professional leadership	n/a	Client ambitions Contract	Regulation OC focus Sustainability Rating Systems
BIM model data input	Scheduling Team appointments BIM Approach	Complexity of BIM model data	Client ambitions	BIM Standards
BIM model use	Professional knowledge/ Skills Team appointments BIM Approach	n/a	Client ambitions	BIM Standards

Further elaboration on the way direct and indirect conditions affected how EC considerations are addressed are presented for each outcome of this outcome category below.

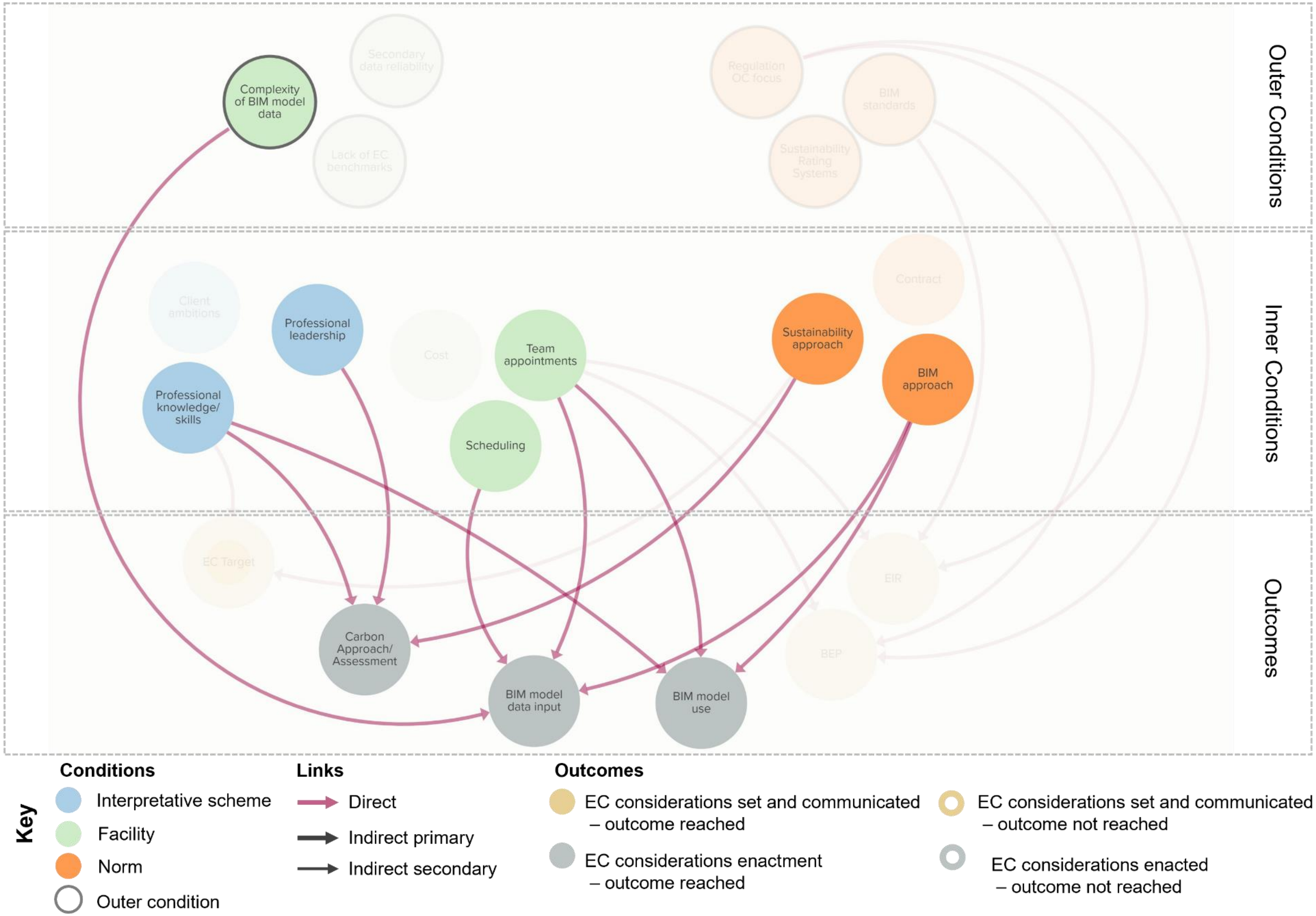

Figure 6.31 Case study 2 - How EC considerations are addressed outcomes and the direct conditions affecting them.

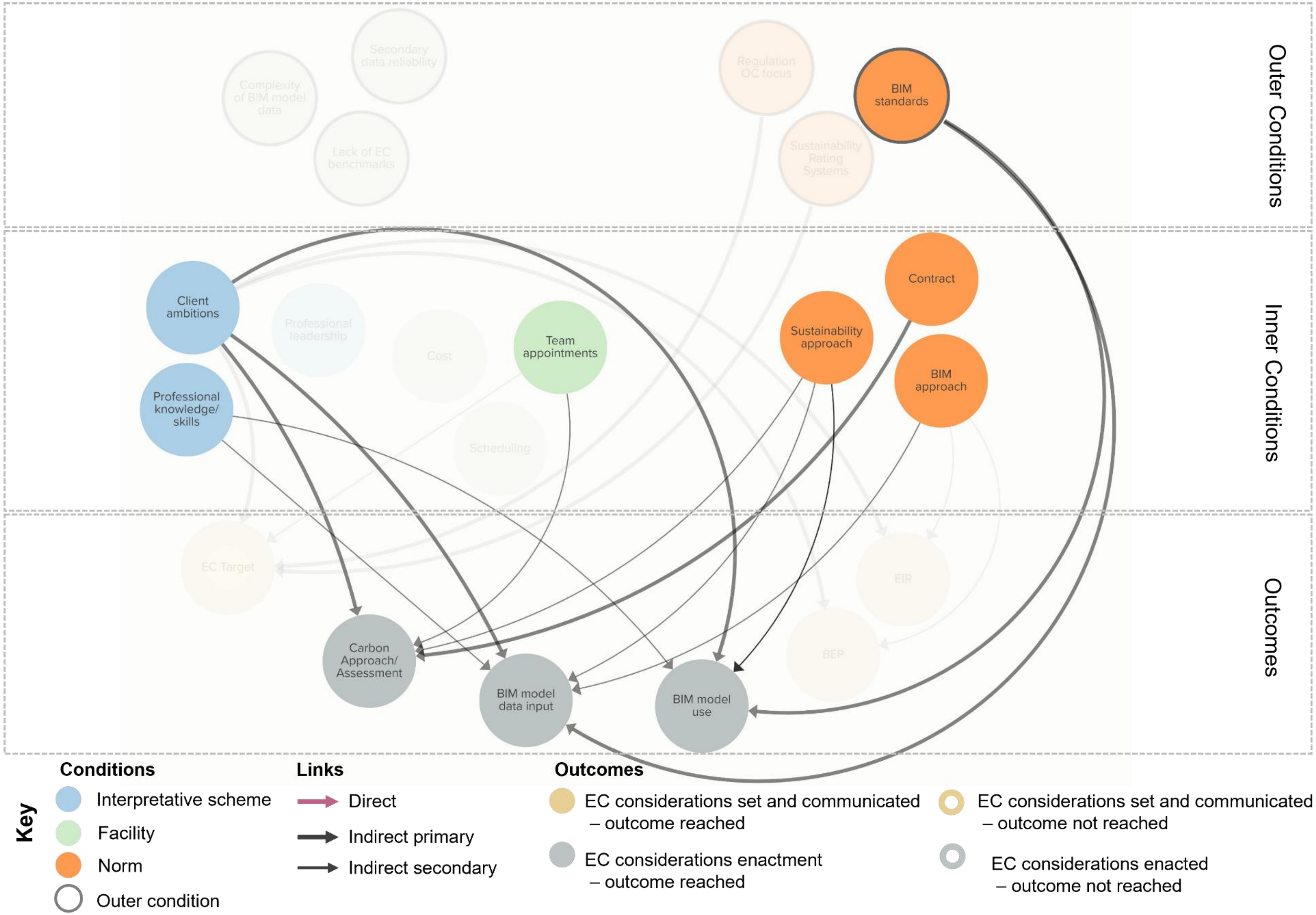

Figure 6.32 Case study 2 - How EC considerations are addressed outcomes and the indirect conditions affecting them.

6.3.3.2.1 Carbon Approach/ Assessment

The carbon approach of the project was fragmented during the initial design stages. During RIBA stages 1 and 2, OC and EC were addressed separately, and OC focus was evident. In an interview with the architect, they mentioned that there was no prioritisation in the sustainability parameters considered in the design development:

> *'There wasn't really a prioritisation of [environmental design] parameters, there has been an effort to incorporate all parameters and address everything equally at the same time.' (Int.3-ARCH).*

However, the RIBA reports show that OC reduction efforts were more thorough compared to EC reduction efforts. EC considerations during these initial design stages focused on overall material reduction and selection of materials with recycled content:

> *'During stages 0-3 the focus of the designers was on material reduction' (Int.3-ARCH), 'Materials selected needs to have a high recycled content and be locally extracted and manufactured.' (RIBAreport-St.1).*

During Stage 1, the Environmental policy section of the RIBA report mentions an energy hierarchy that relates to operational energy reduction and includes passive design elements, decentralised energy supply networks and use of low/zero carbon technologies to meet energy demand. The project BEP specifically mentions operational energy assessment as part of the assessments required:

> *'Energy Analysis - Optimise environmental performance of concept model' (BEP).*

However, there is no mention of EC. Similar to Stage 1, the Stage 2 report shows an OC focus in the carbon approach of the project development. The Sustainability and Energy section of the report only focuses on operational energy and carbon reduction measures such as reduction of annual energy consumption and efficient ways of energy supply:

> *'The design of [the project] has been developed to reduce its annual energy consumption, whilst providing energy in the most environmentally-friendly way to reduce its annual CO_2 footprint. […] The energy efficiency measures for the*

development are a combination of passive design elements and the design of the M&E systems.' (RIBAreport-St.2).

During this stage, the client referred to material choices in their comments on the Stage 2 report, but these were mostly focused on practical issues such as maintenance and cleaning rather than the upfront EC impact of materials (RIBAcomments-St.2-Client). EC carbon assessment during the end of Stage 2 started with the appointment of the LCA consultant. However, the BIM model was not used for the EC assessment during this stage. During Stage 2, the client requested Carbon Footprint data from façade contractors as part of an early tender return with an aim to inform their material choices with the lowest carbon footprint option:

> *'[The client] aims to use materials with the lowest carbon footprint possible for their projects. Please provide data in the table below, where applicable, and submit as part of your tender return. The information will be used to assess and compare material carbon performance between the tendering sub-contractors.' (RequestForInformation-St.2).*

The 'Request for Information' document was a template with data sections to be filled in by the sub-contractors for products without Environmental Product Declarations[14] (EPDs), and was created by the LCA consultants of the project.

During stage 3, thorough whole-life carbon assessment of the project took place which included EC assessment. The lifecycle assessment (LCA) was carried out in accordance with the BS EN 15978 standard, and included embodied carbon impacts associated with the cradle-to-grave stages. During this stage, it was mentioned by the architect that EC information is getting updated in the BIM model:

> *'From Stage 3 and 4 EC details start to get incorporated in the model' (Int.3-ARCH).*

This is reflected in the use of the BIM model for EC assessment which is further described under the 'BIM model use' outcome analysis. With regards to the professionals involved in the EC reduction and assessment, the main design team

[14] Environmental Product Declaration (EPD) is a document that quantifiably demonstrates the environmental performance of a product according to the European Standard EN15804.

and the LCA consultants were the professionals mainly involved, whereas the Quantity Surveyor (QS) team had limited involvement in the process. As mentioned by the architect, specific material information is given by the suppliers at the start of the construction stage.

> *‘It [EC reduction] is a collaborative process with the main design team and the specialists, QS hasn't been involved in the process that much. Suppliers of materials will give the material information at late Stage 4’ (Int.3-ARCH).*

Although EC assessment became part of the project’s sustainability assessments from the end of Stage 2, this was not reported formally to the extent that OC was. The only mention of EC assessment in the RIBA stage 3 report was in the Structural report under the steelwork sustainability design responsibility matrix and in the MEP report:

> *‘Embodied Carbon assessment is being carried out throughout the design process and will continue over the course of construction. This is to identify opportunities to reduce embodied carbon from materials used (i.e. Using cement replacement for concrete and high recycled content in aluminium frames) (RIBAreport-St.3-MEP).*

EC carbon reduction efforts continued to be addressed through material selection during stage 3 and the design team professional knowledge contributed to achieving this. This covered material options that related to architectural, structural and services components and systems such as the selection of timber for curtain walls, aluminium external capping, metal cladding, superstructure steelwork and steel reinforcement with high recycled component and alternative concrete mixes with recycled aggregates.

With regards to material specification during Stage 3, the carbon approach considered the specification of building products with an Environmental Product Declaration (EPD) and materials that achieve an A+ or A rating as defined in the Green Guide to Specification (RIBAreport-St.3-Consultants). The documents related to material specification during this stage demonstrated that the design team showed professional leadership through ensuring that the materials specified during the construction stage would follow the material qualities set during the design stage:

> *'Approval will only be granted where it can be documented that the alternative meets the performance specified in all aspects, including, but not limited to strength, stiffness, durability, robustness and buildability' (RIBAreport-St.3 STR).*

Although EC is not mentioned in the aspects of performance specification mentioned in the report, this gives some scope to engineers to reject a change in material that would increase the EC of the project. The report also mentions the requirement for material quantities to be provided by the contractor:

> *'Obtain the total quantity of each material for each individual components from the same manufacturer.' (RIBAreport-St.3-Consultants).*

This information is important for enabling EC assessment to take place for the project. The professional leadership shown by the design team is enabled by the project's contract, giving the design team control over material choices moving from the design stage to construction.

Although during Stage 3 EC becomes much more visible than during the initial design stages, there is still more focus on addressing OC impacts. An example of this is that in the reports the material specification requirements that relate to OC reduction, such as U-values, and the thermal performance requirement of the building are quantified, and specific acceptable figures are given. For EC, the requirements mentioned in the Stage 3 report are mostly qualitative, focusing predominantly on responsible sourcing and the requirement for material certification.

As such, throughout the design stage, the outer norms that relate to Regulation and Sustainability rating system OC focus had a clear impact on the inner norm 'Sustainability approach' of the project and affected the project's Carbon approach to be more heavily addressing OC impacts. Although OC focus is evident, EC considerations and assessment did take place for this project, and the professional skills of the design team played an important role, both through material selection by the principal design team and EC assessment by the LCA consultants appointed. The professional knowledge of the team was enhanced by the project's 'Team appointments', which were in turn informed by the 'Client ambitions' to deliver a project that addresses carbon reduction holistically. Finally, the project 'Contract' enabled the design team professionals to take leadership during the end of the design stage and ensure that specification documents safeguarded the material choices made by the design team to carry on during the project construction. The analysis therefore shows that the conditions that directly affected the project's Carbon Approach/Assessment were the inner norm 'Sustainability Approach', interpretative schemes 'Professional Knowledge/Skills' and 'Professional leadership'. The indirect primary conditions that affected this outcome were interpretative scheme 'Client ambitions', inner norm 'Contract' and outer 'Regulation OC focus' and 'Sustainability Rating Systems'. The conditions that affected the Carbon Approach/Assessment outcome are presented in Table 6.18 and Figure 6.33.

Table 6.18 Case study 2 - The direct and indirect primary conditions that affected the Carbon approach/assessment outcome (Excerpt from Table 6.17).

	Direct Conditions		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
Carbon Approach/ Assessment	Sustainability Approach Professional knowledge/Skills Professional leadership	n/a	Client ambitions Contract	Regulation OC focus Sustainability Rating Systems

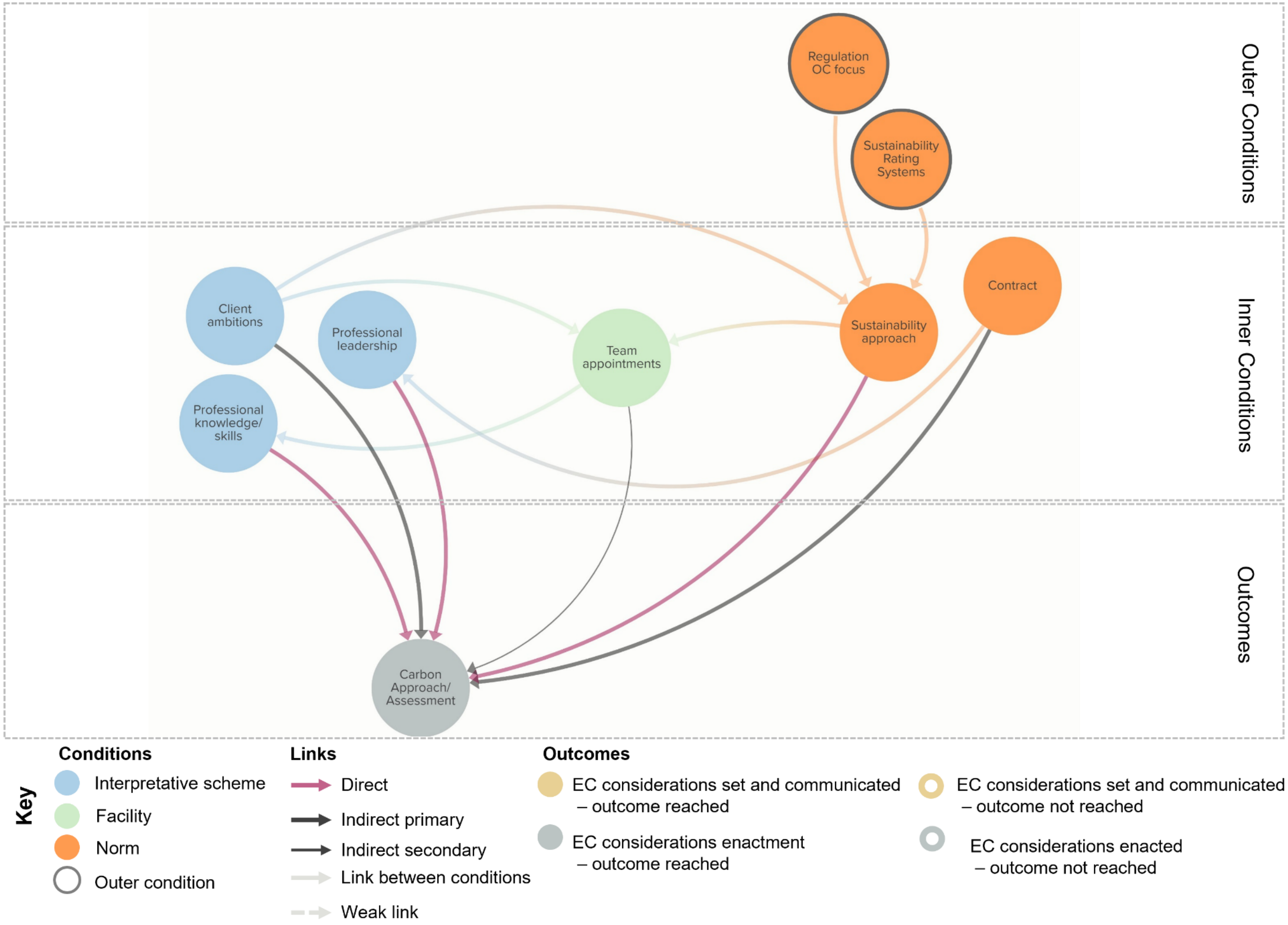

Figure 6.33 Case study 2 - The conditions that affected the Carbon Approach/ Assessment.

6.3.3.2.2 BIM model data input

The conditions that directly affected the project's BIM model data input were 'BIM approach', 'Scheduling', 'Team appointments' and the outer facility 'Complexity of BIM model data'. As a result of the strong BIM approach of the project, the scheduling of the project has accounted for the time required for checking the BIM models managed by each professional team and verifying the information that is embedded in the models (EIR). The strong BIM approach is also evident by the requirement mentioned in the BEP for accurate areas, volumes and dimensions in the BIM model:

> *'Where 2D detailing is overlaid on parts of the 3D model this should not hide inaccuracies that may exist within the model. Accurate areas, volumes and dimensions are expected and should not be compromised to gain a better 2D output.' (BEP).*

Accuracy of the BIM model is essential for using the BIM model for sustainability and energy assessment, therefore, highlighting this as requirement in the BEP shows the strong ambition of the project to use BIM to its full potential.

With regards to EC information in the BIM model, the architects mentioned the barrier of the complexity of model data input and suggested that it would be useful to have readily available EC data to input in the model:

> *'If information or data for EC is available to input in the BIM model that could help. For example, something like Uniclass that includes tables with data, something similar that you can choose from would be useful which would give data available to link into the model, intelligent data from some source.' (Int.3-ARCH).*

With regards to when EC information is added to the model, the architects mentioned that EC information was added to the model during Stage 4. Considering that EC assessment of the project started during stage 3, this could become a barrier in using the BIM model for EC assessment. However, as will be further explained in the BIM model use, the BIM model was used for the EC assessment of the project in conjunction with a spreadsheet that included information missing from the BIM model.

‘Team appointments’ was a key condition in achieving a data heavy and accurate BIM model. Each professional team within the project design team had their own BIM task team Manager to ensure that each team contributed to updating the BIM model with their respective profession information. The appointment of a BIM Information manager that acted as a BIM consultant for the project ensured the quality of the federated model. The BIM Information manager was responsible for monitoring the quality of information within each professional team BIM model and maintaining the federated BIM model throughout the design phase (BEP).

Both ‘Team appointments’ and the ‘BIM approach’ are conditions affected by the ‘Client ambitions’. As mentioned in the Conditions Analysis (section 6.3.2), the client aspired for the project to have a strong BIM approach which also informed the project’s team appointments to include a BIM Information Manager who would help lead the BIM application of the project. The BIM approach of the project was guided by the available industry-wide BIM standards, therefore the outer condition ‘BIM standards’ indirectly affected this outcome. The conditions that affected the BIM model data input outcome are presented in Table 6.19 and Figure 6.34.

Table 6.19 Case study 2 - The direct and indirect primary conditions that affected the BIM model data input outcome (Excerpt from Table 6.17).

	Direct Conditions		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
BIM model data input	Scheduling Team appointments BIM Approach	Complexity of BIM model data	Client ambitions	BIM Standards

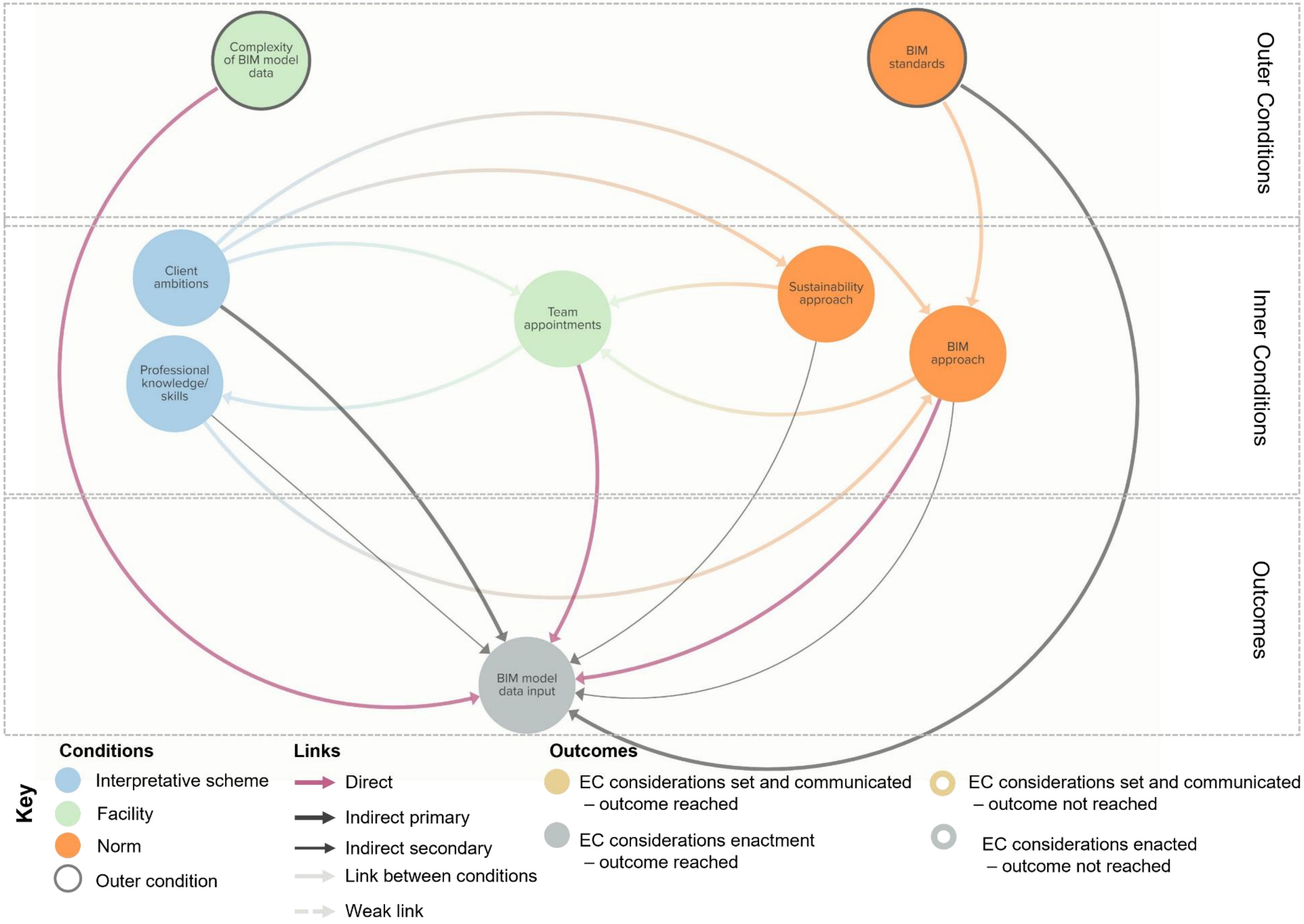

Figure 6.34 Case study 2 - The conditions that affected the BIM model data input.

6.3.3.2.3 BIM model use

The thorough use of the BIM model in this project was enabled by the knowledge and skills of the principal design team who recognised the strengths in using BIM throughout the design development:

> *'There is a big difference working in BIM. In terms of speed, it needs time to set it all up for BIM and the time spent is more in advance. But it is worth it because working with BIM gives a clear image of what happens and gives better control. There is more accuracy and level of detail. It is much better than just working on 2D drawings. You can also do multiple analyses on the same model. There is more work at the beginning to input into the model but it is then easier to extract information from the model' (Int.3-ARCH interview).*

Through their experience in using BIM, the architects acknowledge that although BIM requires more time and effort at the beginning of the design stage to input data in the model, BIM model use then enhances the design development and enables the use of the model for analyses. In this project, although the BIM model data input was enhanced and the BIM model was used for various analyses, the information in the model was not sufficient to use the BIM model directly for LCA. Further to this, the appointed LCA experts, who were responsible for the EC assessments, commonly used in-house developed spreadsheets without any input from the BIM model. The client, however, aspired a strong BIM approach where the BIM model would be used to its full potential. The client asked the LCA consultant and the BIM Information lead to collaborate and find a way to use BIM for EC assessment:

> *'My challenge to you [LCA consultant] is, how can we leverage the technology we have available to streamline our carbon assessment process? if you [LCA consultant] could partner with the team from [BIM Information Lead] to find a way to do this it will save a huge amount of pain for the wider team later down the line, and also give us far greater transparency. I am determined to make this work so let me know what I can do.' (Email-St.2-Client-LCAconsultant-BIMlead).*

The two consultant teams came up with a solution that used the BIM model to extract data for building elements, such as type, size material and quantities, to create a list of materials used in a spreadsheet. The list would then be passed to the

Contractor to fill in information of the material used for construction, such as sourced location, in the same spreadsheet. A final tab in the spreadsheet was created to amalgamate the data and highlight any missing information. This solution enabled the use of the BIM model, the update of material information from design to construction stage and the identification of missing information that would be required for the EC assessment. The BIM model in the case study was therefore used to extract information for the EC assessments, but no software application linked to the BIM model (ie. BIM plug-in) was used for the assessments.

The industry-wide available 'BIM standards' informed the project's 'BIM approach', which has been evident in the projects main BIM documents, the EIR and the BEP. However, the most important conditions that affected this outcome were 'Team appointments' and the 'Client ambitions'. Through the facility of 'Team appointments', the interpretative scheme 'Professional knowledge/skills' facilitated the use of the BIM model by the main design team for the project development. Through 'Team appointments', LCA and BIM consultants were added to the experts that joined the design team to give consultation on EC assessment and BIM application. The client's aspiration for a strong BIM approach drove the collaboration of the BIM and LCA experts to enhance BIM model use to extract information and facilitate EC assessment. The analysis therefore shows that the conditions that directly affected the project's BIM model use were 'Professional knowledge/skills', 'Team appointments' and 'BIM approach'. The indirect primary conditions that affect this outcome were inner interpretative scheme 'Client ambitions' and outer norm 'BIM Standards'. The conditions that affected the BIM model use outcome are presented in Table 6.20 and Figure 6.35.

Table 6.20 Case study 2 - The direct and indirect primary conditions that affected the BIM model use outcome (Excerpt from Table 6.17).

	Direct Conditions		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
BIM model use	Professional knowledge/ Skills Team appointments BIM Approach	n/a	Client ambitions	BIM Standards

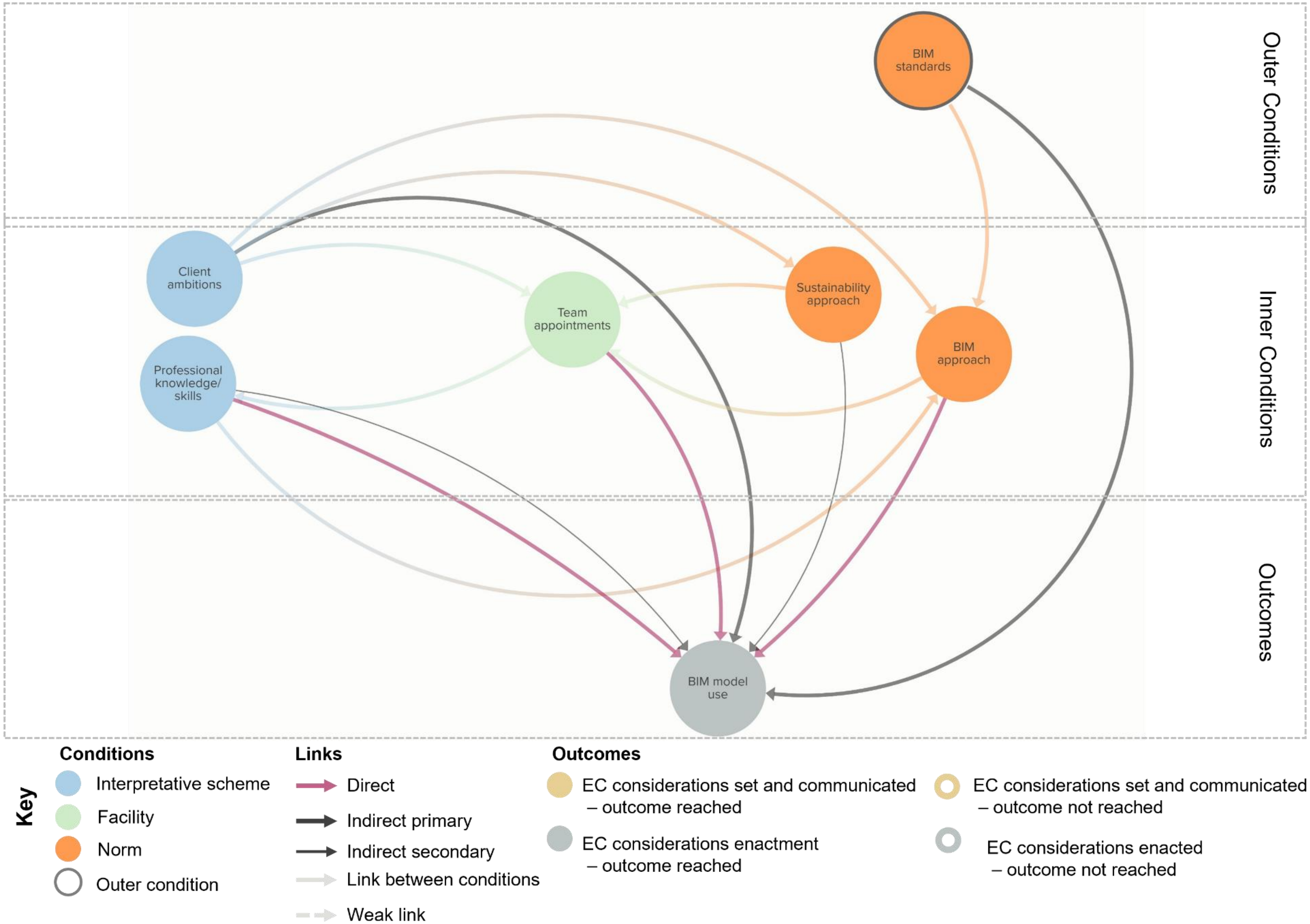

Figure 6.35 Case study 2 - The conditions that affected the BIM model use.

6.3.4 Conclusions

6.3.4.1 Conclusions from Conditions Analysis and Analysis of Strategic Conduct

The conditions that directly affected the project's outcomes were primarily inner facility 'Team appointments' (four out of six outcomes) and interpretative scheme 'Professional knowledge/skills' (three out of six outcomes). Together they affect all six project outcomes. Inner norms 'Sustainability approach' and 'BIM approach' and outer norms 'Regulation OC focus' and 'BIM standards' all affected two out of six project outcomes. The inner norms affected the outcomes that related to EC target, Carbon approach and the BIM model for the project, whereas the outer norms affected the outcomes that related to BIM information management documents, the EIR and the BEP. Three conditions ('Complexity of BIM model data', 'Scheduling' and 'Professional leadership') only affected one outcome that specifically related to them, for example, the Complexity of BIM model data' affected the BIM model data input. 'Client ambitions', 'Cost', 'Contract', 'Lack of EC benchmarks', and 'Sustainability rating systems' didn't affect directly the project outcomes. All direct conditions affecting the project outcomes are presented in Figure 6.36.

Figure 6.36 Case study 2 - Quantitative presentation of direct conditions affecting outcomes.

Through the Conditions Analysis, the indirect primary conditions affecting the outcomes were identified. From the identified indirect primary conditions, interpretative scheme ‘Client ambitions’ affected all six outcomes of the project. The only other inner indirect primary condition identified was ‘Contract’ which affected only one project outcome, the Carbon approach/assessment. All three outer norms indirectly affected two project outcomes each, the ‘Regulation OC focus’ and ‘Sustainability rating systems’ affected the two outcomes that relate directly to EC, the EC target and the Carbon approach/assessment. The ‘BIM standards’ norm affected the two outcomes that relate to the project’s BIM model. All indirect primary conditions affecting the project outcomes are presented in Figure 6.37.

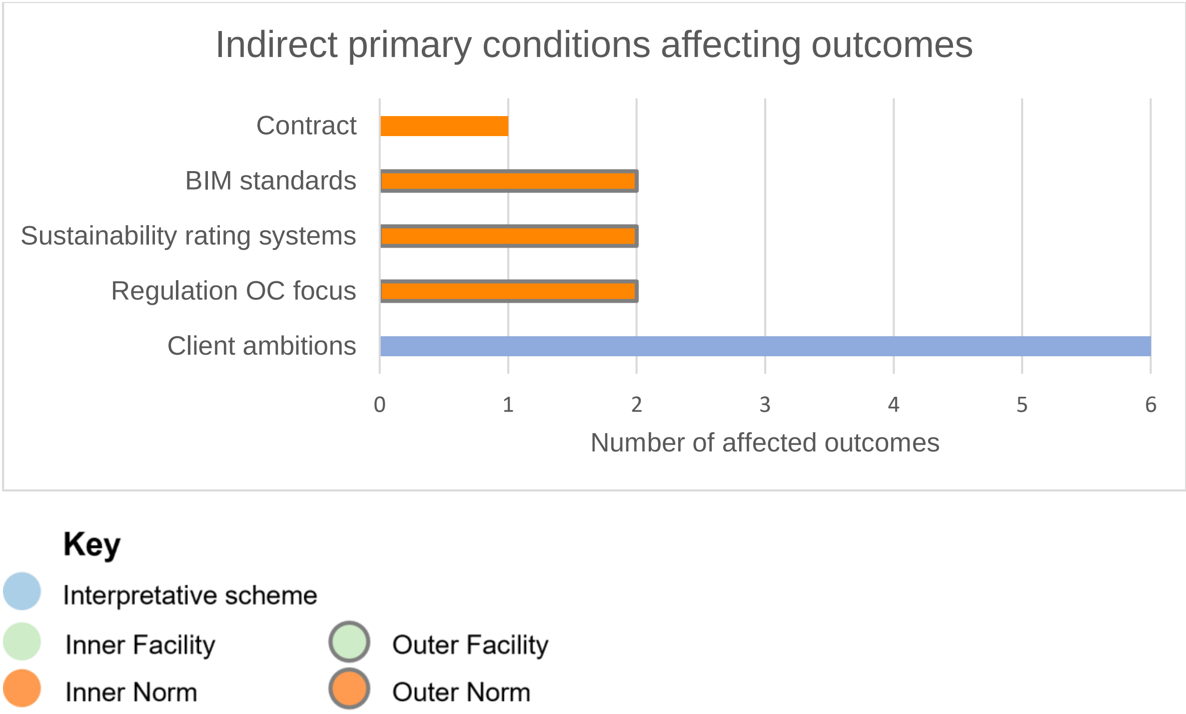

Figure 6.37 Case study 2 - Quantitative presentation of indirect primary conditions affecting outcomes.

6.3.4.2 Conditions, Mechanisms and Outcomes

Considering the conclusions of the conditions analysis and analysis of strategic conduct, it is evident that ‘Client ambitions’ were dominant in affecting the project outcomes. The client in this case study had high aspirations for the project’s sustainability and BIM application so ‘Client ambitions’ acted as an **enabling condition** for the inclusion of EC considerations and their communication through BIM. Due to the client ambitions, the sustainability approach of the project extended beyond what is required by industry wide regulations and sustainability rating systems and included EC reduction aspirations The lack of industry-wide EC benchmarks didn’t affect the establishment of a whole-building carbon target for the building. The client as an administrative power holder employed their power over the project inner norms and facilities to enhance the design team’s professional knowledge and establish **position-practice relations** that empowered the design team to actively contribute to how EC considerations were set and communicated. Through the appointment of BIM consultants who led the project’s information management, the client ensured that the EIR and BEP documents were created to set the information requirements and information exchange planning for the project. Considering the relationship of the project outcome to industry-wide institutionalised practice (see section 5.8.1.4), the contextual outcome shows transformation of the industry’s status quo. The direct and indirect primary conditions, mechanisms and outcomes that relate to this outcome category are summarised in Table 6.21.

Table 6.21 Case Study 2 - How EC considerations are set and communicated Conditions, Mechanisms and Outcomes.

Conditions	**Mechanisms**	**Outcome**	
Direct & Indirect Primary	**Position-practice Dialectic of control**	**EC considerations Set and communicated**	**Contextual**
Direct: Outer: BIM Standards and Regulation OC focus Inner: Professional Knowledge/Skills, Team appointments, Sustainability approach **Indirect Primary:** Regulation OC focus and Sustainability rating systems, Inner: Client ambitions	**Position practice relations:** Client legitimising inner norms of sustainability and BIM approach. Design team expertise used to contribute to inner norms. Enhanced position-practice relation between client and design team.	EC target set and EC information communicated through BIM although still EC less mentioned compared to OC.	Transforms status quo.

Team appointments as a project facility was crucial in this case study as it **enabled** the enhancement of the design team knowledge and skills to deliver the strong sustainability and BIM approach ambitions of the client. The interpretative scheme ‘Professional knowledge/skills’ was expanded through the appointment of LCA and BIM consultants. The appointment of the BIM consultant resulted a strong BIM approach for the project with enhanced collaboration amongst the design team and a data rich BIM model. The appointment of the LCA consultants enabled LCA assessment to take place for the project and their collaboration with the BIM consultants resulted in the use of the BIM model for the facilitation of LCA assessment. The outer facility ‘Complexity of BIM model data’ affected the project’s BIM model data input resulting in lack of some data required for EC assessment within the BIM model. This, however, didn’t hinder the use of the BIM model, which was used to extract information for EC assessment and the missing information was overcome through the use of spreadsheets where the missing data could be added. This solution was enabled through the collaboration of the BIM and LCA consultants of the project. The appointment of experts to facilitate the principal design team in addressing EC considerations through the use of BIM creates new **position-practice relations** amongst the design team, where new roles are introduced for addressing EC considerations through the use of BIM. Although the team appointments and inner project norms were mainly controlled by the client, the professionals of the design team didn't appear as sub-ordinate agents in the case study. They had high **dialectic of control** over affecting the project outcome that relates to how EC considerations were addressed. This was particularly evident in the specification of materials at the end of the design stage where the design team took leadership to ensure material choices made during the design stage would carry on during construction. Considering the duality of structure perspective and how the outcome category 'How EC considerations are addressed' relates to industry-wide practices (see section 5.8.1.4), the contextual outcome shows enhancement of the industry's status quo. The direct and indirect primary conditions, mechanisms and outcomes that relate to this outcome category are summarised in Table 6.22.

Table 6.22 Case Study 2 - How EC considerations are addressed: Conditions, Mechanisms and Outcomes.

Conditions	Mechanisms	Outcome	
Direct & Indirect Primary	**Position-practice Dialectic of control**	**EC consideration address**	**Contextual**
Direct: Outer facilities Complexity of BIM model data, Secondary data reliability Inner: All norms, Scheduling and Professional knowledge/skills **Indirect Primary:** All outer norms, inner Client ambitions and Cost	**Position practice relations:** Team appointments introduced expert roles to the team which resulted in enhanced coordination and collaboration. **Dialectic of Control:** High for the design team	BIM model use for building element data extraction but not for LCA assessment.	Enhances status quo.

6.4 Case Study 3

This section presents the analysis of the third case study using the Explanatory phase analytical framework. Firstly, a description of the case study is presented. The analysis then follows the same structure as Case Study 1 and 2, presenting the Conditions analysis, Analysis of Strategic Conduct and then leading to the Conditions, Mechanisms and Outcomes.

6.4.1 Case Description

This case study considers the design stage of a residential development project in South Wales classified as C according to the Town and Country Planning (Use Classes) Order 1987. The project includes 144 homes out of which two thirds are affordable, which includes intermediate rent, low-cost home ownership and social rental housing and one third is market housing. Table 6.23 summarises basic information about the case study, such as the use the location and size of the project. The client is a housing development company with an ambition to create positive change in the delivery of housing, part of which includes reduction of carbon emissions for their projects. As part of the client brief, the project had high sustainability aspirations which included a requirement for all homes designed as part of the development to meet an EPC[15] 'A' rating and SAP[16] score of 96 or above, local material use, and a low energy and sustainable fabric first design approach. The project is part funded by the Welsh Government's Innovative Housing Programme (IHP), according to which, successful projects would have to demonstrate innovation in at least one of but no more than three of the seven goals of the Well-being of Future Generations (Wales) Act (WFGA). The project focused on three innovation areas: Place, Energy and CO_2. The project follows a Design and Build single stage procurement route according to which, the initial design team led the design until the start of RIBA Stage 4 and leadership passed to the appointed contractor during RIBA Stage 4. The architect team that was involved in the initial design was novated to the contractor side in Stage 4. With regards to BIM application, the project can be considered as BIM Level 1 as BIM was only used as a

[15] Energy performance certificate (EPC) is a review of a property's energy efficiency. EPC gives a property an energy efficiency rating from A (most efficient) to G (least efficient).
[16] The Standard Assessment Procedure (SAP) is the methodology used by the government to assess and compare the energy and environmental performance of dwellings. SAP scores range from it 1 to 100+ (100 representing zero energy cost and anything over indicates energy export).

software tool for three-dimensional project design by the architectural team and not a collaborative method for sharing project information.

Table 6.23 Case Study 3 basic information.

Case Study	Building use/ Use Class*	Location	Size
	Residential/ C	South Wales	144 homes in 6.2 hectares

The project's high sustainability aspirations were also reflected in the team appointments of the project. The selection of the principal design team was made according to their sustainability credentials and their ability to respond to the client's brief and secure the Welsh Government IHP funding. Information about the type and size of main project stakeholders, which are the client, and the principal design team is included in Table 6.24. The design team sustainability expertise and the client's sustainability aspirations are also included in the table. This information was gathered from the respective companies' website information and the projects that they have delivered. Depending on whether sustainability was core to their practice, sustainability expertise was ranked as low/ medium and high. The rankings were colour-coded red (low), amber (medium) and green (high) respectively.

Table 6.24 Case Study 3 main stakeholder information.

	Client	**Architect**	**MEP Engineers**	**Structural Engineers**	**Quantity Surveyor**
Type/ size	Private, housing developer	Nine studios in UK and one internationally	Fifteen offices in UK and one international office.	Global company with offices in 40 countries	Global consultancy with offices in 55 countries
Sustainability Expertise/ Aspirations (for client)	Environmental Sustainability Strategy for their projects	Sustainable design stated as principle and projects include sustainability.	Consultancy offers assessment on various environmental design and sustainability aspects.	Sustainable design stated as principle and projects include sustainability	Sustainability stated as part of the Property & Asset Management Services offered.

The data collection for the CS is presented in detail in section 3.3.6.1. Within the following sections, reference to empirical data is made using the same coding structure presented for CS2 (section 6.3.1).

6.4.2 Conditions Analysis

This section considers the industry level (outer) and project level (inner) conditions of the project and how they influenced each other. Figure 6.38 presents all conditions relevant to the project and the links that show their relationships. As mentioned in the introduction of this chapter, outer conditions are categorised as Facilities and Norms, and inner conditions are categorised as Interpretative Schemes, Facilities and Norms. For this case study, outer facility ‘Government financial initiative’ and outer norm ‘Sustainability reports and guidance’ were added to the outer conditions considered as they had an impact on the project’s inner conditions and outcomes.

All outer conditions apart from the ‘Government financial initiative’ and the ‘Regulation OC focus’ didn’t affect other conditions. By performing an outdegree analysis, the ‘Government financial initiative’ was identified as the condition that affected the most other conditions (4), namely, the interpretative scheme ‘Client ambitions’, the inner facility ‘Cost’ and the inner norms ‘Sustainability approach’ and ‘Contract’.

> *‘The funding was really what was driving the picture, the project just couldn’t have happened without the funding. The client was a knowledgeable client, kind of a responsible client in a sense that they wanted to do the best they could’ (Int-ARCH).*

Inner facility ‘Cost’ was influenced by the government funding as the project was part-funded through the government initiative. As this was essential for the project development, securing the government funding affected the client ambitions. As part of the requirements to secure the government funding, the project had to demonstrate high sustainability standards as well as demonstrate innovation in up to three goals out of which two were CO_2 and energy. As such, the ‘Government financial initiative’ also had an impact on the project’s ‘Sustainability approach’. The inner norm ‘Contract’ was also affected by the ‘Government financial initiative’ to include clauses that would secure the consistency between product specification during the design stage and procurement during the construction stage. More detail on the clauses included in the contract are discussed in the Carbon Approach/ Assessment section.

By performing an indegree analysis, the ‘Sustainability approach’ was identified as the condition that was mostly affected by other conditions. As mentioned above, the ‘Sustainability approach’ was affected mainly by the ‘Government financial initiative’ and the ‘Client ambitions’ and as mentioned in the project report, it was also affected by the ‘Regulation OC focus’:

> *‘The reduction of operational energy use is still very much the priority’ (Report-EC).*

This shows that the ‘Regulation OC focus’ still makes the client and the design team prioritise operational energy use and its associated carbon emissions. However, the project focused on CO_2 as one of the three innovation areas for the funding application, this ensured that the project’s sustainability approach expanded further than the regulation requirements to include EC considerations.

The ‘Sustainability approach’ in turn influenced the projects inner facilities ‘Team appointments’ and ‘Scheduling’. ‘Team appointments’ were made so that the required professional knowledge and skills were available to respond to the sustainability approach. With regards to the EC considerations, no expert consultants were appointed to undertake the life-cycle assessments (LCA) for the project. The architect practice included this as part of their service. At the time of their appointment, the practice didn’t have inhouse LCA expertise but saw this project as an opportunity to expand their knowledge and service to include this. The project was considered as a research project for the practice and as such, no additional fee was charged to undertake the assessments. The ‘Sustainability approach’ also affected the inner facility ‘Scheduling’ by allowing time for the assessments to be undertaken. As the architectural practice had no prior experience in performing LCA they had no indication of how long the assessments would take, as such, specific timescales were not included in the project scheduling. However, the project schedule allowed for flexibility in order for the assessments to take place. More detail on lessons learnt with regards to time required for the assessments is included in the Carbon Approach/ Assessment section.

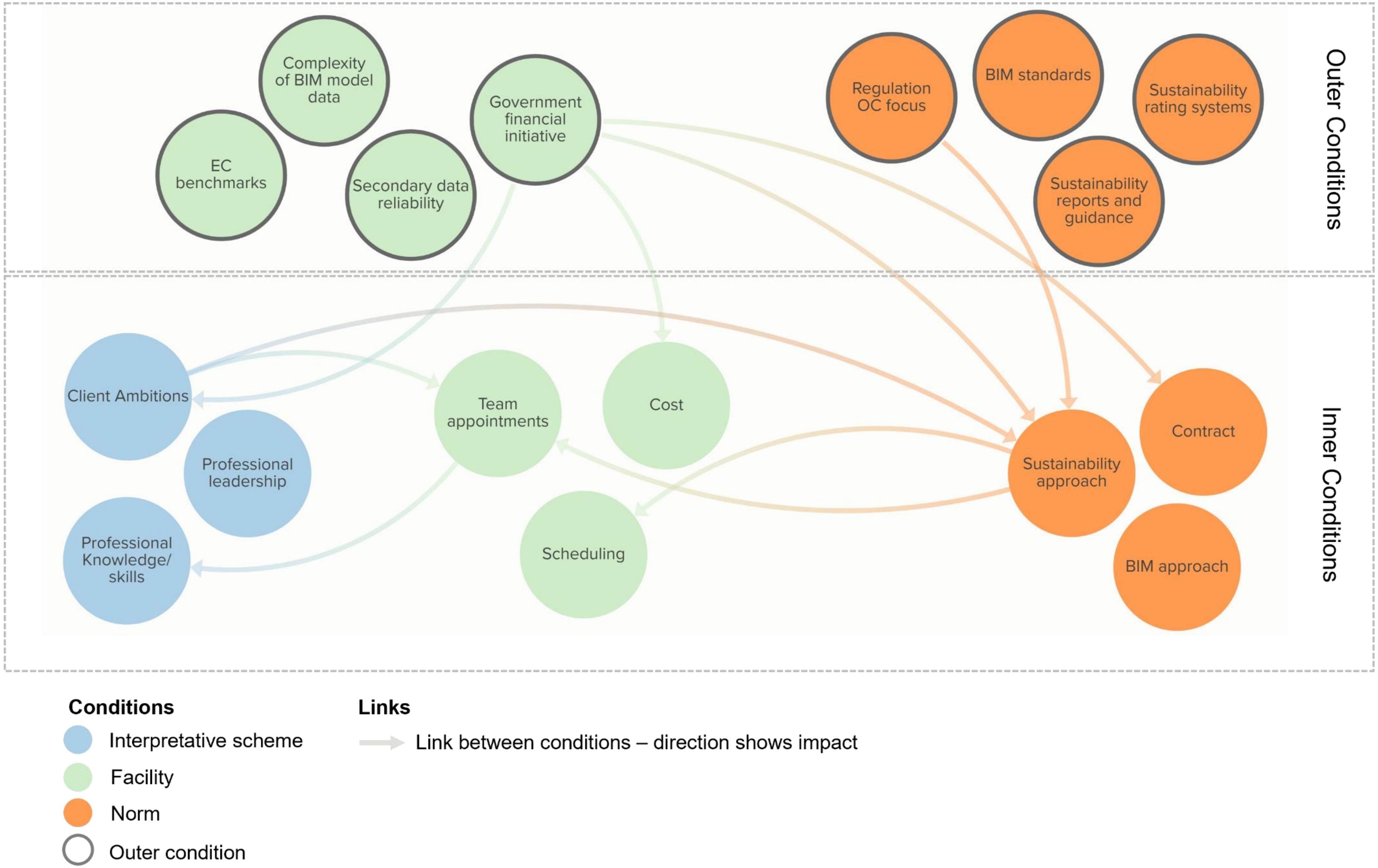

Figure 6.38 Case study 3 - Conditions and their relationships.

6.4.3 Analysis of Strategic Conduct

The analysis of Strategic conduct aims to understand how the conditions presented and analysed in section 6.4.2 affected the project outcomes. The project outcomes consider EC considerations and BIM application and are organised in two categories: ‘How EC considerations are set and communicated’, and ‘How EC considerations are addressed’. In both categories, the application of BIM as an information management process and as a software is considered. Firstly, conditions that directly affected outcomes are identified and presented with red arrows in the diagrams. Through consideration of the condition analysis presented in section 6.4.2, the indirect conditions that affected the project outcomes a deeper understanding is achieved. The indirect conditions are divided into primary if they are not impacted by any other condition and secondary if they are affected by other conditions. Indirect conditions are presented in with grey arrows in the diagrams and the thickness of the arrows represents the two categories.

Figure 6.39 and Figure 6.40 present the direct and indirect conditions respectively of all project outcomes. In the following sections, the two outcome categories are analysed in more detail and the project outcomes within each category are discussed and presented in separate diagrams for more clarity.

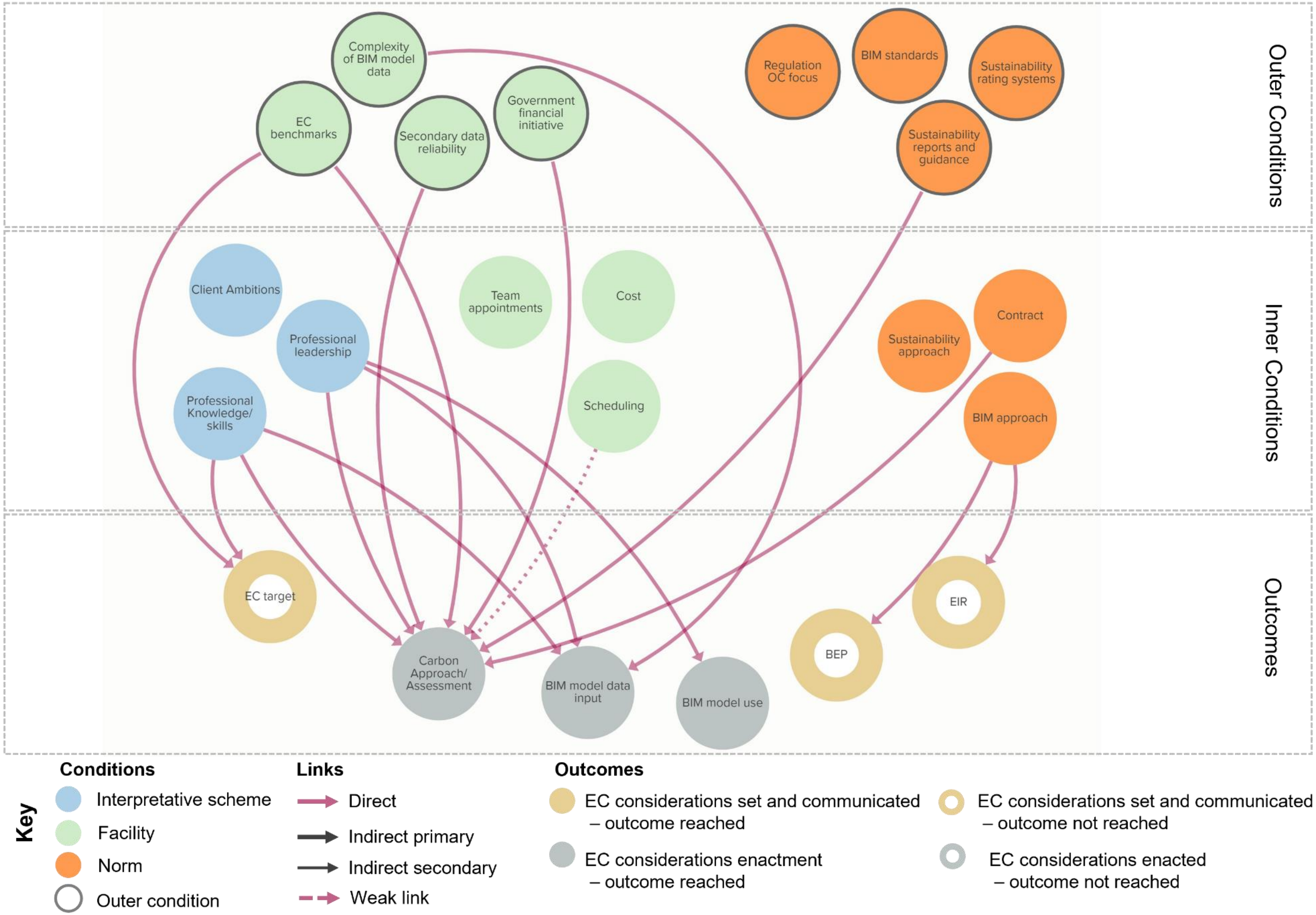

Figure 6.39 Case study 3 - All outcomes and the direct conditions affecting them.

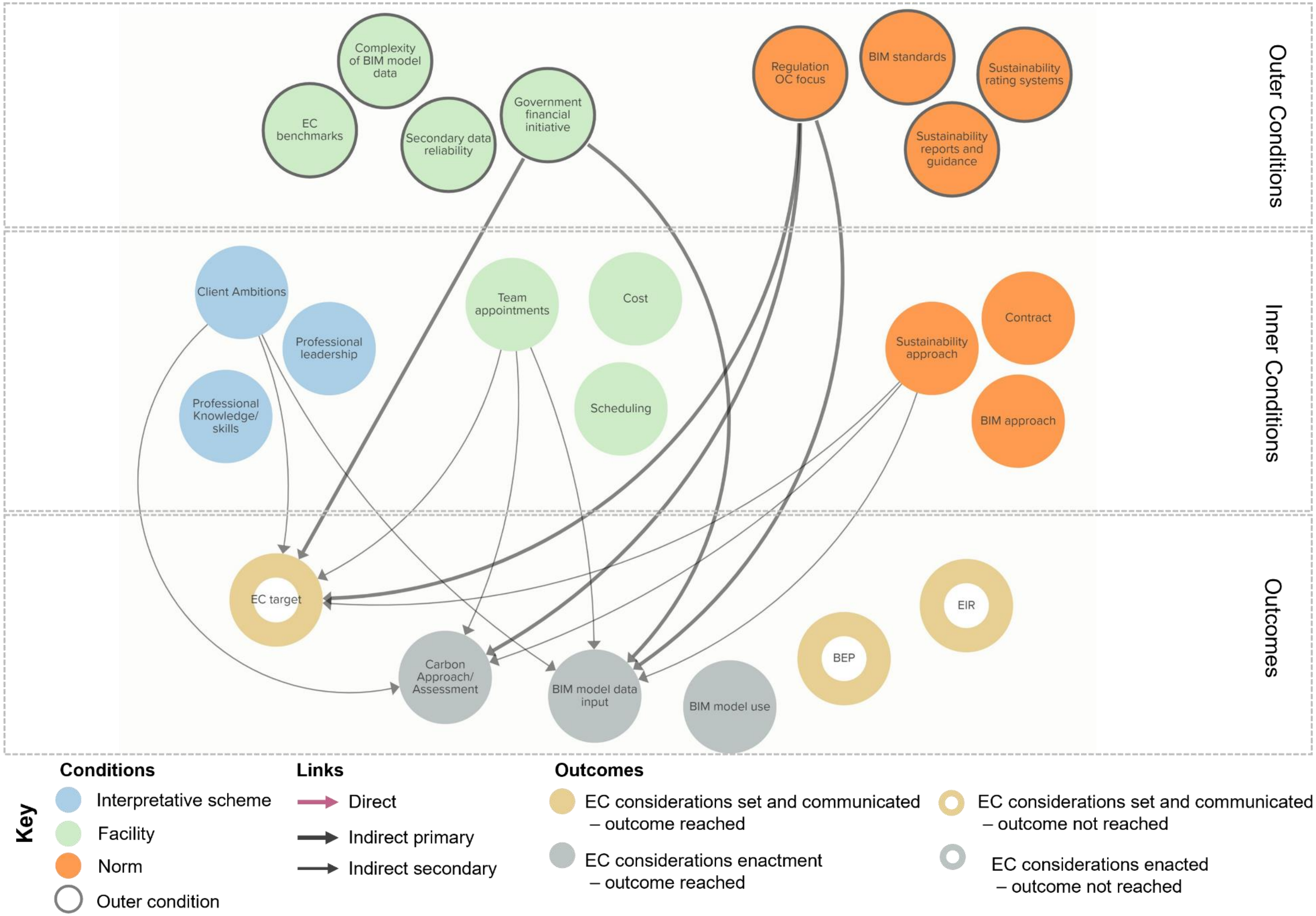

Figure 6.40 Case study 3 - All outcomes and the indirect conditions affecting them.

6.4.3.1 How EC considerations are set and communicated

The outcomes that relate to how EC considerations are set and communicated are the project's 'EC target', 'EIR' and 'BEP'. The direct and indirect inner and outer conditions that affected these outcomes are presented in Figure 6.41 and Figure 6.42 respectively and summarised in Table 6.25. Outcomes in this category are directly affected by inner norm of 'BIM approach', and the interpretative scheme 'Professional knowledge/skills'. Outer conditions that affect them are the 'EC benchmarks'.

Through the conditions analysis presented in section 6.4.2, the relationships of conditions are considered and the indirect conditions that affect these outcomes are identified. The indirect primary conditions that affected outcomes that relate to how EC considerations are set and communicated are 'Regulation OC focus' and 'Government financial initiative', none of which are outer conditions. No inner primary conditions were identified for this outcome category.

Table 6.25 Case study 3 - The direct and indirect primary conditions that affected how EC considerations are set and communicated.

	Direct Conditions		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
EC Target	Professional knowledge/skills	EC Benchmarks	n/a	Regulation OC focus Government financial initiative
EIR	BIM approach	n/a	n/a	n/a
BEP	BIM approach	n/a	n/a	n/a

Further elaboration on the way direct and indirect conditions affected how EC considerations are set and communicated are presented for each outcome of this outcome category below.

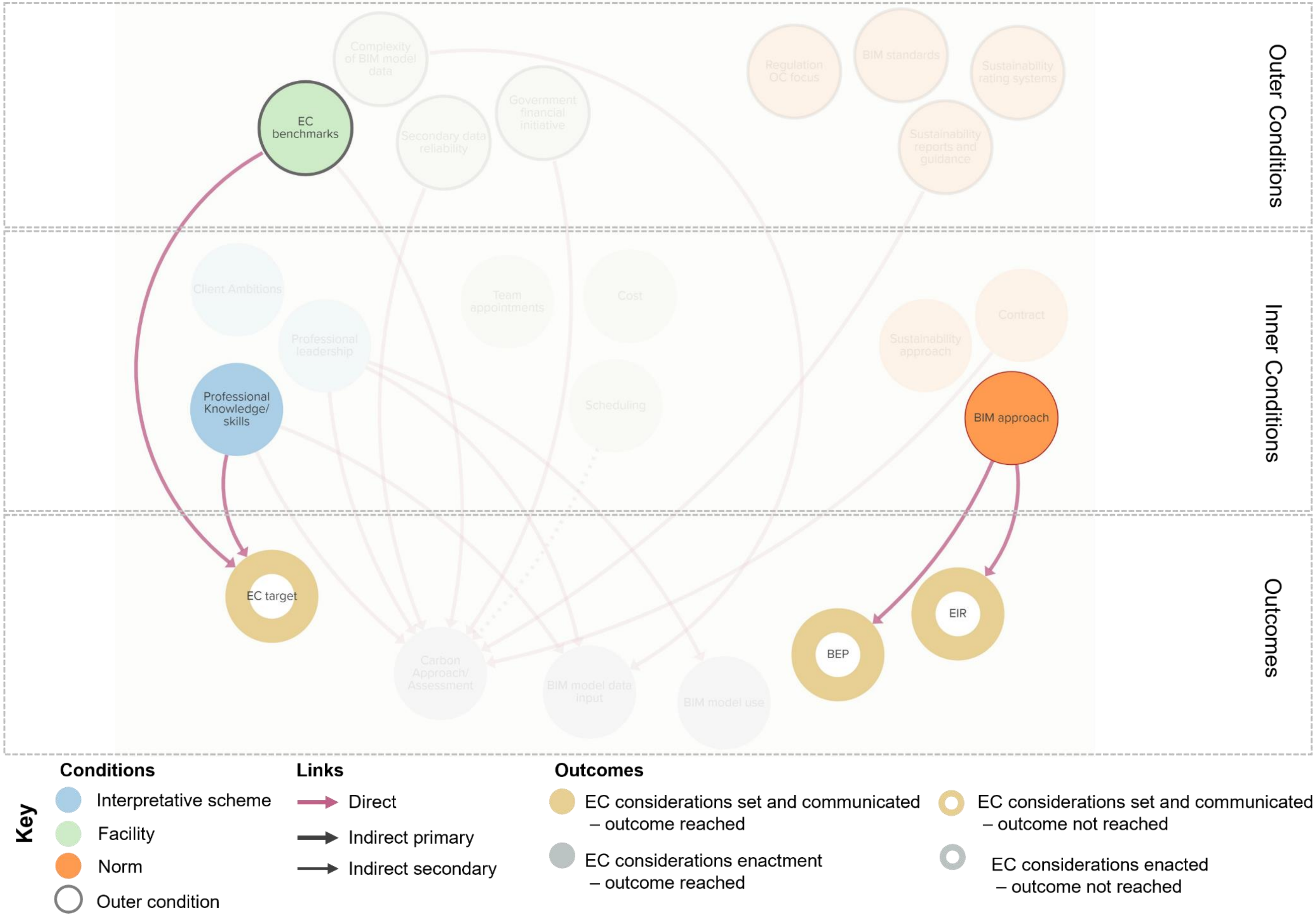

Figure 6.41 Case study 3 - How EC considerations are set and communicated outcomes and the direct conditions affecting them.

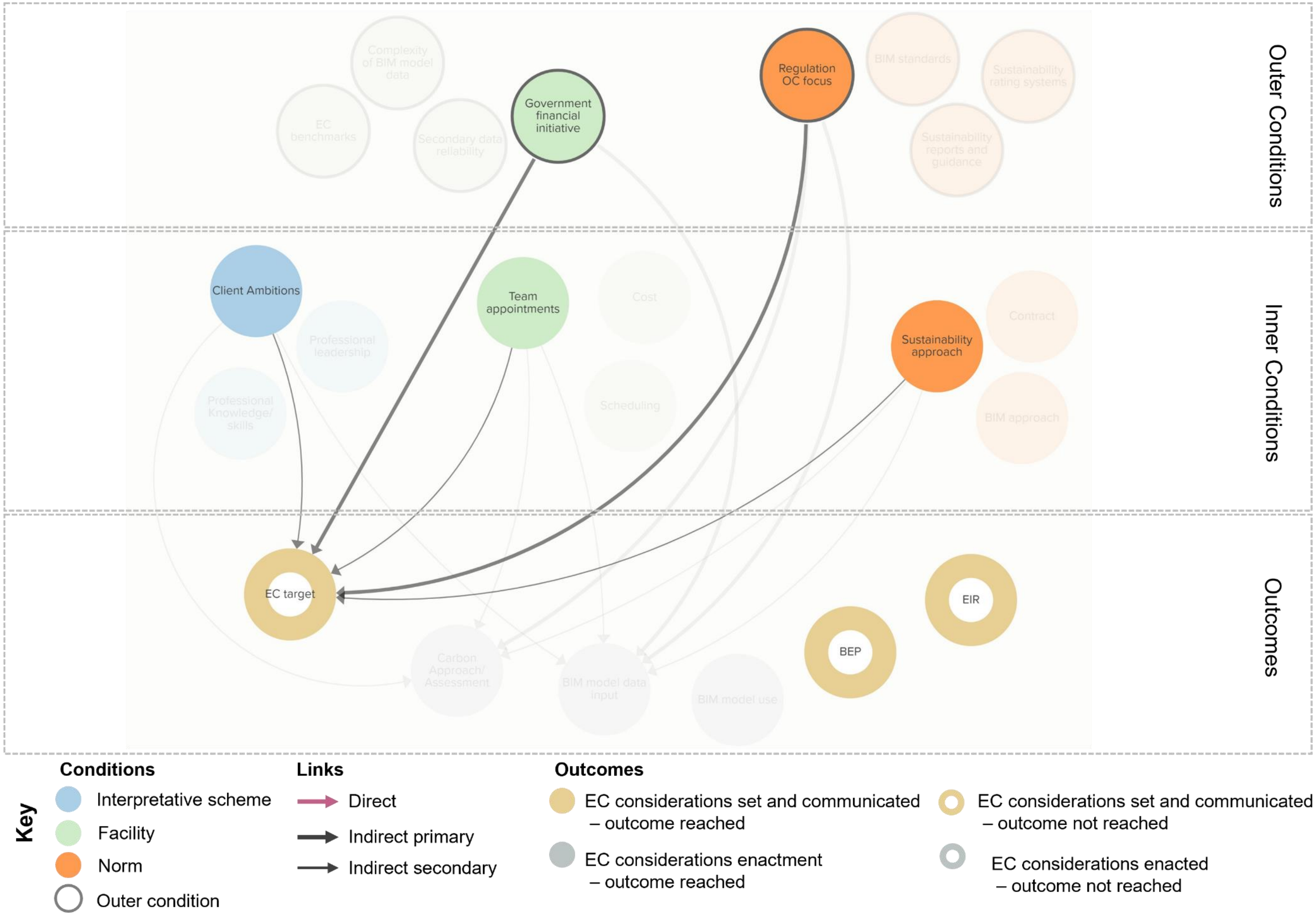

Figure 6.42 Case study 3 - How EC considerations are set and communicated outcomes and the indirect conditions affecting them.

6.4.3.1.1 Embodied Carbon Target

Although the client had high sustainability aspirations for the project, EC considerations were not initially within the client's ambitions as the sustainability approach of the project mainly focused on operational energy performance which was influenced by the industry's regulation focus. However, EC consideration and assessment was presented by the lead architect as a way to secure the Government Innovation Housing Programme funding:

> *'We had a client who had a very strong desire to achieve high performing homes but the focus was very much on operational energy performance. I suggested that, ok, operational energy is great but at the time climate emergency declaring had just started and there was an article in an architectural journal that I remember reading about embodied carbon and I thought, ok, we got a chance here, if we are bidding for this funding let's look at whole life carbon.' (Int.-ARCH)*

Although EC considerations were included within the project design, a specific EC target was not set for the project at either building or element level. One of the factors that contributed to this was the lack of EC benchmarks during the time that the project targets were being set, in RIBA Stage 1. EC benchmarks however did become available at the stage when the life-cycle assessments took place at the end of 2019/ beginning of 2020. This included the UKGBC Net Zero Carbon Buildings: A Framework Definition and the RIBA Sustainable Outcomes Guide in 2019, and the LETI Climate Emergency Design Guide in January 2020 (RIBA 2019b; UKGBC 2019; LETI 2020a).

> *'There wasn't a target set for the project, we think we have done the best thing intuitively, lets now measure it to see how it performs and compare it to the benchmarks which were out there at the time. For us it was like: Are these benchmarks achievable? We weren't setting out to meet a target, it was not a requirement for the project, it was more a case of let's see how we do compared to these benchmarks. It didn't matter if we didn't meet it, but it helped us understand where are we? How are we performing?' (Int.-ARCH)*

The benchmarks that became available were used to compare the LCA results of the project against them to create an understanding of how well the project performed in relation to its life-cycle carbon emissions. This comparison also enabled a critical assessment of the benchmarks by the architectural practice in relation to the benchmarks' achievability. As mentioned in the project's embodied emissions assessment report:

> *'Homes at [the project] are low rise and light weight, clearly these targets will prove a challenge to meet when considering the constraints of mid to high rise homes.' (Report-EC).*

Another factor that contributed to the lack of an EC target for the project was the lack of confidence by the architect team who drove the EC inclusion to the project:

> *'One of the reasons why we didn't charge for it (EC assessment) is we didn't know where it was going to go, we didn't know if we were going to drop it, or whether it was going to work, it was the first time we trialled it, so we didn't charge the client at all, it was like an internal research project for us really' (Int.-ARCH)*

Although this statement relates to the lack of a fee charged for the LCA by the architectural practice, it also shows the lack in confidence by the architect team in performing these assessments. Although the architectural practice had the professional knowledge and skills to specify materials and products with reduced embodied carbon impacts, they had only done this in an intuitive way, without quantifying EC impacts through life-cycle assessment. This lack of expertise together with the lack of EC benchmarks at the start of the project made them reluctant to set a target for EC. However, this project was viewed as an opportunity to build in-house expertise in LCA and a way to understand EC impacts quantitatively:

> *'Up until now we have had to rely on intuition and limited information in order to specify materials, processes and products which we believe to be inherently low in embodied energy and carbon. As a result we have found it increasingly frustrating that we are not able to rely on a similar standard of assessment in order to ascertain the most appropriate options for each given project. We wish to find a way of generating an understanding of embodied energy figures in the same way that we currently do for operational energy data.' (Report-EC)*

From the above, it can be seen that the direct conditions that affected the EC Target outcome are the outer facility ‘EC benchmarks’ and the architects’ ‘Professional knowledge/skills’, both of which created a barrier in setting a specific EC target for the project. The outer condition ‘Government financial initiative’ however which influenced the project’s ‘Sustainability approach’ and ‘Client ambitions’ drove the inclusion of EC considerations for the project despite the ‘Regulation OC focus’. The conditions that affected the EC target outcome are presented in Table 6.26 and Figure 6.43.

Table 6.26 Case study 3 - The direct and indirect primary conditions that affected the EC target outcome (Excerpt from Table 6.25).

	Direct Conditions		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
EC Target	Professional knowledge/skills	EC Benchmarks	n/a	Regulation OC focus Government financial initiative

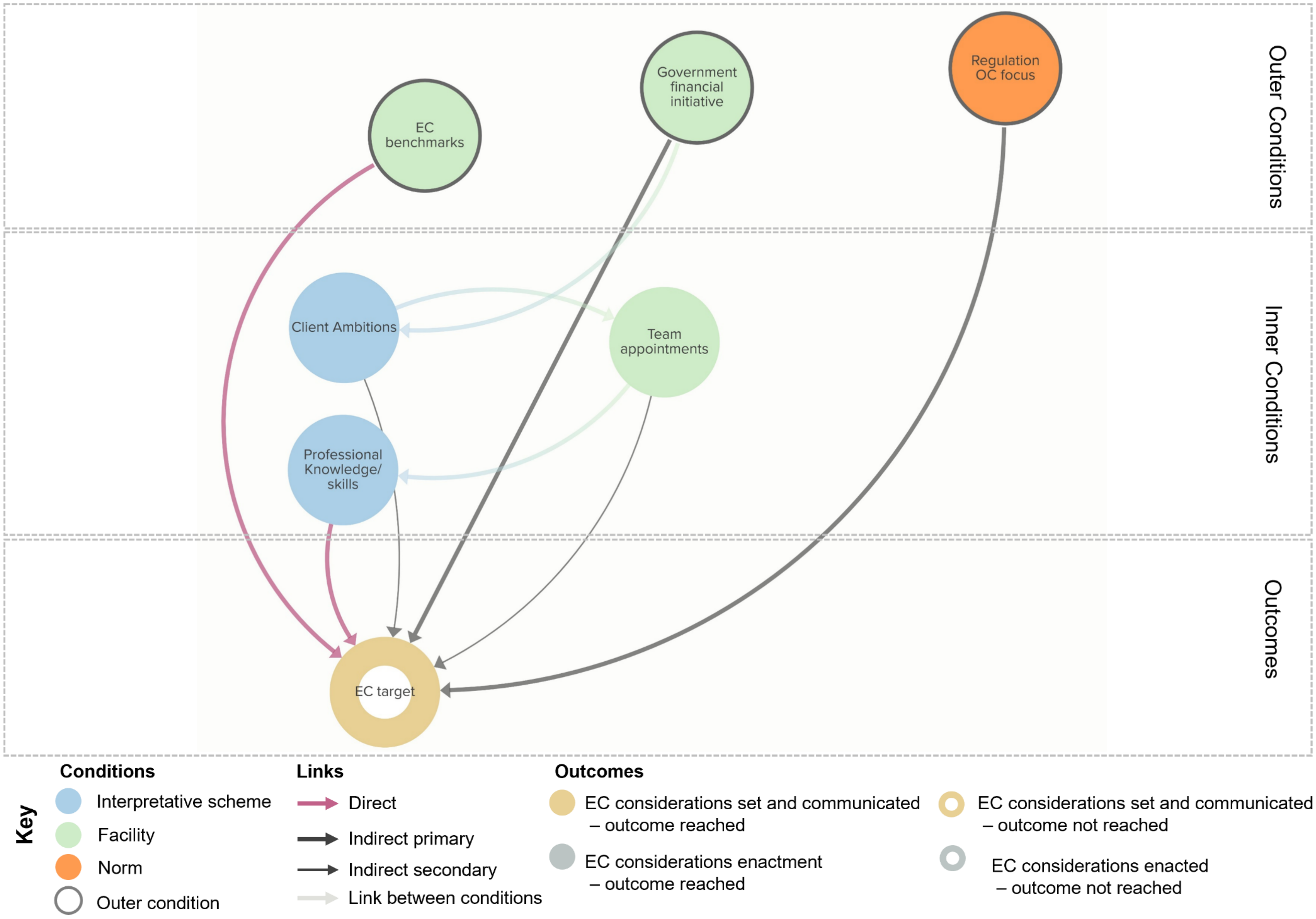

Figure 6.43 Case study 3 - The conditions that affected the EC target.

6.4.3.1.2 Employers Information Requirements (EIR) and BIM Execution Plan (BEP)

As the project was at BIM level 1, the BIM approach of the project did not request for BIM to be used in a collaborative way for information management. According to the project architect (Int.-ARCH), this is common for residential projects:

> *'For whatever reason in residential it (BIM) is not embraced, they tend to use BIM in a lonely sense, in some cases the structural engineer will also be modelling in BIM, and we collaborate where we can or an MEP consultant but typically it's just only us (ARCH). But it would help if everyone used BIM in terms of assessments. (Int.-ARCH)*

No information requirements or information management was made in advance for the project and the information exchanges all took place post tender during Stage 4b. As such, documents such as an EIR and a BEP were not produced for the project. The direct and only condition that affected this outcome was the project's inner norm 'BIM approach' which, as mentioned above, followed a BIM level 1 approach which is common for residential projects. Although it is not within the scope of this research to investigate BIM use for different building uses/ typologies, this is an interesting finding and further research could explore how and why BIM application changes for different building typology design within the sector. The conditions that affected the EIR and BEP outcomes are presented in Table 6.27 and Figure 6.44.

Table 6.27 Case study 3 - The direct and indirect primary conditions that affected the EIR outcome (Excerpt from Table 6.25).

Outcome	**Direct Conditions**		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
EIR	BIM approach	n/a	n/a	n/a
BEP	BIM approach	n/a	n/a	n/a

Figure 6.44 Case study 3 - The conditions that affected the EIR and BEP.

6.4.3.2 How EC considerations are addressed

The outcomes that relate to addressing EC considerations are the project's 'Carbon Approach/Assessment', 'BIM model data input' and 'BIM model use'. The direct and indirect inner and outer conditions that affected these outcomes are presented in Figure 6.45 and Figure 6.46 and summarised in Table 6.28.

The outcomes that relate to how EC considerations are addressed were directly affected by the project's inner norm 'Contract', inner facility 'Scheduling' and interpretative schemes 'Professional knowledge/skills' and 'Professional leadership'. All outer facilities: 'EC Benchmarks', 'Secondary data reliability', Government financial initiative' and 'Complexity of BIM model data' affected this outcome category. The only outer norm that directly affected these outcomes was 'Sustainability reports and guidance, whereas the outer norm 'Regulation OC focus' only had an indirect impact.

Table 6.28 Case study 3 - The direct and indirect primary conditions that affected how EC considerations are addressed.

	Direct Conditions		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
Carbon Approach/ Assessment	Professional knowledge/ skills Professional leadership Contract Scheduling	EC Benchmarks Secondary data reliability Government financial initiative Sustainability reports and guidance	n/a	Government financial initiative Regulation OC focus
BIM model data input	Professional knowledge/ skills Professional leadership	Complexity of BIM model data	n/a	Government financial initiative Regulation OC focus
BIM model use	Professional leadership	n/a	n/a	n/a

Further elaboration on the way direct and indirect conditions affected how EC considerations are addressed are presented for each outcome of this outcome category below.

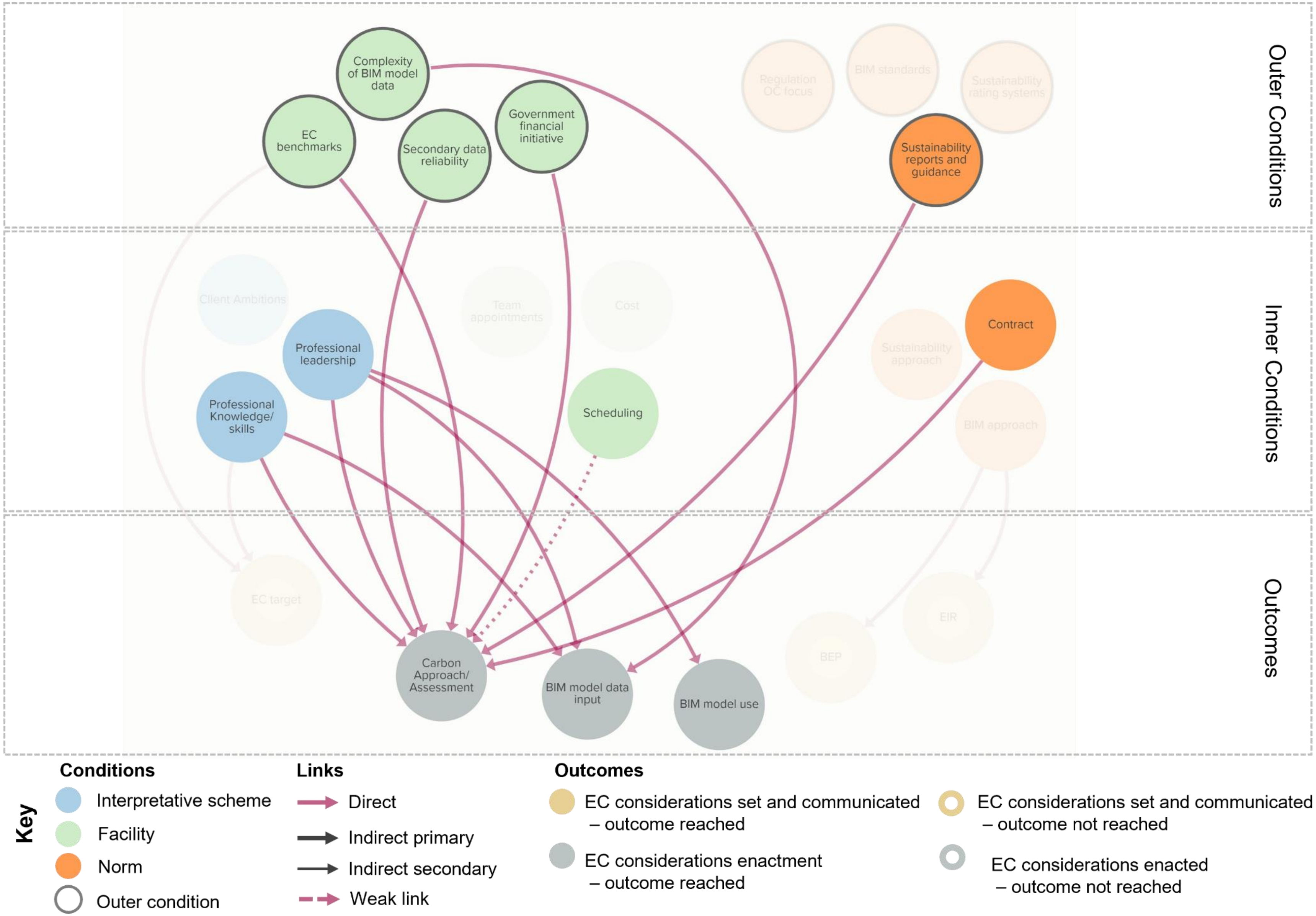

Figure 6.45 Case study 3 - How EC considerations are addressed outcomes and the direct conditions affecting them.

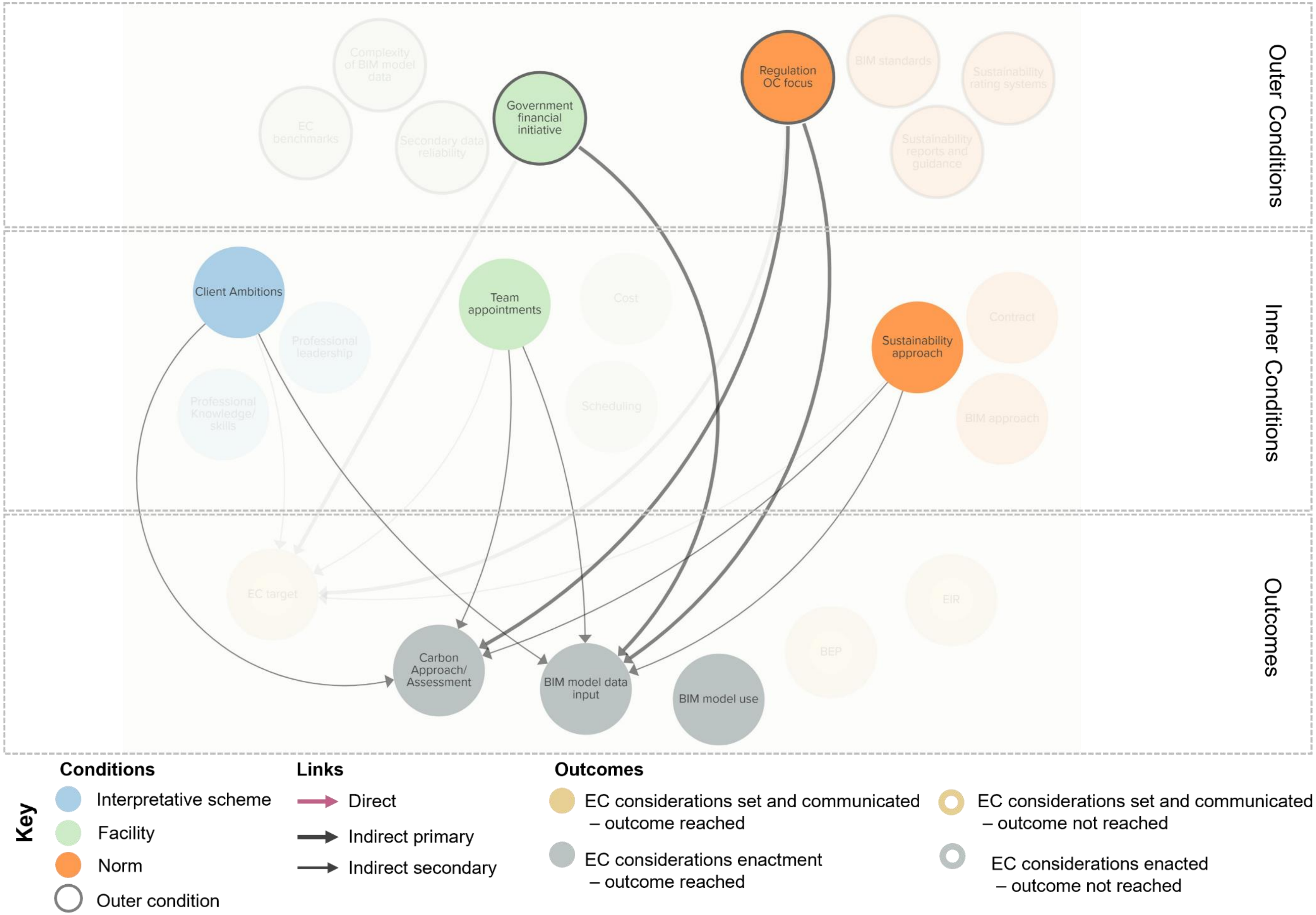

Figure 6.46 Case study 3 - How EC considerations are addressed outcomes and the indirect conditions affecting them.

6.4.3.2.1 Carbon Approach/ Assessment

Although there was no specific EC target set for the project, EC assessment was included as part of the project's carbon reduction efforts. This was initiated by the lead architect of the project as part of a personal driver to address this aspect of carbon during a time when climate emergency was being declared across the UK:

> *'I've always been interested in sustainable design practice; at that time, we were in 2019, climate emergencies were being declared and I attended one of those protests with my daughter so for me there was kind of a personal thing, like, I am an architect, I work in an industry which is responsible for at least 40% of emissions, it has a massive impact, so there is kind of a personal responsibility that I felt. And the second part for me was, the fact of quantifying things, sort of, yes, we do have an intuition in terms of if we build out of timber and pick certain materials some are going to be better than the other, but how much better? And how are we making a difference? Is that difference enough? How can we do better? How can we measure and then learn from things?' (Int.-ARCH).*

This sense of personal responsibility and the need to quantitatively understand embodied carbon impacts expressed by the project lead architect shows professional leadership in addressing carbon reductions in a holistic and informed way. To get the client to agree to expanding the project's sustainability approach and incorporate embodied carbon assessment for the project, the lead architect suggested that this inclusion would enhance their chances to secure government funding:

> *'When I suggested that we sort of widen that remit to include embodied carbon, the way it was received was well this is actually a very good strategy to get this funding because it pushes the innovation to the extra level which will be appealing to Welsh government, it will make the assessment on the funding therefore we are more likely to secure a greater level of funding to make the project go forward, and that was the case really. And it tied with what the Welsh Government had put in their document, and we sort of grabbed it and ran with it.' (Int.-ARCH).*

As such, the outer norm ‘Government financial initiative directly affected the ‘Carbon approach/ assessment’ outcome of this project as an enabling condition. Whereas inner conditions ‘Client ambitions’ and ‘Sustainability approach’ were secondary indirect conditions that related to this project outcome. As mentioned in the Embodied Carbon Target section of this case study, the architectural practice had not previously performed LCA as part of their services. As such, they didn’t have the inhouse expertise or software to perform the analyses. The project architect also showed professional leadership in convincing the practice to invest in time and tools to upskill and enable them to perform the EC assessments:

> *‘I needed to translate that personal drive into a business case for the company. That took a bit of time and a bit of convincing. I sold it on the basis that, if we were doing this, we’d be sort of leaders in the field, that there are not many architects at the moment that are able to do this, or that they’re more niche, and it was definitely the way the industry was going, and I still think that it is moving to that direction. I said look, you can do two things, you can either follow, or get someone else to do it when it does become mandatory, or you can lead it and learn from it and be leaders in the field yourselves. So I pushed the latter, it was a tough sell because the software is not cheap, it was an investment, and obviously anything business related needs to see some sort of return on that, we were helped by the fact, obviously you can claim back tax credits for R&D (Research & Development) which we did which makes things a little bit easier.’ (Int.-ARCH).*

The driver for the company to invest in the software and upskill their staff to be able to perform LCA was to raise their competitiveness amongst the market and become one of the niche architectural practices that offer LCA of their design proposals. This was facilitated by the UK government ‘Research and Development Expenditure Credit’ which is a tax credit available to companies that work on research and development projects. The practice was able to claim this tax credit which enabled the purchase of the software required for the LCA. As such, ‘Government financial initiative’ was an enabling condition for EC assessment at project and at practice level. The project allowed for flexibility for the LCA to take place. The first assessment took longer (4 weeks) as there was a learning curve due to the unfamiliarity of the architect with the process and the software. Subsequent assessments took a week for BIM model preparation and another week to perform the assessment. For material iterations of the same design, the assessments took 2-3 days per iteration (Int.-ARCH). As there were no specific timescales set for the assessments, the inner facility 'Scheduling' is represented as a weak link to this project outcome. However this flexibility to the project scheduling was essential for the assessments to take place, therefore 'Scheduling' is presented as a direct link to this project outcome.

'Sustainability reports and guidance' were a driver in relation to the selection of timber construction. The Committee on Climate Change report 'UK housing: Fit for the future?' promotes the use of timber in new homes with an aim to increase the carbon storage of new UK homes (CCC 2019). The project followed this guidance and used the comparison of the timber construction against a 'business as usual' scenario which considered a masonry construction to demonstrate the benefits of timber use quantitatively. However, the architect who performed the LCA found that there was lack of guidance available in relation to the assessments' scope and the approach towards sequestered carbon in timber:

> *'There was an absence of guidance at the time. And in terms of the scope as well, what's included? What's not, how do you treat sequestered carbon in timber it wasn't clear, it really wasn't clear.' (Int.-ARCH).*

As such, the outer norm 'Sustainability reports and guidance' appeared both as a driver and a barrier that related to the 'Carbon approach/ assessment' outcome of this case study. As part of the sustainability approach of the project, both the timber and the supply chain used for the timber frame construction was sourced locally, using timber sourced from Welsh forests and a local timber frame manufacturer (Report-EC). The use of local timber and supply chain created concerns for the project in relation to available skills by the local supply chain and potential cost increase for the project:

> *'Using Welsh timber for structural frame was a massive talking point on the project. Is there a sufficient supply chain in existence that is going to be able*

> *to support this for a project of this scale? Are we going to see inflated cost because of lack of supply? This was a real concern. The contractors engaged with a local sawmill and said they could meet the demand for the project, and they have in fairness. Cost was something that was discussed, the contractors needed to put the order in place well in advance so that the timber would be there on time. The uplift on cost wasn't massive, it was covered by the IHP funding, it was in the region of 5%. What they did find was there was more rejected timber in the factory, because of the use of the Welsh timber but that is part of the process. But that was a big worry for the project.' (Int.-ARCH)*

However, the use of locally sourced timber was part of the government funding requirement, and the additional cost was covered by the secured funding, so 'Government financial initiative' was both the driver and the enabler for the use of locally sourced timber for the project. The life-cycle assessments for the project took place when the project was at the end of Stage 3, and throughout Stage 4. The assessments were performed for a sample of seven house types of the housing development, for which a range of wall, floor and roof options were compared to business as usual. Apart from material selection, form factor and its impact on carbon intensity was also considered. Form factor appeared to have a significant impact on the embodied carbon intensity, and a recommendation was included in the conclusions of the carbon assessment report that form factor needs to be considered for both operational and embodied carbon impacts for projects (Report-EC). The LCA performed also considered building services, photovoltaic panels and home lithium-ion batteries, which were all compared in relation to their embodied carbon payback through energy generation and storage. The building services, energy generation and storage systems were found the hardest to gain EC information for:

> *'MEP was the hardest area to obtain data. For example, heat pumps, you couldn't find the specific manufacturer data, it was impossible to get hold of, you had to select the best equivalent. For the batteries we couldn't find data for the exact product and used equivalent. For the other materials not so bad actually. The more eco-driven products such as wood fibre there is an obvious benefit for these manufacturers to have EPDs because it is part of their selling*

point, so you are more likely to find EPDs for those sorts of materials' (Int.-ARCH)

As can be seen from the above extract, embodied carbon 'Secondary data reliability' was a barrier for EC assessment, particularly for building service systems for which several assumptions had to be made for the LCA. The assessments showed that their contribution to the building capital EC is significant; however, when considering the houses' whole-life carbon, these systems have great benefits for whole-life carbon reduction (Report-EC). To safeguard low EC impact material specifications made during the design stage when the project was novated to the contractor, the project's contract included clauses that related to material specification, sourcing of materials and the requirement to perform LCA at practical completion. Certain design aspects that were required by the funding secured for the project, such as the use of Welsh locally sourced timber, were also included in the contract.

'Any proposed product substitutions should evidence the product's Global Warming Potential (GWP) in kgCO_2eq/declared unit using an EPD to EN15804 (minimum scope stages A1:A3) for the product to be considered. Products and materials which exceed the Global warming potential (GWP) measured in kgCO_2e per declared unit by 10% or more compared to the baseline specification will be deemed not equal unless the contractor can demonstrate by calculation the substitution will result in fewer emissions.' (Anderson and Adams 2020).

'There was a contract requirement, for the contractor to complete and update the EC assessment at practical completion, and it set out what was expected of them in terms of recording, things like site energy use which tends to be an estimate at design stage. But if the contractor keeps good record of that you can update those estimates. Design stage LCA is updated through construction stage and then at practical completion the final assessment is handed over to the client. That requirement is in the deliverables for the contractor.' 'That was tied back to the Funding requirement, certain things were stipulated, for example it had to be Welsh timber, it was a requirement, had to be timber clad, triple glazing, some elements were non-negotiable. All these were in the contract.' (Int.-ARCH)

The above shows that the inner norm ‘Contract’ directly affected the ‘Carbon approach/ assessment’ outcome. It was also an enabling condition for material choices to be safeguarded and for LCA to take place at the end of the construction stage.

The project was a learning experience for the architectural practice who performed the LCA and it was particularly useful for them to enhance the understanding of the project carbon in a holistic and informed manner. This made them realise that depending on intuition for EC reduction of projects is not sufficient and that a structured process for EC assessment needs to be integrated into the design process:

> *‘And through this process, we learnt a hell of a lot. Some of our results were actually quite surprising. So in my view it needs more than intuition, it needs a structured process and measurement of embodied carbon needs to be integrated into the design approach for sure. And it is difficult because it is sort of an emerging area of the profession, but it is something that for me, it is really important.’ (Int.-ARCH)*

Apart from the need for an established and integrated approach to EC in building design, what is interesting about the above statement is that the architect considers EC considerations and assessment as an emerging part of their profession rather than something that should be addressed by a specialist EC consultant or another profession of the principal design team. The conditions that affected the Carbon approach/ assessment outcome are presented in Table 6.29 and Figure 6.47.

Table 6.29 Case study 3 - The direct and indirect primary conditions that affected the Carbon approach/assessment outcome (Excerpt from Table 6.28).

Outcome	**Direct Conditions**		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
Carbon Approach/ Assessment	Professional knowledge/skills Professional leadership Contract (Scheduling)	EC Benchmarks Secondary data reliability Government financial initiative Sustainability guidance	n/a	Government financial initiative Regulation OC focus

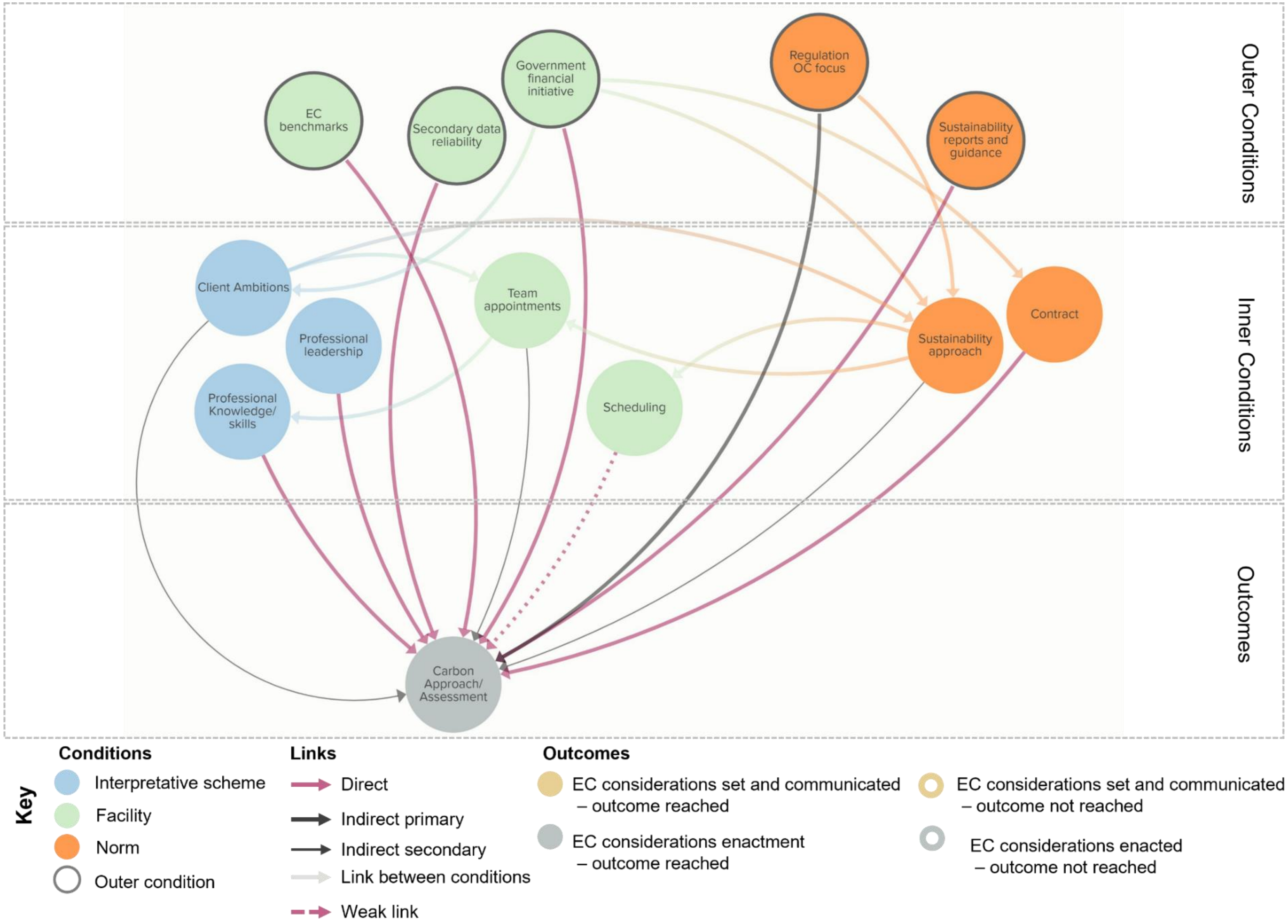

Figure 6.47 Case study 3 - The conditions that affected the Carbon Approach/ Assessment.

6.4.3.2.2 BIM model data input

The BIM model information input required for the LCA assessments was gathered by the lead architect and it mainly involved the MEP consultants and the timber frame specialists. As the homes of the project had a structural timber frame, the structural engineers mainly focused on civils work such as drainage which was out of scope for the LCA. The information for the timber frame was given by appointed specialist sub-contractor used a specialist 3D software which was BIM compatible. The information supplied by the MEP consultants was in the form of 2D drawings and further conversations were held for clarifications on the building services used. Although the project didn't use BIM for information management and information collation in a BIM level 2 federated model, collaboration amongst professionals for information exchanges was very good and the professional skills of each team enabled defining the BIM model information required for the assessments. This however related mainly to the MEP consultants involved, whereas Quantity Surveyors (QS) were not involved in material quantity information for the project:

> *'No they (QS) didn't help. There was a real lack of understanding in choosing this form of construction (timber frame), and moving to these low EC materials, what impact that would be in terms of cost. They developed an elemental cost plan, but during the design stages when we were picking between different things and making choices, there wasn't that granularity of detail from QS to understand it. So ideally in this situation we might have 10 different wall types and an associated cost, so you can make a decision based on both carbon and cost, that's the ideal scenario, but that just wasn't available. You might have a cost rate for timber frame, or for some cladding, but yeah that didn't work. It was us (ARCH) driving and calculating the quantities, not the QS. And even when an external company does the LCA, we are the ones to give quantities from our BIM model usually.' (Int.-ARCH).*

The lead architect was very familiar with the BIM software and as such, 'Professional knowledge/skills' interpretative scheme acted as an enabling condition for the BIM model data input for the project. However, the outer facility 'Complexity of BIM model data' was identified as a barrier, particularly during early design stages when building elements are not defined at the required detail:

'There is complexity. The example was the timber frame model. It took a while, it was exported to ifc, the problem is that it sees it as a lump of stuff, it is like a volume of stuff and you need to tell it what that stuff is, that timber frame mode, it might have elements of timber, it might have elements of steel webbing, it might have different elements in it. You then need to separate that out and work out the percentage of what is what, if you have a web joist it is imported as volume of stuff but most of that joist is empty space, some of it is metal, some of it is timber, you need to work out cross sectional basis how much of what material is actually contained in this is in a lump of 3D data. Air space is not acknowledged in BIM elements, so it takes an elaboration of BIM model to get accurate results. That is particularly a problem for early stage, because the BIM model at concept stage is really rough, really basic, it is just masses of stuff, the walls aren't defined. That is a real problem in doing early stage LCA models, which is frustrating because that is where the biggest savings in EC are made. Maybe it will be more refined down the line, I don't know.' (Int.-ARCH).

The 'Professional knowledge/skills' of the architect was affected by the inner facility 'Team appointments' which was in turn affected by the inner norm 'Sustainability approach' of the project. As such 'Team appointments' and 'Sustainability approach were indirect secondary conditions that affected the BIM model data input outcome. The 'Government financial initiative' and 'Regulation OC focus' were conditions that affected the 'Sustainability approach' and are indirect primary conditions that affected this outcome. The conditions that affected the BIM model data input outcome are presented in Table 6.30 and Figure 6.48.

Table 6.30 Case study 3 - The direct and indirect primary conditions that affected the Carbon approach/assessment outcome (Excerpt from Table 6.28).

	Direct Conditions		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
BIM model data input	Professional knowledge/ skills Professional leadership	Complexity of BIM model data	n/a	Government financial initiative Regulation OC focus

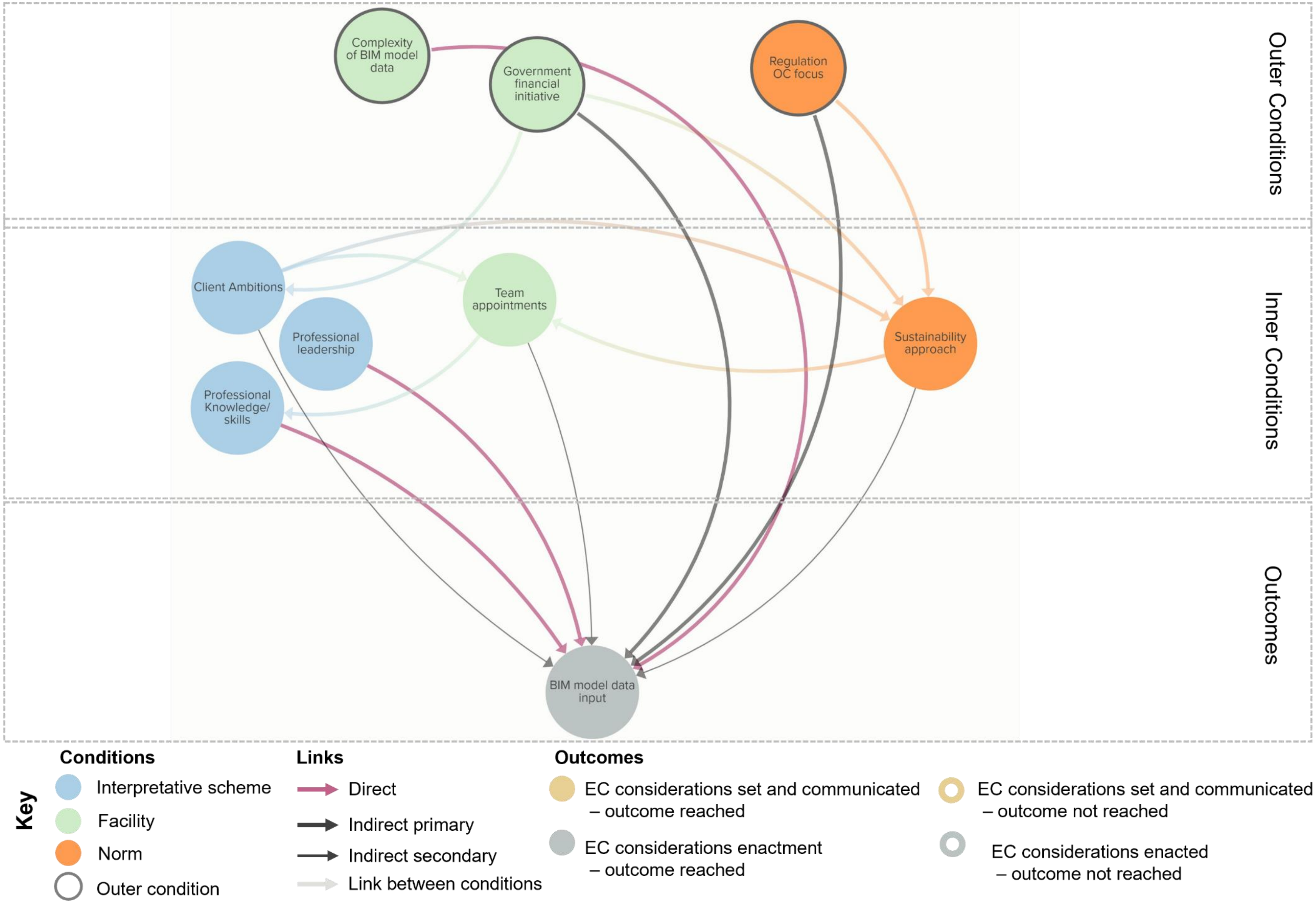

Figure 6.48 Case study 3 - The conditions that affected the BIM model data input.

6.4.3.2.3 BIM model use

The BIM model was directly used for the life-cycle assessments of the project. A web-based BIM plug-in software was used on which the BIM model was imported for the quantity information of materials. The EC impact of materials was given either through the use of EPDs or when an EPD was not available, through secondary databases built in the software, such as the ICE[17] database. The architectural practice who led the inclusion of EC considerations to the project and performed the life-cycle assessments took leadership in the use of BIM for the assessments. They recognised that BIM is a process that supports information management across the building life stages and found that it can be a natural tool to use for LCA to inform their design and specification:

> *'Building Information Modelling (BIM) is a process. It is a way of designing, drawing and producing information for the design, construction and maintenance of buildings. It is about the flow of data between stages across the project's life, from inception to demolition. Having Life Cycle Assessment integrated within our architectural workflows has potential to significantly improve our ability to transition to a net-zero carbon built environment as decisions of specification can be tested in a live model.' (Report-EC)*

The architect practice identified benefits in using the BIM plug-in software for LCA which related to EC product information as well as facilitation and streamlining of the LCA process:

> *'Material mapping can be associated directly via the [BIM] plug-in, or the [web-based software] web browser which allows for more refined selections. Over time [the software] learns your common selections making the process quicker. [web-based software] incorporates various useful prompters and Workflow checklists to build the required LCA assessment.' (Report-EC)*

As some of the barriers identified for LCA are lack of practitioner expertise, lack of EC information of building materials and time that the assessment takes, the above benefits mentioned are very important for practitioners who are not very familiar with LCA assessment. The prompters and workflow check lists can guide the

[17] Inventory of Carbon and Energy (ICE) is a widely recognised embodied energy and carbon database for building materials.

inexperienced practitioners, the opportunity to look for material EC information through web-search or incorporated databases can facilitate the lack of available material EC information and as the practitioners start using the software, commonly used materials are saved which reduces the time that the LCA assessments require. An important learning outcome of this project was that when the BIM model is used directly for LCA, the accuracy of the BIM model is crucial for the LCA results to be accurate:

> *'The resulting Life Cycle Assessment will only be as accurate as the BIM model itself; the data is used on a "as it is" basis. Therefore, rubbish in equals rubbish out! The main goal is to ensure that the BIM model contains sufficient information for LCA purposes. Great care and precision must be given to the elaboration of the 3D model as it will directly impact on the LCA results.' (Report-EC)*

As such, the BIM model data input is particularly important for the BIM model to be used for LCA, particularly when it is used directly through a BIM plug-in software like in this case study. The architects that managed the BIM model used for the LCA took leadership in ensuring that BIM model data was sufficient and accurate to enable its use for the LCA. Considering the above, the condition that directly affected the BIM model use outcome is 'Professional leadership' whereas there was no other condition affecting this outcome. The conditions that affected the BIM model use outcome are presented in Table 6.31 and Figure 6.49.

Table 6.31 Case study 3 - The direct and indirect primary conditions that affected the BIM model use outcome (Excerpt from Table 6.28).

Outcome	**Direct Conditions**		**Indirect Primary Conditions**	
	Inner	**Outer**	**Inner**	**Outer**
BIM model use	Professional leadership	n/a	n/a	n/a

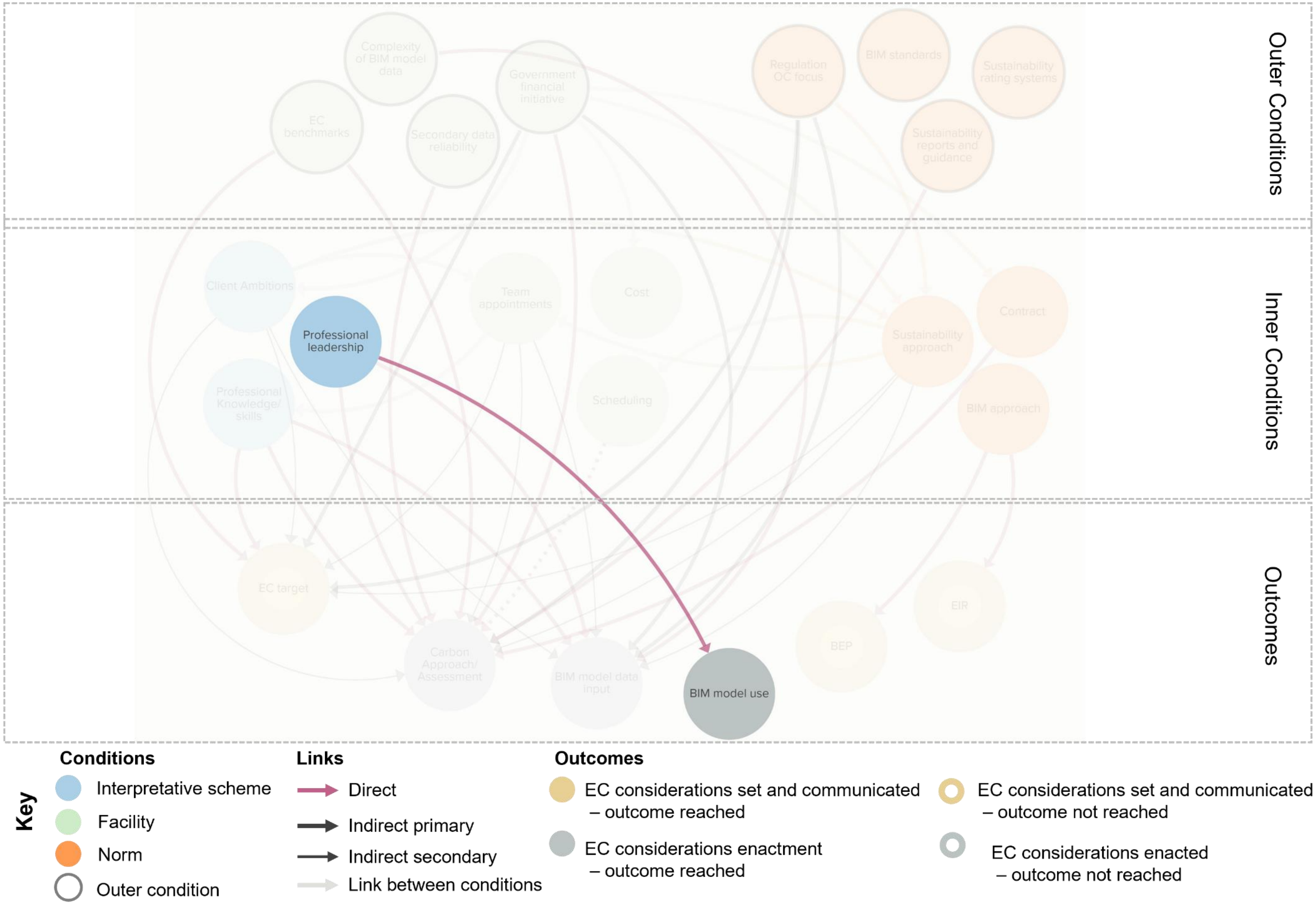

Figure 6.49 Case study 3 - The conditions that affected the BIM model use.

6.4.4 Conclusions

6.4.4.1 Conclusions from Conditions Analysis and Analysis of Strategic Conduct

The conditions that directly affected the project's outcomes were primarily the inner interpretative schemes 'Professional knowledge/skills' and 'Professional leadership' (three out of six outcomes). Outer facility 'EC benchmarks' and inner norm 'BIM approach' affected two outcomes each. The 'EC benchmarks' affected the 'EC target' and the 'Carbon approach/ assessment' outcomes. The 'BIM approach' which was characterised as BIM level 1 affected the two outcomes that related to information management through BIM: the 'EIR' and the 'BEP'. Four conditions ('Government financial initiative', 'Secondary data reliability', 'Complexity of BIM model data' and 'Sustainability reports and guidance') only affected one outcome that specifically related to them, for example, the 'Complexity of BIM model data' affected the 'BIM model data input'. Inner norm 'Contract' and inner facility 'Scheduling' only affected the 'Carbon approach/assessment' outcome. All direct conditions affecting the project outcomes are presented in Figure 6.50.

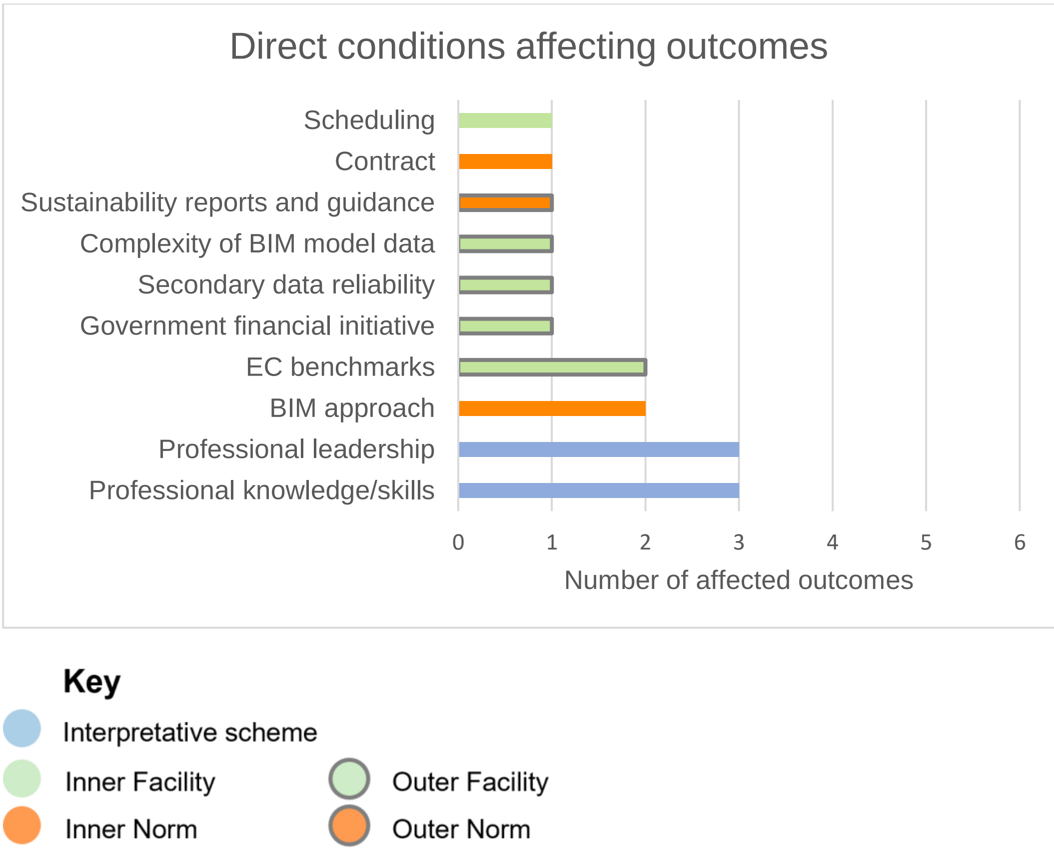

Figure 6.50 Case study 3 - Quantitative presentation of direct conditions affecting outcomes.

Through the Conditions Analysis, the indirect primary conditions affecting the outcomes were identified. Indirect primary conditions are defined as conditions that indirectly affected an outcome by affecting other conditions and are not affected by any other condition. Two indirect primary conditions were identified to affect the project outcomes: ‘Regulation OC focus’ and ‘Government financial initiative’. The ‘Government financial initiative’ affected a number of inner conditions (‘Client ambitions’, ‘Sustainability approach’, ‘Contract’ and ‘Cost’). As such, ‘Government financial initiative’ resulted in affecting direct conditions: inner facility ‘Team appointments’ and inner norm ‘Sustainability approach’. The ‘Regulation OC focus’ didn’t affect many inner conditions; it only affected the inner norm ‘Sustainability approach’. However, as mentioned above, as the ‘Sustainability approach’ affected other conditions that had a direct impact on project outcomes, ‘Regulation OC focus’ was an indirect primary condition that affected three out of six project outcomes. All indirect primary conditions affecting the project outcomes are presented in Figure 6.51.

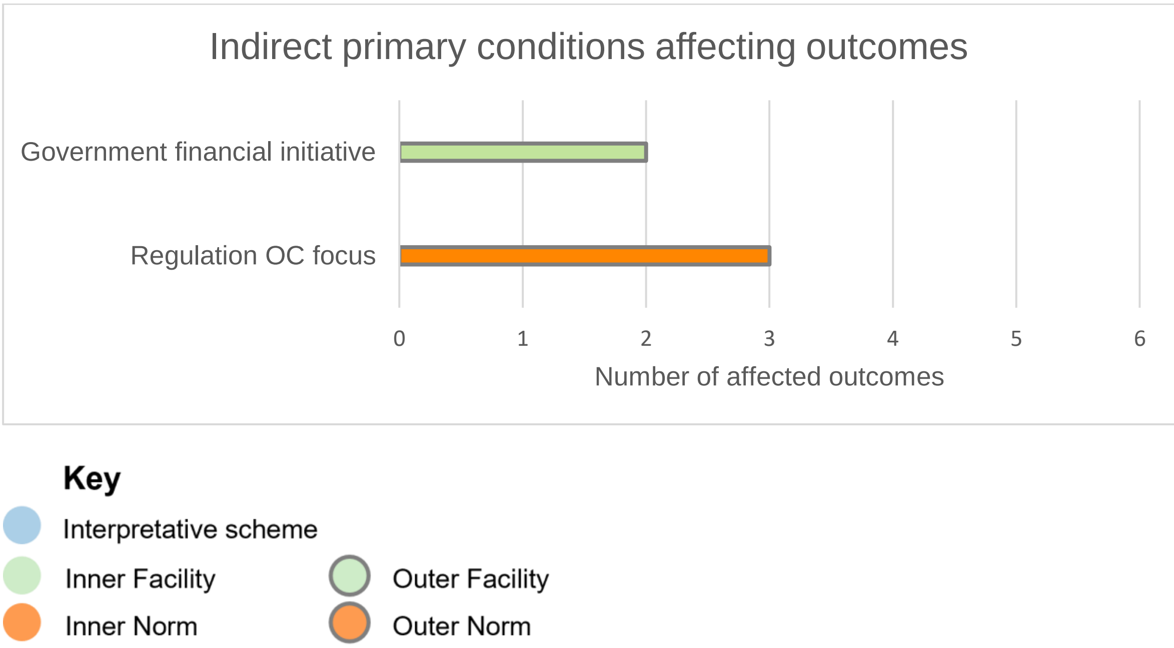

Figure 6.51 Case study 3 - Quantitative presentation of indirect primary conditions affecting outcomes.

6.4.4.2 Conditions, Mechanisms and Outcomes

Although no EC target was set, EC considerations and assessment was included as part of the project’s requirements. The main **barrier** for this was the lack of EC benchmarks during the time that the project targets were being set. The lack of experience in quantification of EC impacts by the project architect who led the EC approach and assessment for the project acted as a constraining condition for EC target setting. As such, the **dialectic of control** was limited for the design team with regards to setting a specific target for the project which related to lack of resources available to them, both in the form of benchmarks, and in the form of their own skill limitations. The **position-practice relations** for the project show a power dynamic where the main project architect drives inner project norms that relate to sustainability. The client already had high sustainability aspirations; however, these were mostly focused on OC influenced by the industry-wide regulations. The Government financial initiative acted as an **enabling condition** for the architect to push for EC inclusion within the project sustainability aspirations. This however was not the case for BIM application for the project which followed a BIM level 1 approach. Considering the relationship of the project outcome to the industry-wide practice, the **contextual outcome** shows enhancement of the industry's status quo through the expansion of the projects sustainability approach to include EC considerations. However, transformation of the status quo wasn't achieved as there was lack of an EC target for the project and there was lack of EC information management through BIM. The direct and indirect primary conditions, mechanisms and outcomes that relate to this outcome category are summarised in Table 6.32.

Table 6.32 Case Study 3 - How EC considerations are set and communicated Conditions, Mechanisms and Outcomes.

Conditions	Mechanisms	Outcome	
Direct & Indirect Primary	**Position-practice Dialectic of control**	**EC considerations Set and communicated**	**Contextual**
Direct: Outer: EC Benchmarks Inner: Professional Knowledge/Skills, BIM approach **Indirect Primary:** Government financial initiative, Regulation OC focus	**Position practice relations:** Client legitimising inner norms of sustainability and BIM approach. Design team expertise used to contribute to inner norms. Enhanced position-practice relation between client and design team.	EC target not set, no BIM information management. However, EC considerations and assessment included as part of project requirements.	Enhances status quo.

The main **driver** for addressing EC considerations through LCA was the 'Professional leadership' of the project architect, who saw EC consideration inclusion and EC assessment as part of their professional responsibility towards the declared Climate emergency. The main **enabling condition** for the LCA to take place was the ‘Government financial initiative’, which incentivised the client to expand the sustainability approach of the project to include EC. The Government funding that was secured also facilitated the specification of locally sourced timber frame construction for the project, as it covered for the increased cost of the use of locally sourced timber. The Government funding also affected the project contract to include clauses that would secure material specification of the building design during the construction stage. Another enabling condition was the design team and supply chain ‘Professional knowledge and skills’ which made the use of low EC materials feasible for the project. No expert LCA consultant was appointed for the project, as such, the **position-practice relations** of the design team didn’t include expert roles to address EC considerations. The project followed a BIM level 1 approach, so there was no information management through BIM. However, the collation of the information required for the EC assessments was made by the architects through collaboration amongst the design team which reinforces the leading position of the architectural practice in this case study. The architectural practice used this project as an opportunity to expand the services they provide to include LCA for projects. As there was a learning curve for the architects in performing the LCA, the flexibility of the project ‘Scheduling’ enabled LCA assessments to take place which included both skills building for the architects as well as performing the assessments. The BIM model was used directly for the LCA, which required the purchase of a BIM plug-in software. This was facilitated by the UK government ‘Research and Development Expenditure Credit’. As can be understood from the above, the **dialectic of control** of the architect who led the inclusion and assessment of EC for the project was enhanced by outer facilities in the form of available funding and tax relief. Inner facilities and norms, such as ‘Scheduling’ and ‘Contract’ also contributed to the high dialectic of control of the architect by securing the resources available and legitimising project norms to secure low EC impact specification. Considering the relationship of the project outcome to the industry-wide practice, the **contextual outcome** shows transformation of the industry’s status quo. The direct and indirect primary conditions, mechanisms and outcomes that relate to this outcome category are summarised in Table 6.33.

Table 6.33 Case Study 3 How EC considerations are addressed Conditions, Mechanisms and Outcomes.

Conditions	Mechanisms	Outcome	
Direct & Indirect Primary	**Position-practice Dialectic of control**	**EC consideration address**	**Contextual**
Direct: Outer: All facilities, Sustainability reports and guidance Inner: Professional leadership Professional knowledge/skills Contract, (Scheduling) **Indirect Primary:** Government financial initiative, Regulation OC focus	**Position practice relations:** No expert roles introduced. Architectural practice at a leading position in relation to EC information and use of BIM for LCA. **Dialectic of Control:** High for the design team through outer facilities and inner facilities and norms.	BIM model used directly for LCA.	Transforms status quo.

6.5 Chapter Summary

In this chapter, three case studies were analysed using a the explanatory phase analytical framework that was informed by the theory of structuration and the exploratory phase findings. The conditions of each case study were categorised using structuration theory concepts and a conditions analysis was conducted to analyse the relationships between different conditions. The analysis of strategic conduct was then presented to analyse how the conditions and their relationships affected project outcomes, which were in turn categorised in relation to the research focus: how EC considerations are set and communicated, and how EC considerations are addressed in a BIM enabled project. The conditions analysis and analysis of strategic conduct enabled the identification of the conditions that affected the outcomes and revealed the generative mechanisms that triggered these conditions to produce the outcomes. This chapter informed the next chapter which considers the contextual similarities and differences of the three cases to enable a cross-case comparison of their Condition, Mechanism, and Outcome (CMO) configurations.

Chapter 7 Cross-case comparison

7.1 Introduction

This chapter considers the findings from the three case studies that were presented in Chapter 6 to conduct a cross-case comparative analysis. The three case studies are initially compared in relation to their outer and inner contexts to identify similarities and differences of outer and inner conditions amongst the three cases. The categorisation of conditions follows the theoretical concepts used for Phase 2 analysis (as presented section 5.8.2), where outer conditions are categorised as 'facilities' and 'norms', and inner conditions are categorised as 'interpretative schemes', 'facilities' and 'norms'. The cross-case analysis then moves on to compare the Condition-Mechanism-Outcome (CMO) configurations of the three case studies to address the research questions: (1) 'How EC considerations are set and communicated' and (2) 'How EC considerations are addressed'. This chapter presents an analysis of the impact of context on setting and addressing EC considerations in a BIM-enabled project.

7.2 Outer context comparison

As mentioned in the introduction of this chapter, the outer context conditions are conceptually categorised as 'Facilities' and 'Norms'. These categories are populated by empirical findings as presented in section 5.8.2 to compare similarities and differences of the three case studies. For the 'Facilities' category when considering the outer context, the following resources were included:

- Secondary data reliability: Databases for material EC
- BIM model data: Complexity relating to the information stored within the BIM model
- EC benchmarks: the lack of EC benchmarks available to the construction industry
- Financial initiatives

For the 'Norms' category when considering the outer context, the following rules, protocols. guides or codes of conduct were included:

- Regulations OC focus: Construction industry regulations and their focus on OC

- BIM standards: Standards available that relate to BIM use in the UK construction industry
- Sustainability rating systems: Rating systems that assess the environmental impact of buildings
- Sustainability reports and guidance

The design stage of Case studies 1 and 2 took place approximately during the same time period, starting at the end of 2017 and ending toward the end of 2018. For Case study 3 however, the design stage took place approximately one year later, starting at the end of 2018 and ending at the end of 2019/ beginning of 2020. During 2019, climate emergency was declared by the UK building industry and further resources and norms relating to EC became available. These resources and norms included EC benchmarks, guidance and new versions of sustainability rating systems. Figure 7.1 presents a timeline of when these resources and norms became available against the RIBA stages of the three case studies.

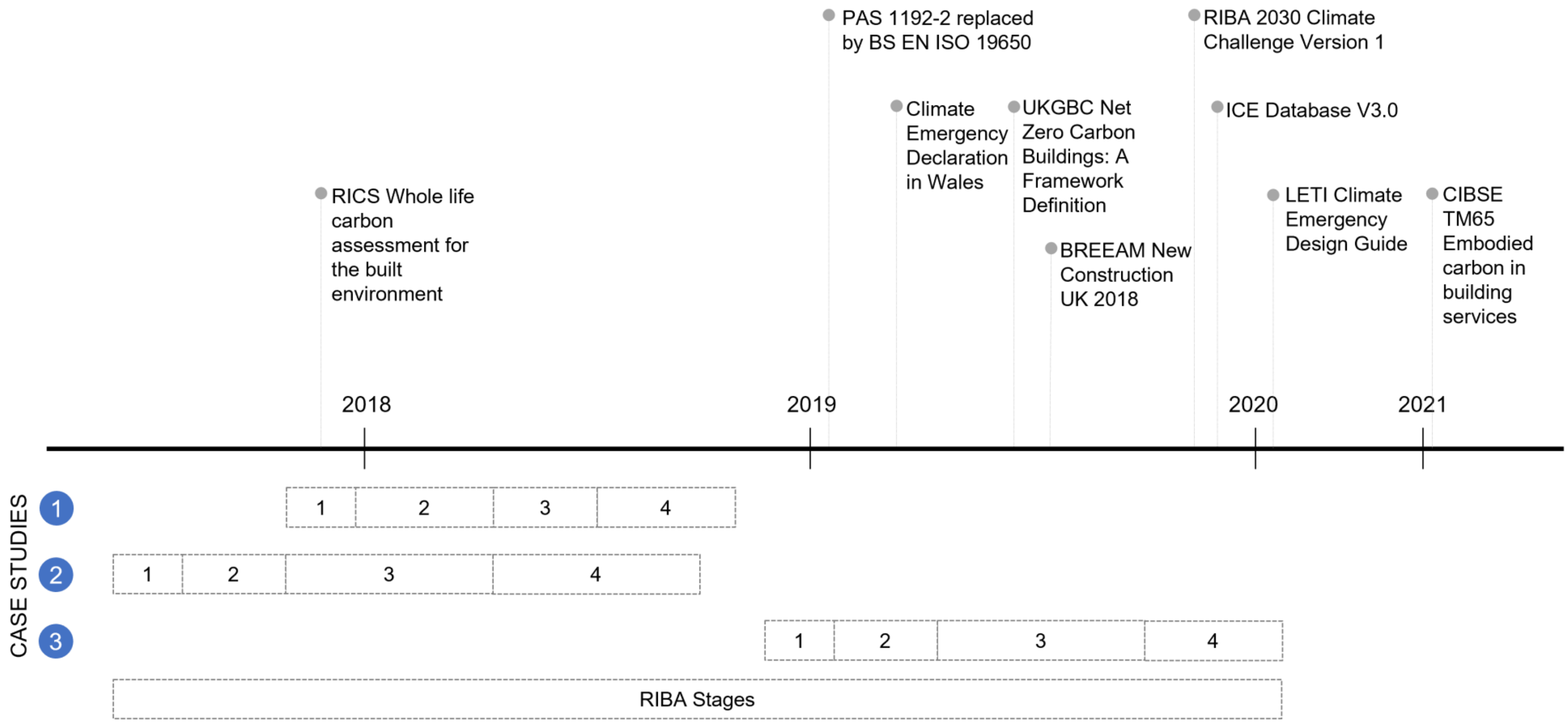

Figure 7.1 Resources and Norms timeline against RIBA stages of the three case studies.

7.2.1 Outer Facilities

With regards to outer facilities, the outer facilities that presented differences amongst the three case studies were ‘EC data reliability’, ‘EC benchmarks’ and ‘Financial initiatives’. Table 7.1 presents the outer facilities for the three case studies, and highlights which facilities presented differences amongst the three cases through grey highlight.

Table 7.1 Outer facilities comparison. Highlight represents identified differences amongst the case studies.

	CS1	**CS2**	**CS3**
EC Secondary data reliability	Reliance on Secondary data.	No reliance on secondary data, own EC database.	ICE database version 3. Partial reliance on Secondary data . Lack of EC data on MEP services.
EC benchmarks	No UK EC benchmarks available.	No UK EC benchmarks available.	Emergence of UK EC benchmarks during the time of assessments
Complexity of BIM model data	Complexity of building element data particularly during early design stages.	Complexity of building element data particularly during early design stages.	Complexity of building element data particularly during early design stages.
Government financial initiatives	n/a	n/a	Welsh Government Innovative Housing Programme UK Government Research and Development Expenditure Credit

7.2.1.1 EC data reliability

For Case Studies 1 and 2, a leading EC UK database, the Inventory of Carbon and Energy (ICE) was still at version 2, which had not been updated since 2011. For CS1, lack of reliability of secondary EC data created a challenge in assessing the EC carbon of the project. This, however, wasn’t the case for CS2 which had LCA experts appointed for conducting the LCAs for the project. For CS2, the LCA experts did not rely on the ICE database as they found it overly generic and outdated. Instead, they used product EPDs and EC information spreadsheets they developed inhouse. A new version of the ICE database was made available in November 2019, which was during the time that life-cycle assessments were being conducted for CS3. For CS3, the ICE database was used to get generic product values when EPDs were not available. For this CS, reliability of secondary data was only problematic due to the limited availability of EC data on MEP services.

7.2.1.2 EC benchmarks

'EC benchmarks' were not available during the design stage of CS1 and CS2. Similarly, to 'EC data reliability', this became a constraining condition for the inclusion of an EC target for CS1 but did not hinder CS2 to set an EC target for the project. This was because CS2 EC target setting was enabled by the sustainability approach that the project took and the professional skills that the appointed LCA consultants brought to the project. For CS3, EC benchmarks became available at the time when LCA took place for the project. However, as these were not available when project targets were being set and due to the lack of confidence in LCA by the architect team who was novice in driving EC inclusion to projects, no EC target was set for CS3. Outer facilities in the form of EC benchmarks and EC databases appear to have an increased impact when the LCA is performed by members of the principal design team (as observed in CS3) than when external LCA consultants are appointed (as observed in CS2).

7.2.1.3 Financial initiatives

The facility 'Government financial initiative' was only relevant to CS3, as CS1 and CS2 did not have this outer facility available. For CS3, government financial initiatives played an important role in enabling EC considerations for the project to be set and addressed. The Welsh Government Innovative Housing Programme created an incentive for the client to include EC considerations and assessment for the project and enabled the use of locally sourced timber for the project. The UK Government Research and Development Expenditure Credit enabled the architectural company that undertook the LCA to invest in LCA software.

7.2.1.4 Complexity of BIM model data

The facility that remained the same for the three case studies was 'Complexity of BIM model data'; however, this facility did not affect the case studies in the same way. For all three case studies, the complexity in BIM model data was highlighted, particularly during the early design stages when building elements were not well defined. However, for CS1, this complexity deterred the use of BIM as a tool for EC information management and carbon assessment. For CS2 and CS3, this complexity was acknowledged but was addressed through collaboration of the BIM and LCA experts in CS2 and through professional skills in CS3.

7.2.2 Outer Norms

With regards to outer norms, the outer norms that presented differences amongst the three case studies were 'Sustainability rating systems', 'BIM standards' and 'Sustainability reports and guidance'. Table 7.2 presents the outer norms for the three case studies, and highlights which norms presented differences through grey highlight.

Table 7.2 Outer Norms comparison. Highlight represents identified differences amongst the case studies.

	CS1	**CS2**	**CS3**
Regulation OC focus	Lack of regulatory requirement for EC.	Lack of regulatory requirement for EC.	Lack of regulatory requirement for EC.
Sustainability rating systems	BREEAM 2014 version.	BREEAM 2014 version.	EPC and SAP
BIM standards	PAS 1192-2	PAS 1192-2	BS EN ISO 19650
Sustainability reports and guidance	RICS Whole life carbon assessment for the built environment	RICS Whole life carbon assessment for the built environment	Additional reports and guidance

7.2.2.1 Sustainability rating systems

The differences in 'Sustainability rating systems' was related to the building use typology, where CS1 (educational building) and CS2 (commercial building) were registered under BREEAM UK New Construction non-domestic buildings version 2014. CS3 (housing development project) used sustainability rating systems that apply to domestic buildings, such as EPC[18] and SAP[19].

[18] Energy performance certificate (EPC)
[19] Standard Assessment Procedure for the Energy Rating of Dwellings (SAP)

7.2.2.2 BIM standards

For CS1 and CS2 the design stage took place during 2017-2018 and for both projects the PAS 1191-2 standard was followed. The design stage of CS3 took place in 2019 (one year after the design stage of CS1 and CS2) when the BIM information management standard PAS 1192-2 was replaced by BS EN ISO 19650. However, since CS3 was a BIM level 1 project that did not use BIM for collaborative information management for the project, this outer norm did not affect the project.

7.2.2.3 Sustainability reports and guidance

In 2019 climate emergency was declared across the UK which resulted in the publication of a number of reports and guides that related to addressing carbon emissions of the building sector, such as the UK Green Building Council's Net Zero Building: A Framework Definition, LETI's Climate emergency guide and RIBA 2030 Climate Challenge Guide. These resources included newly introduced EC benchmarks that aimed to assist the construction sector to tackle carbon emissions in a more holistic way. As such, for CS1 and CS2, the main guidance document available relating to EC was RICS Whole life carbon assessment for the built environment professional statement and there were no EC benchmarks available. For CS3, the 2019 EC benchmarks became available when LCA was being conducted for the project, and therefore the benchmarks did not inform the targets set for the project. However, they enabled a comparison of the CS3 LCA results against these benchmarks by the project team and an understanding of how these results compared against the industry's expectations to address carbon emission reductions.

7.2.2.4 Regulation OC focus

For all three case studies, there was lack of a regulatory requirement relating to embodied carbon emissions. However, as will be discussed further in the case studies' inner context comparison (section 7.3), this affected each project in a different way. Considering the above comparison of Outer norms for the three case studies, it can be seen that although all norms apart from 'Regulation OC focus' were different for CS3, only the 'Sustainability reports and guidance' norm presented a difference that had an impact on the project.

7.3 Inner context comparison

As mentioned in the introduction of this chapter, the inner context conditions are conceptually categorised as 'Interpretative Schemes', 'Facilities' and 'Norms'. These categories are populated by empirical findings as presented in section 5.8.2 to compare similarities and differences of the three case studies.

For the 'Interpretative Schemes' category when considering the inner context, the following interpretative schemes were included:

- Client Ambitions: Client ambitions for the project that relate to sustainability and BIM application.
- Professional Knowledge and skills: Design team knowledge and skills that relate to sustainability and BIM application.
- Professional leadership: any process or act made by the design team professionals to influence activities toward EC target setting and realisation through BIM application in the project case study.

For the 'Facilities' category when considering the inner context, the following resources were included:

- Team appointments: Professional appointments that make up the project's design team
- Scheduling: The project's timetable
- Cost: Financial cost as part of the project budget

For the 'Norms category when considering the inner context, the following rules, protocols. guides or codes of conduct were included:

- Sustainability approach: the approach to sustainability taken in the project with a focus on carbon
- BIM approach: the application of BIM in the project in relation to information management, with a focus on EC information
- Contract: the project contractual agreement

7.3.1 Interpretative Schemes

Table 7.3 presents a summary of the comparison of the Interpretative schemes 'Client ambitions', 'Professional knowledge/skills' and 'Professional leadership' for the three case studies and highlights which interpretative schemes presented differences amongst the three cases through grey highlight.

Table 7.3 Interpretative Schemes comparison. Highlight represents identified differences amongst the case studies.

	CS1	CS2	CS3
Client ambitions	Mostly focused on sustainability rating	High sustainability aspirations that extended beyond sustainability rating.	High sustainability aspirations mostly driven by Government financial initiative.
Professional knowledge/ skills	Principal design team high sustainability skills and high BIM skills. No LCA skills by sustainability consultant.	Principal design team high sustainability skills and high BIM skills. LCA skills and BIM coordination through consultants.	Principal design team high sustainability skills, BIM skills only by architectural team. LCA skills building for architect through the project.
Professional leadership	Some leadership shown through requests of expertise appointments.	Some professional leadership shown through safeguarding material specification.	High professional leadership by architect in relation to EC consideration and assessment, and BIM use for LCA.

7.3.1.1 Client ambitions

For CS1, the client ambitions mostly focused on the achievement of BREEAM Excellent rating for the project. The project targets were therefore set in relation to that aspiration and did not explicitly include EC considerations. For CS2 and CS3, the clients had sustainability aspirations that extended beyond what was required for the achievement of the sustainability rating that the projects aimed to secure. For CS3, the client ambitions were mostly driven by the aim to secure the Government funding for the project. However, for CS2, the ‘Client ambitions’ were not influenced by the project’s outer context. The outer context had an impact on ‘Client ambitions’ for case studies 1 and 3 where ‘Client ambitions’ were influenced by the ‘Sustainability Rating Systems’ for CS1 and the ‘Government financial initiative’ for CS3.

7.3.1.2 Professional knowledge/ skills

For all case studies the principal design team had high ‘Professional knowledge/ skills’ that related to sustainability and BIM application. With regards to BIM application, for CS1 and CS2 the principal design teams had high BIM skills, however for CS2, the information management of the project was facilitated by the appointment of BIM consultants. For CS3, only the architectural team had BIM skills and used BIM as a tool, whereas no information management took place for the project as it was a BIM level 1 project. When considering expertise in conducting LCA, CS1 lacked this expertise completely, whereas for CS2 this expertise was secured through the appointment of LCA consultants, and for CS3 through the upskilling of the architect team.

7.3.1.3 Professional leadership

Professional leadership was evident in all three case studies but was relevant to different aspects. For CS1, professional leadership was shown by the sustainability consultant and the architect team through their requests to appoint expert roles to cover the lack of LCA skills and to reinforce the BIM approach of the project respectively. For CS2, professional leadership was shown in relation to ensuring that material choices during the construction stage would follow the material qualities set by the material specification during the design stage. The highest professional leadership was shown in CS3 where the lead architect pushed for the inclusion of EC considerations and EC assessment for the project. As LCA skills and software were not available by the architect team, the professional leadership extended beyond convincing the client to include this for the project, to convincing the architectural practice to invest in upskilling their workforce and purchasing software to enable them to offer LCA as part of the services they offer.

7.3.2 Inner Facilities

Table 7.4 presents a summary of the comparison of the Inner Facilities ‘Team appointments’, ‘Scheduling’ and ‘Cost’ for the three case studies and highlights which inner facilities presented differences amongst the three cases through grey highlight.

Table 7.4 Inner Facilities comparison. Highlight represents identified differences amongst the case studies.

	CS1	CS2	CS3
Team appointments	No BIM consultant, no LCA experts	BIM consultants and LCA experts	No BIM consultants. No LCA expert.
Scheduling	Tight scheduling	Scheduling that enabled BIM model checking and LCA.	Flexible scheduling to enable LCA skills building and LCA assessment
Cost	Additional cost for team appointments hindered BIM and LCA expertise to be appointed. Cost also hindered timber to be considered as a structural material.	Cost reduction through material reduction less than cost of LCA consultant appointment.	No additional cost for LCA as there was no fee associated with it. Project cost part-funded by Government funding. Additional cost due to timber construction covered by funding.

7.3.2.1 Team appointments

For all case studies, the team appointments included a principal design team that had the skills to deliver a highly sustainable building. However, in relation to LCA skills and BIM application, CS2 had LCA and BIM consultants appointed which facilitated the information management of the project and secured the required LCA skills for whole-life carbon assessment of the project. The lack of LCA expertise of the principal design team resulted in the lack of EC assessment for CS1, as no LCA experts were appointed to address this skills gap. BIM information management was also weak for CS1 as there were no BIM consultants appointed to act as BIM information managers/ leads. For CS3, although there was lack of LCA skills by the principal design team, this skills gap was addressed through upskilling of the lead architect to undertake the LCA for the project. The upskilling included the familiarisation of the lead architect with the use of the LCA software purchased by the practice for conducting the LCA of the project. This was part of the practice’s effort to expand the services they provide to include LCA for projects. As CS3 was a BIM level 1 project, no information manager was required.

7.3.2.2 Scheduling

With regards to ‘Scheduling’ CS1 had a tight schedule which was mostly reflected on delays of BIM model sharing amongst the design team which in turn resulted in discrepancies of the building design between the different professional teams. As no LCA was conducted for CS1, scheduling did not account for the time required for LCA to be conducted for the project. For CS2 however, the project scheduling was made so that it enabled the respective BIM models of the professional teams to be checked and federated, and also enabled LCA to take place. For CS3, as there was a requirement for the architectural practice to upskill in order to perform the LCA, the project scheduling allowed for flexibility for the practice to upskill and conduct the LCAs.

7.3.2.3 Cost

Cost appeared to have different implications for the three case studies. For CS1, the additional cost that would be incurred to appoint experts for BIM and LCA hindered these team appointments. For CS2, however, the EC considerations and assessment resulted in material use reduction and consequently the reduction of the project’s capital cost. The savings made through reduced material use were greater than the cost of the LCA consultant appointment which facilitated the saving. However, for both CS1 and CS3 the use of lower EC impact materials was found to increase the capital cost of the project. For CS1, this hindered the use of timber as a structural material. Whereas for CS3, the additional cost incurred by the use of timber was covered by the Government funding, a facility that was not available for CS1. Further to this, for CS3, there was no cost associated with the LCA service provided by the architects, as it was considered as an opportunity for skills building by the practice.

7.3.3 Inner Norms

Table 7.5 presents a summary of the comparison of the Inner Norms ‘Sustainability approach’, ‘BIM approach’ and ‘Contract’ for the three case studies and highlights which inner norms presented differences amongst the three cases through grey highlight.

Table 7.5 Inner Norms comparison. Highlight represents identified differences amongst the case studies.

	CS1	CS2	CS3
Sustainability approach	Mostly driven by BREEAM target.	Holistic approach to carbon that extended further than the BREEAM target requirement. Influenced by the client.	Holistic approach to carbon, influenced by professional leadership and the government financial initiative.
BIM approach	Level 2, weak approach	Level 2, strong approach	BIM Level 1
Contract	Design and Build. No safeguarding of material specification.	Design and Build. Safeguarding of material specification	Design and Build. Safeguarding material specification.

7.3.3.1 Sustainability approach

The 'Sustainability approach' was driven by different conditions for the three case studies. For CS1, the sustainability approach of the project was mostly driven by the BREEAM target and followed a cost-effective approach in achieving the targeted BREEAM rating of Excellence. Considering however the heavy focus of regulation and sustainability rating systems on OC, this resulted in lack of whole-life carbon assessment for the project. For CS2 and CS3, the sustainability approach extended beyond the requirements of what was required to achieve the sustainability rating systems target, which resulted in the EC considerations to be included and addressed for the projects. However, for CS2, extending beyond the requirements of the sustainability rating achievement was due to the client's high sustainability aspirations, whereas for CS3, the driver for this was the professional leadership shown by the project lead architect, and was facilitated by the government financial initiative. Considering the above, it can be seen that CS1 and CS2 both aimed for a BREEAM Excellent rating under BREEAM 2014 scheme; however, their sustainability approach differed significantly.

7.3.3.2 BIM approach

The BIM approach also differed significantly for the three projects. This was not surprising because CS1 and CS2 were BIM level 2 projects whereas CS3 was a BIM level 1 project. CS3 did not use BIM for information management and collaboration amongst the different professional teams. The BIM approaches applied by CS1 and

CS2 were different despite their BIM level 2 target. CS1 had a weak BIM level 2 approach which was characterised by the lack of a BIM information manager/ lead, lack of the establishment of Employers Information Requirements (EIR) at the start of the project and a delayed establishment of the BIM execution plan (BEP). CS2 however, had a strong BIM level 2 approach with both EIR and BEP established for the project during the start of the design stage. This was enabled by the appointment of the BIM consultants who guided the BIM information management for the project.

7.3.3.3 Contract

All three case studies were under a Design and Build contract, according to which, the design responsibility passes from the principal design team to the appointed contractor during RIBA stage 4. This can have implications with regards to material substitution from what the design team specified to what the contractor selects to use. These potential implications were addressed for CS2 and CS3 by adding clauses to the contract according to which substituted materials should meet the same performance requirements as the materials specified by the design team. In CS1, there were no safeguards of material specification during the construction stage in the project's contract.

7.4 Condition-Mechanism-Outcome (CMO) comparison

The following two sections compare the Condition, Mechanism and Outcome (CMO) configuration of the three case studies in relation to the two outcome categories: 'How EC considerations are set and communicated' and 'How EC considerations are addressed'. As part of the Context comparison, as described in section 5.8.1.2 the conditions that were identified as 'driver' or 'barrier' and 'enabling' or 'constraining' for this outcome are identified[20]. The mechanisms considered are theoretically informed and are the same that were considered in Chapter 6 for the Phase 2 analysis of the case studies: 'Position-practice relations' and 'Dialectic of control' (see section 5.8.2). The outcome in both outcome categories is divided in two sections: 'Project outcome' which presents what was observed in relation to this outcome for the case study and 'Contextual outcome' which considers how the

[20] As mentioned in section 5.8.1.2, a condition is identified as a 'driver' or 'barrier' when it is the initiating condition for the outcome (who or what influenced this outcome to be), whereas conditions that facilitated or hindered the outcome are identified as 'enabling' or 'constraining' respectively (how this outcome came to be)

observed project outcome relates to the industry's status quo (section 5.8.1.4 presents what is considered as status quo). The contextual outcomes are categorised as 'preserves', 'enhances' or 'transforms' as per their relation to the industry status quo (section 5.8.1.4 explains these categories).

7.4.1 Condition-Mechanism-Outcome (CMO) for 'How EC considerations are set and communicated'

As can be seen by the case studies' CMO comparison, the only case study for which an EC target was set and communicated through BIM information management, showing a transformation of the industry's status quo, was CS2. The driving condition for this was 'Client ambitions', as the client required the inclusion of EC considerations to the project and a strong BIM approach for the project. The 'Team appointments' were fundamental to achieve the clients' requirements leading to the appointment of LCA and BIM consultants to secure the required expertise for the project team. Whilst 'Client ambitions' was a driving condition for CS2, it presented a barrier for CS1, which did not include EC considerations for the project and had a weak BIM Level 2 approach, resulting in preservation of the industry's status quo. The 'Regulation OC focus' and 'Sustainability rating systems' impacted the CS1 approach to sustainability, which resulted in the lack of EC considerations set for the project. The 'BIM standards' placing the responsibility of EIR creation on client resulted in lack of the establishment of explicit information requirements for the project. For CS3, EC considerations were included in the project; however the driving condition for this was not 'Client ambitions', but 'Professional leadership' shown by the project lead architect. The enabling condition for this was the outer facility 'Government financial initiative' which incentivised the client to include EC considerations for the project in order to secure the government funding. However, although reducing EC impacts was part of included in the project's aspirations, a quantitative EC target was not set for the project. The condition that acted as a barrier for this was the industry's 'EC benchmarks', which were not available when the project targets were set. As the architect team lacked experience in quantification of EC impacts, the limited 'Professional knowledge/ skills' also acted as a constraining condition for EC target setting. Conversely, while EC benchmarks were not available in CS2 either, the expertise of the LCA consultants fostered the identification of quantifiable EC targets. With regards to communicating information requirements through BIM, this was not done for CS3 as it was a BIM level 1 project. As such, project outcome shows enhancement to the industry's status quo, but not transformation. The project 'BIM approach' was the barrier regarding this aspect of the project outcome.

As can be observed by the above, driving conditions for the inclusion of EC considerations are interpretative schemes; 'Client ambitions' for CS2 and 'Professional leadership' for CS3. Structures of signification therefore appear to affect inner norms and facilities through legitimising norms and controlling project resources. Outer norms, such as BIM standards, give power to clients to set the project information requirements rather than reinforce the design team's power over establishing these requirements. This, together with the client's control over project resources can create a position-practice relation between the client and the design team where the client overrides the design team's role in the process of the building design, as observed in CS1. For CS2 however, a more balanced position practice relation between the client and the design team enabled the design team to contribute to inner norms. For this case study, potentially constraining outer facilities and norms such as lack of 'EC benchmarks' and 'Regulation OC focus' didn't appear to have an effect on the project outcome. For CS3 EC considerations were mostly driven by the lead architect, showing a position-practice relation where the professional takes the leading role in legitimising the project's inner norm that related to sustainability. However, due to the initial lack of expert LCA skills by the professional team, the lack of available 'EC benchmarks' affected the EC target setting of the project, and no specific EC targets were set for the project. The dialectic of control of the professional team was low as they did not have the required resources to tackle the EC target setting for the project. Considering this, it appears that outer conditions tend to have an impact on the project outcome when professionals have a low dialectic of control. Table 7.6 presents the CMO comparison between the three case studies for 'How EC considerations are set and communicated'.

Table 7.6 'How EC considerations are set and communicated' cross-case CMO comparison.

Case Studies	Conditions		Mechanisms	Outcome	
	Driver/ Barrier	**Enabling/ Constraining**		**Project**	**Contextual**
CS1	**Barrier:** Client ambitions	**Constraining:** BIM standards Regulation OC focus Sustainability rating systems EC benchmarks	**Position practice relations:** Client legitimising inner norms of sustainability and BIM approach. Design team role overridden by client.	No EC considerations set. No communication of EC information requirements through BIM	Preserves status quo.
CS2	**Driver:** Client ambitions	**Enabling:** Team appointments	**Position practice relations:** Client legitimising inner norms of sustainability and BIM approach. Design team expertise used to contribute to inner norms. Enhanced position-practice relation between client and design team.	EC target set and EC information communicated through BIM although still EC less mentioned compared to OC	Transforms status quo.
CS3	**Barrier** EC Benchmarks **Driver:** Professional leadership **Barrier:** BIM approach	**Constraining:** Professional knowledge/ skills **Enabling:** Government financial initiative	**Dialectic of control:** Limited for the design team; lack of available benchmarks and professional skills. **Position practice relations:** Main architect drives inner norms for project that relate to sustainability.	EC target not set, no BIM information management. However, EC considerations and assessment included as part of project requirements.	Enhances status quo.

7.4.2 Condition-Mechanism-Outcome (CMO) for 'How EC considerations are addressed'

For CS1 EC considerations were limited; no LCA was conducted for the project and as such, BIM was not used as an EC information management tool. One barrier for this was the lack of LCA skills by the principal design team and the project's sustainability consultant. The 'Complexity of BIM model data' and 'EC secondary data reliability' acted as constraining conditions to the lack of LCA skills by the project team to address EC considerations. The project team requested for LCA and BIM consultants to be added to the team to address this skills gap, however, this was not actioned by the client due to the increased cost that the consultant appointment would incur. As such, 'Client ambitions' acted as another barrier and 'Cost' was a constraining condition for EC considerations to be addressed for the project. The project 'Scheduling' was also identified as a constraining condition, particularly in relation to BIM application for the project, as the tight project timetable resulted in discrepancies amongst the BIM models of the respective professional teams. The project outcome for CS1 shows preservation of the industry's status quo. For both CS2 and CS3 LCA was conducted; however, in CS2 the BIM model was only used to extract building element data whereas in CS3 the BIM model was used directly to perform the LCA. As such, the CS2 project outcome shows an enhancement of the industry status quo, whereas CS3 shows transformation. The two cases also present differences in relation to the conditions that affected this outcome. For CS2, the driving condition for the project outcome were 'Client ambitions', with the client driving a holistic approach to addressing the carbon impact of the project. The main enabling condition was 'Team appointments' that secured LCA skills for the project through the appointment of LCA consultants. The barrier to using BIM directly for the LCA appeared to be the 'Complexity of BIM model data'. The LCA for CS2 was conducted through the use of the LCA consultants' in-house built spreadsheets. For CS3, the driving condition for this outcome was the 'Professional leadership' shown by the lead architect of the project. The main enabling condition was the 'Government financial initiatives' which acted as an incentive for both the client to include LCA for the project and for the architectural practice to upskill their workforce and acquire the required software to be able to perform the assessments. For both CS2 and CS3, the project ‘Scheduling’ and ‘Contract’ also appeared as enabling conditions for addressing EC considerations. For CS2 the project scheduling was made so that it enabled the respective BIM models of the professional teams to be checked and federated LCA to take place whereas for CS3, flexibility in project scheduling allowed for the architect team to both gain the required LCA skills and perform the assessments. With regards to the projects’ contracts, in both CS2 and CS3 the contracts included clauses to safeguard the performance requirements of specified materials during the construction stage.

For CS1, as the design team did not have the required LCA skills and the client did not respond to their request for LCA experts to be appointed, the dialectic of control of the design team for addressing EC considerations through whole-life carbon assessment was limited. The client appeared as the power holder over the required project ‘Team appointments’ and ‘Cost’. For both CS2 and CS3 the design team appeared to have high dialectic of control over addressing EC considerations for the projects. For CS2 the client appeared as the power holder; however, unlike CS1, the client exerted this power to enhance the ability of the design team to address EC considerations. For CS3, the dialectic of control of the design team was enhanced by outer facilities in the form of available funding and tax relief.

Whereas position practice relations for setting and communicating EC considerations was focused on the relations between the client and the design team, when considering how EC considerations are addressed, it is the position practice relations amongst the design team professionals that appeared to be triggered as a mechanism affecting the project outcome. For both CS2 and CS3 where LCA took place, the professionals involved in the EC information exchange process were the LCA consultant (for CS2 only), the architect, the structural engineer, the MEP engineers and the appointed sub-contractors past tender stage. In both cases, the quantity surveyor had limited to no involvement in the process. As mentioned above, for CS2 LCA was conducted by the appointed LCA consultants, whereas for CS3 LCA was conducted by the project architect. As such, the position practice relations observed amongst the professional teams for the two cases were different. For CS2 the introduction of expert roles warranted a higher degree of coordination and collaboration amongst the design team which was achieved through enhanced BIM information management. Throughout the design process, the professional teams updated their respective BIM models which were then used for the project federated BIM model. The federated BIM model was maintained by the project's BIM information manager. This was then used by the LCA consultants to extract quantity information for the LCA. For CS3, the position practice relations appeared to have the architect in the leading position in relation to EC information collation and its input to the BIM model. The architect collated the required information from the other design team professions when this was required for the assessments and then updated their BIM model with that information. The complexity of the BIM model data was reduced as the data was input solely by the architect, who then used the BIM model directly for LCA. As such, the information management requirement for the project was reduced. It can therefore be discerned that the requirement for information management is linked to the degree of control over the BIM model data input by the professional performing the LCA. For a higher degree of control over the BIM model data input, the requirement for information management was reduced, whereas for a lower degree of control over the BIM model data input, the requirement for information management was increased. An observation related to the position-practice mechanism concerns the professional practice of the architect. For CS2, both LCA and BIM information management was made by appointed consultants. However, for CS1 and CS3 that did not have expert appointments, it was observed that for CS1 the federated model was managed by the architect and for CS3 the architect team undertook the LCA. It can therefore be seen that for the two projects where there was a lack of expert appointments, the architect role expanded to undertake these tasks. Such observation of practice leads to the potential requirement for re-defining the role of the architect and the position practices that relate to BIM application and LCA. Table 7.7 presents the CMO comparison between the three case studies for 'How EC considerations are addressed'.

Table 7.7 'How EC considerations are addressed cross-case CMO comparison.

Case Studies	Conditions		Mechanisms	Outcome	
	Driver/ Barrier	**Enabling/ Constraining**		**Project**	**Contextual**
CS1	**Barrier:** Professional knowledge/ skills Client ambitions	**Constraining:** Complexity of BIM model data EC secondary data reliability Cost Scheduling	**Dialectic of Control:** Limited for the design team due to client administrative power over project's facilities and norms.	Limited EC considerations in building design, no whole building LCA. No use of BIM model for EC assessment.	Preserves status quo.
CS2	**Driver:** Client ambitions **Barrier:** Complexity of BIM model data	**Enabling:** Team appointments Scheduling Contract	**Position practice relations:** Team appointments introduced expert roles to the team which resulted in enhanced coordination and collaboration. **Dialectic of Control:** High for the design team through inner facilities and norms. Low for LCA consultant over BIM model data input	BIM model use for building element data extraction but not for LCA assessment.	Enhances status quo.
CS3	**Driver:** Professional leadership	**Enabling:** Government financial initiative Scheduling Contract	**Position practice relations:** No expert roles introduced. Architectural practice at a leading position in relation to EC information and use of BIM for LCA. **Dialectic of Control:** High for the design team through outer facilities and inner facilities and norms. High for architect performing LCAs over BIM model data input	BIM model used directly for LCA.	Transforms status quo.

7.5 Conclusions

The previous sections of this chapter compared the outer and inner contexts of the three case studies and the Condition, Mechanism and Outcome (CMO) configurations for the two outcome categories ‘How EC considerations are set and communicated’ and ‘How EC considerations are addressed’. The CMO configurations enabled the identification of initiating conditions that acted as a driver or barrier and conditions acted as enabling or constraining for the project outcomes. The mechanisms were theoretically informed and considered ‘Position-practice relations’ and ‘Dialectic of control’; however, they were triggered in different empirical manifestations for the two project outcome categories. For the ‘How EC considerations are set and communicated’ outcome category, position-practice relations concerned relations between the client and the design team in legitimising inner project norms whereas dialectic of control was triggered in relation to the design team access to inner project resources. For the ‘How EC considerations are addressed’ outcome category, position-practice relations concerned relations within the design team whereas dialectic of control was triggered in relation to BIM model data input of the project. Through the comparison of the CMO configuration of the three case studies and the consideration of the project outcomes in relation to the industry status quo, two pathways can be proposed for each outcome category that consider the conditions and mechanisms required to enable the project outcomes to enhance or transform the industry status quo.

7.5.1 How EC considerations are set and communicated

For both case studies that included EC considerations (CS2 and CS3), the driving conditions for EC consideration inclusion were interpretative schemes; ‘Client ambitions’ for CS2 and ‘Professional leadership’ for CS3. As such, EC consideration inclusion can be either client or design team driven. When client drives EC considerations for the project, the main enabling condition is inner facility ‘Team appointments’ to ensure the professionals appointed have the required skills for LCA and BIM application. The position-practice relations that concern legitimising project norms are balanced between the client and the design team. The dialectic of control of the design team over inner project resources is high as the client employs their power over project resources to facilitate the design team and overcome potentially constraining outer facilities and norms such as lack of EC benchmarks. As such, the dependence of the design team on outer conditions is low.

When the design team drives the EC considerations for the project, the main enabling condition is outer facility ‘Government financial initiative’ which enables the design team to incentivise the client for inclusion of EC considerations. The position-practice relations that concern legitimising project norms are shifted to the design team for this pathway. The dialectic of control of the design team over inner project resources is low due to the client’s control over project resources. As such they have high dependence on outer conditions which can be potentially constraining. Figure 7.2 shows the two pathways for ‘How EC considerations are set and communicated’.

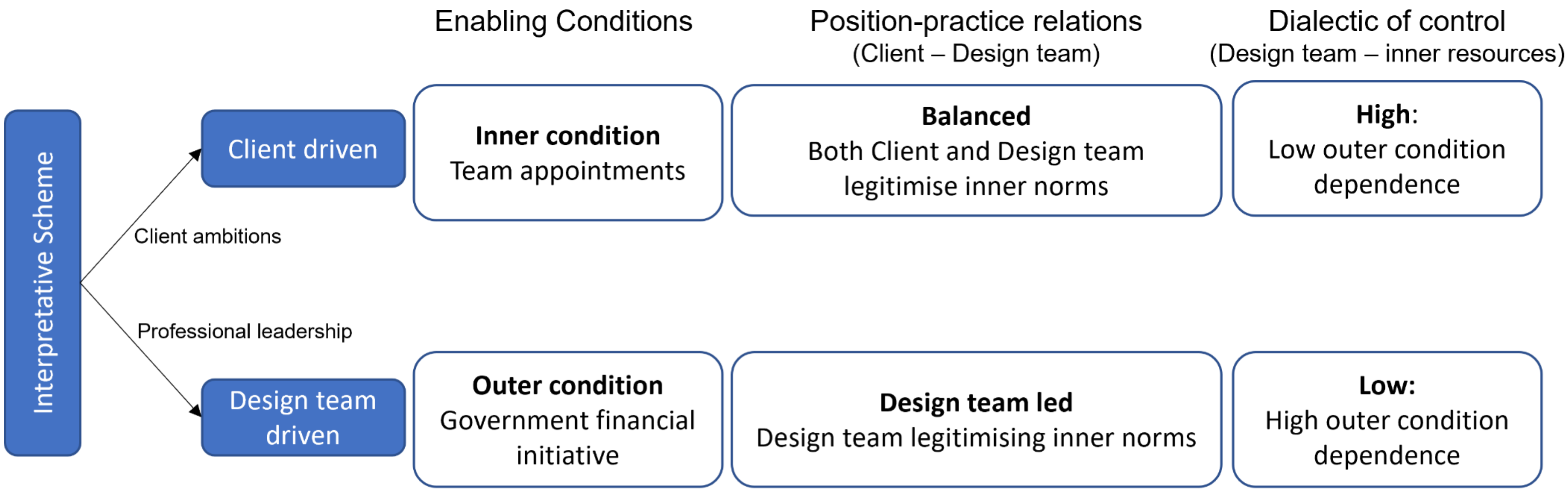

Figure 7.2 Two pathways for how EC considerations are set and communicated.

7.5.2 How EC considerations are addressed

For both cases that EC considerations were addressed and LCA was conducted, interpretative scheme 'Professional knowledge/skills' was the condition that ensured the main enabling condition. However, for CS2, the LCA assessment was conducted by the appointed LCA consultant, whereas for CS3 by the project lead architect.

When LCA is conducted by consultants, the enabling condition is the inner facility 'Team appointments' which addresses the professional skills requirement and introduces new roles and relations amongst the project design team. As the BIM model data input is made by the respective professionals and not by the consultant conducting the LCA, the dialectic of control over the BIM model data input is low. This creates a high information management requirement. As such, a strong BIM approach through the appointment for a BIM information lead is required. This also falls within the 'Team appointment' enabling condition to address this high information management requirement through BIM application.

When LCA is conducted by a member of the principal design team, the enabling condition is 'Government financial initiative' which addresses the skills development of the design team and the requirement for inner facilities such as LCA software purchase. The position-practice observed in this case is an expanded role for the principal design team professional, which in CS3 was the project lead architect to include LCA as part of their practicing tasks for the project. In this case, as the architect directly inputs the data to the BIM model, the dialectic of control over BIM model data input is high, and the requirement for information management through BIM is low. Figure 7.3 shows the two pathways for 'How EC considerations are addressed'.

Inner facilities 'Scheduling' and 'Contract' are enabling conditions for both pathways. 'Scheduling' for projects that LCA consultants are appointed needs to ensure that the time required for the assessments to be conducted is incorporated to the project timetable. For the pathway where the LCA is conducted by a design team professional, the project timetable needs to allow for flexibility when LCA skills development is required by the professional. The project contract needs to include clauses to secure low EC impact material specification made by the design team during the construction stage. This is particularly important for Design and Build procurement for which the design responsibility is novated to the contractor at the end of the design stage.

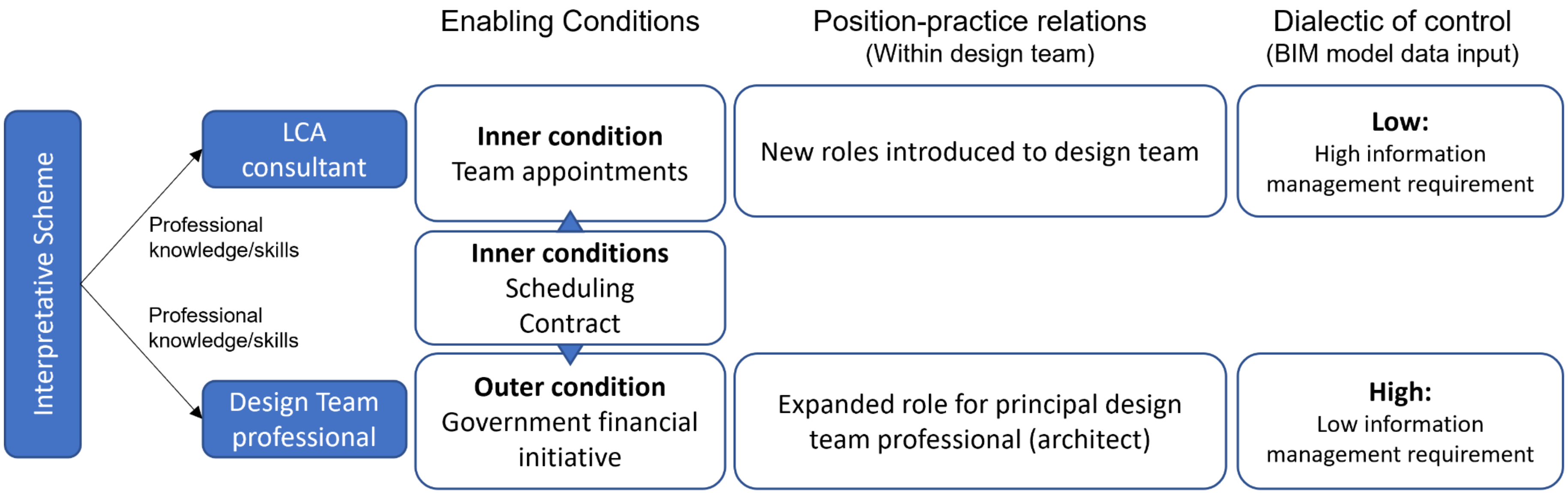

Figure 7.3 Two pathways for how EC considerations are address

This chapter compared the contexts of the three case studies and considered the conditions and mechanisms that affected the project outcomes that relate to 'How EC considerations are set and communicated' and 'How EC considerations are addressed'. The project outcomes were also considered with regards to their relation to the industry's status quo. This analysis resulted in the development of two pathways for each outcome category to enhance or transform the industry's status quo. The following chapter discusses the research findings in relation to the literature and considers the contribution of the findings to the body of knowledge that relates to the topic area of this research.

Chapter 8 Discussion

8.1 Introduction

This chapter reflects on the main findings of this research and relates them to relevant literature. The chapter is organised around the two topic areas of this research, ‘How EC considerations are set and communicated’ and ‘How EC considerations are addressed’. The findings within both topic areas were analysed in relation to the four themes that emerged during the research analytical process: ‘Position-practices’, ‘Dialectic of control’, ‘Outer and inner context impact’. From the analysis, the study’s theoretical, methodological and empirical contributions were derived and are presented at the end of the chapter.

8.2 How EC considerations are set and communicated

8.2.1 Client could be an enabler, or a barrier for embodied carbon considerations

An extensive literature review on the drivers for green buildings conducted by Darko et al. (2017) has identified clients as one of the ten top drivers mentioned in literature; however this refers to green buildings which is a wider scope and does not specifically consider EC considerations. The UK Green Building Council in 2017 issued a report aiming to provide guidance to clients for the inclusion of EC considerations and measurements in building projects (UKGBC 2017). In the report the clients are mentioned as instigators of the sustainability approach of projects. As such, the report suggests that EC considerations can be introduced to the industry as a response of the supply chain to the client demands. While the clients could be instigators, in the empirical work presented in the thesis, it was observed that for CS1 ‘Client ambitions’ were restricted to sustainability ratings and become a barrier for EC inclusion (section 6.2.3). Unlike the design team professionals, clients don’t have sustainability expertise and tend to prioritise decisions on the basis of capital cost reduction of the project, which is what was observed in CS1. Thus, while EC considerations are dependent on the client, this can either be a barrier or a driver for EC inclusion to design considerations.

It is highly important to incentivise clients for EC consideration inclusion in building design. Orr et al. (2019) highlight the need to align incentives of clients, design team and policy makers in order to achieve reduced EC in building structures. The need to incentivise and also educate clients was acknowledged by Schweber and Haroglu (2014) whose study urged policy makers to adopt a capacity building approach for enabling sustainable building construction. As observed in all case studies of this research, the client controls project resources and as such is in an administrative power position in relation to the design team (section 7.3). As such, the client appears as an important actor affecting EC consideration inclusion. In CS3, the Government financial initiative acted as an incentive for the client to include EC considerations and assessment for the project (section 6.4.3). Thus, the findings of this study highlight the importance of top-down initiatives in enabling EC considerations through incentivising clients.

8.2.2 Professionals as middle agents for embodied carbon considerations

Apart from client ambitions, professional leadership can also be a driving condition for EC consideration and inclusion. In CS3, the project architect was the professional that showed leadership and pushed for EC considerations to be included for the project and for their architectural practice to make the necessary investments and staff upskilling to include LCA as part of their services (section 6.4.3). Thus, professional leadership is not just relevant to companies or practices, but it can be down to the individual to drive change for both a project and incorporating EC as part of the services of the practice. This finding aligns with Moncaster et al. (2019)'s study which demonstrated the importance of individual team members in driving innovation, as the design team pushed for the innovative use of materials to reduce environmental impact. Moreover, socio-technical transitions literature has also highlighted the significance of innovation emerging in niches through dedicated actors (Verbong and Geels (2010). Janda and Parag (2013) suggested that building professionals could be considered as middle agents that can drive low-carbon innovations and practices. However, when focusing specifically on EC, Pomponi et al. (2020) contended that the fragmented experience of industry practitioners in tackling EC creates the requirement for the client to contribute towards the inclusion of EC to projects. Indeed, in CS1 a fragmented carbon approach by different professionals of the design team was observed which was related the different levels of knowledge and skills in tackling EC. Professional leadership was shown through the request of the appointment of an expert to facilitate EC considerations and assessment for the project; however, this was not facilitated by the client (section 6.2.3). In CS3 on the other hand, professional leadership by the design team was successful in incorporating EC considerations to the project, for which the incentivisation of the client to agree to the inclusion of EC considerations played a determining role (section 6.4.3). Thus, this study supports that both professional leadership and the client are necessary for the inclusion of EC.

8.2.3 BIM information requirement setting requires expertise that clients do not have

With regards to EC information management and communication, according to the BIM standards available during the design stage of the case studies, the client is expected to set the information requirements for the project. Blay et al. (2019) studied managing change in BIM level 2 projects and one of the change management challenges they identified was the insufficient prescription of project information requirements by clients. Dowsett and Harty (2019) also found that lack of clarity of information requirements by clients posed challenges for projects which resulted as a barrier for information delivery for the different professions of the design team. Lindblad (2019) has questioned the view that clients are the '*single most essential change agent*' for information management and collaboration through BIM. The results of this thesis concur with these studies with regards to the challenges posed due to the client's inability to fulfil responsibilities in setting information requirements. Clients commonly lack the expertise to establish these requirements in relation to EC information. This results in lack of EC considerations in the Employers Information Requirements (EIR) or complete lack of setting these requirements for the project. For CS1, the design team acknowledged the need for a BIM information lead to be appointed to enhance the project's information management, but this was not facilitated by the client (section 6.2.3). In the absence of a BIM expert, the architect team managed the federated BIM model of the project, which showed an expansion of the architect role as part of its position-practice for the project.

8.2.4 Balanced position-practice relations between the design team and the client are crucial for EC considerations and a BIM approach that supports them.

The position-practice relations between the client and the design team were found to affect the way inner project norms such as the sustainability approach and BIM approach of the project (structures of legitimation) are defined for projects, which has an impact on both the inclusion of EC considerations as well as the use of BIM as an information management system for the communication of EC information requirements (section 7.5.1). The importance of design team appointments cannot be overstated, especially when it comes to incorporating EC considerations into building design and BIM application due to the lack of client expertise in these areas. Banteli et al. (2018) emphasize the critical role of the early appointment of a Sustainability Coordinator (SC) for ensuring the inclusion of EC in design considerations whereas Morgan (2019) suggested that BIM adoption depends amongst other factors on leadership support of the design team. Balanced position-practice relations between the client and the design team were observed in CS2 which enabled the design team to contribute to project's EC considerations and information management through BIM (section 7.4.1). Thus, the findings from this thesis highlight the importance of balanced position-practice relations between the client and the design team for the enhancement of the design team input on setting the project's approaches that relate to EC inclusion and BIM application for projects.

8.2.5 Interdependencies between inner and outer resources of a project

As project resources are mainly controlled by the client, when EC consideration inclusion is design team driven project resources that can facilitate EC inclusion such as the project budget and team appointments that ensure the required professional skills for LCA are not easily accessible to the design team (section 7.5). As seen in CS1 (section 6.2.4) and CS3 (section 6.4.4), the design team had low dialectic of control over inner project resources which resulted in higher dependence on industry-wide resources such as Government financial initiatives and benchmarks, guidance and secondary databases that relate to EC. The dependence on outer resources is even higher when the professionals are novice to LCA, as observed in

CS3. Although there are studies that have considered the lack of industry and project resources (Akadiri 2015; Anand and Amor 2017; Pan and Teng 2021) and the lack of competencies by professionals (Pomponi et al. 2020) as barriers to EC considerations, there is lack of literature that considers the interdependencies between inner and outer project resources and their relation to the capabilities of professionals for EC inclusion. Thus, this thesis addresses this gap by establishing a relation between the design team dialectic of control over inner project resources and their dependence on outer resources.

8.2.6 Project cost and top-down financial initiative impact on EC considerations

Although adding EC considerations to building projects incurs additional cost for the project as part of the LCA fees or through the use of low EC impact materials, EC considerations don't necessarily result in an overall capital cost increase for the project. For CS2, reduction of material use as part of the efforts to reduce the project's EC impact resulted in greater savings than the cost of the LCA consultant fee (section 6.3.2). The potential of reduction of a projects' capital and operational cost through addressing EC was noted by Anderson and Adams (2020) who advocate that addressing EC can be considered as a means of cost management of building projects. The authors also include case studies for which cost savings were achieved through addressing EC. Akadiri (2015), however, found that practitioners' perceived that the selection of low environmental impact materials incurs additional costs for building projects and this was identified as the main barrier for the use of these materials in specification. Quantification of the impact of EC consideration inclusion on the project cost was beyond the focus of this thesis; however, this research highlighted that further research on this topic would better inform clients and practice about the impact of including EC considerations on projects' cost. The requirement of comparative information that relates to the cost of sustainable materials and techniques was also noted by Akadiri (2015).

As cost appears to be an important factor to clients for EC consideration inclusion, top-down financial initiatives can act as incentives for EC consideration inclusion. Government financial initiatives such as funding for innovative projects can facilitate LCA for projects by requesting LCA as part of the conditions to secure the funding whereas initiatives such as tax relief for companies that engage in research and development can support companies to cover costs for required LCA software as was observed for CS3 (section 6.4.3). Oluwole Akadiri and Olaniran Fadiya (2013) in their study on the determinants of environmentally sustainable practices in the UK construction industry identified Government regulation to be the most important driver of sustainable practices. However, currently there is lack of government regulation that relates to EC in the UK. As such, top-down incentives in the form of financial initiatives that include EC as part of their requirements can facilitate the EC inclusion for building projects. Green financial schemes that promote the inclusion of EC such as green bonds have been noted by Anderson and Adams (2020) who include examples of national and international financial incentives that include EC as part of their requirements. The findings of this thesis expand the view of Anderson and Adams (2020) that access to green financial initiatives is one of the benefits of EC consideration inclusion and reinforces the importance of these initiatives for EC inclusion for building projects.

8.3 How EC considerations are addressed

8.3.1 Developing new and expanding existing professional skills

To address EC considerations, the enabling condition was professional skills that relate to life-cycle assessment of the building design. These skills were either available to the project through the appointment of LCA consultants as observed in CS2 (section 6.3.1) or through one of the principal design team professionals, which was the project architect for CS3 (section 6.4.1). As can be seen there are no clearly established roles as to who is responsible for addressing EC considerations for projects. Regardless of who is responsible to address EC and perform the LCA for a project, a collaborative approach amongst the design team is required; however, the carbon approach of different design team members may vary.

The way that the professional skills are brought to the project constitute two pathways for addressing EC considerations for projects (section 7.5.2). For both pathways a shift in position-practices within the team is required. When professional skills are brought by the appointment of LCA consultants, this shift in position-practices is expressed through the introduction of new roles to the design team. When professional skills are brought by a principal design team professional, the shift in position-practices is expressed through the expansion of the role of the professional, as was observed in CS3 for the project architect. Abbott (1988) in his seminal work on the systems of professions gives an extensive analysis on how change in the system of professions generated by external forces generates new task areas that are addressed either by existing or new professions. New knowledge or skills are mentioned in this analysis as internal sources that complement external sources in changes of professional systems. Skills that relate to LCA can be considered such an internal source. According to the above, the requirement to address EC considerations can be considered as an external source whereas the required LCA skills as an internal source for change in the systems of professions for building projects. The two pathways suggested in this thesis show how these are reflected in practice through the establishment of new or expanded roles within the design teams.

In both case studies for which EC considerations were addressed (CS2 and CS3), the project's Quantity Surveyor (QS) had limited if any involvement to the LCA process (section 6.3.3 and 6.4.3). As QS is the profession involved in aggregating material quantities for the project costing, QS have been mentioned in literature as the profession that could be involved in providing the material quantity information required for the LCA (Anderson and Adams 2020). The UK Green Building Council has also stated that QS are one of the professions to be involved in initial discussions about EC of projects (UKGBC 2015). Notably, a very useful resource for the UK industry for addressing EC is the Royal Institute of Chartered Surveyors (RICS) *Whole life carbon assessment for the built environment*, which is a professional statement document for RICS members (RICS 2017). The statement is mandatory for RICS members and is intended to provide guidance for the standardisation of LCA. Although the document is accessible and can be used as guidance by other professions, the fact that it is addressed as a mandatory requirement by the RICS professional body demonstrates an expectation of the profession's involvement in LCA. Giesekam and Pomponi (2018) consider that LCA knowledge relates to QS and sustainability specialists and fail to recognise that despite the guidance available to QS, QS knowledge and involvement in the LCA process in practice is not necessarily as expected. As such, the findings of this thesis show limited involvement of the QS professionals in addressing EC for the case studies considered in this thesis which contradicts current literature and the industry’s expectation in relation to the involvement of the QS profession in the LCA process. Wu et al. (2014) conducted a review on the BIM-based cost estimating practices of quantity surveyors in the UK. The study highlights the capability of automatic quantity take-off through BIM as a great opportunity for the QS profession to address the traditional time-consuming cost estimation process. However, the study found that the QS professionals in the UK were struggling to adopt the use of BIM for cost estimation. Although this study focuses on BIM use by QS for cost estimation, the use of BIM for material quantity information is also relevant to LCA. This thesis found that the QS were not involved in providing material quantities for LCA in the case studies and that QS professionals’ lacked familiarisation with BIM; which concurs with the Wu et al. (2014) publication.

8.3.2 Lack of carbon approach consensus between different professions

Another finding related to position-practice was observed in CS1, where the lack of an established approach to address EC for the project led to the variations to carbon approaches by different professions of the design team (section 6.2.3). Lack of consensus amongst professionals was also identified by Orr et al. (2019) in their study that focused on engineering practitioners’ views on use of efficient use of structural materials for EC reduction. The finding of this thesis expands on this by identifying that lack of consensus does not only relate to engineering practitioners and structural material efficiency but is visible in the carbon approaches by the different built environment professionals of the design team such as architects and structural engineers (section 4.3.3). This finding agrees with Pomponi et al. (2020) who noted that there is fragmentation amongst different communities of practice in the building sector with regards to their knowledge and approaches towards tackling EC.

Industry-wide resources such as guides and benchmarks that relate to EC are enabling conditions that can address this lack of consensus, particularly for the pathway where LCA is conducted by a principal design team member who is novice to LCA as was the case in CS3 (section 7.2.1). This agrees with Pomponi et al. (2020) who found that although there is currently some EC guidance available to industry, practitioners desire more and improved resources in the form of guidance, benchmarks, data and tools.

8.3.3 Lack of trust in the BIM model and the relation between model data input and information management requirement

As mentioned in section 2.5, BIM can facilitate addressing EC considerations either through information management or through the use of the BIM model to perform the life-cycle assessments (LCA). Through the aggregation of EC impacts from element level to building level, the BIM model can reduce the complexity of whole-life carbon calculations, which has been identified as one of the barriers for tackling EC (Capper et al. 2012). However, BIM model use for conducting LCA relates to BIM model data input and eventually trust in the BIM model. BIM model fragmented data input by the different professional teams can result in lack of trust in the BIM model's reliability for its direct use for LCA. This was mentioned by the sustainability consultant of CS1 (section 4.3) and observed in CS2 (section 6.3.3). Indeed, in a study that compared LCA results using an LCA tool and a BIM plug-in, Bueno and Fabricio (2018) found discrepancies between the results generated by the two different tools. The authors ascribed the discrepancies to simplifications of the BIM model made by building designers who are not familiar with the information requirements for LCA. Hollberg et al. (2020) had similar findings in their study evaluating BIM-based LCA results for building design; they found that LCA results during initial stages of the design were misleading due to the input of 'placeholder' materials in the BIM model that lacked the appropriate detail for the assessments. The importance of BIM model data input and their impact on the accuracy of LCA results has also been stressed by Anderson and Adams (2020).

For CS2, carbon assessment was made by LCA consultants who had low dialectic of control over the BIM model data input (section 6.3.3). The lack of trust in the BIM model was addressed through enhanced information management for the project and the BIM model was used for extracting material quantities but was not used directly for LCA. The BIM model was used directly for LCA in CS3, where BIM model data input and LCA was conducted by the project architect (section 6.4.3). Although CS3 was a BIM level 1 project and as such BIM was not used for the project's information management, the high dialectic of control of the architect over the BIM model data input enhanced trust in the BIM model and facilitated the use of the BIM model for the LCA. This showed that the requirement for information management through BIM is not deterministic for the BIM model use for LCA, but that it is linked to the degree of control over the BIM model data input by the professional performing the LCA. The information management requirement is increased for a lower degree of control over the BIM model data input. By definition, BIM is not merely a software but a process that encapsulates information and data management to which multiple benefits of BIM application are attributed (Succar 2009; Eadie et al. 2013). However, there is lack of empirical studies that jointly consider who performs the LCA, their control over the BIM model and information management requirements (section 2.5). Considering the two different pathways with regards to the professional performing the LCA, this thesis has revealed a relation of dialectic of control over BIM model data input and information management requirement through BIM.

8.3.4 Including EC considerations in project management and procurement contract processes

In both pathways for addressing EC considerations (section 7.5.2), the project's scheduling and contract were found to be important conditions for enabling EC to be addressed. Reducing the project's EC impact requires alternative design options to be assessed in relation to their life-cycle carbon impacts, which in turn requires time for the assessments to take place. As such, accounting for this time in the project scheduling is essential to enable alternative design options assessments. Akadiri (2015) includes a similar finding according to which project tight scheduling acted as a barrier for building professionals to consider sustainable alternatives when specifying materials. Although design stages during which LCA assessments should take place have been stated by guidance documents for the inclusion of EC (UKGBC 2017; Anderson and Adams 2020), a clear requirement to incorporate time allowances for these assessments to the project scheduling is not explicitly raised. The requirement for appropriate project scheduling that accounts for design optimisation stages has been identified by leading industry practices, who have stressed the importance of scheduling to design optimisation to consider EC impacts (Buro Happold 2022).

For project contracts where the design responsibility passes from the design team to the contractor during the construction stage, the materials specified by the design team may be substituted by the contractor. As such, the addition of clauses to the contract that safeguard the material choices made by the design team as was observed for CS2 and CS3 are essential. This finding agrees with Anderson and Adams (2020) who highlight the importance of incorporating EC in the project procurement process and include examples of projects that have included carbon reporting and LCA requirements as part of clauses of the project contract. LETI (2020b) also stresses the requirement for low carbon alternatives and EC standard clauses for material specification to inform the procurement process. The finding of the thesis reinforces the guidance available to industry and stresses the importance of project contracts and procurement as an inner project resource that can facilitate the reduction of EC impacts of projects.

8.4 Theoretical development for explanatory accounts of EC considerations in BIM-enabled projects

8.4.1 Looking from the position of critical realism to explain how EC considerations are set and addressed in BIM-enabled projects

The empirical contributions of this study stem from the critical realist view taken in relation to the topic. As discussed in section 2.5, literature that considers EC considerations in BIM-enabled projects has mainly focused on the technological aspects BIM for EC assessment. This technological deterministic approach views technology as an external force that shapes the actions of individuals and therefore as the primary driver of technological-related change (Symon 2000). Technological determinism however has been criticised by socio-technical scholars who argue that it fails to account for the unstable character of technological innovation (Callon 1986; Latour 1990). Furthermore, Plesner and Horst (2013) have highlighted that technological determinism focuses on potential technological benefits disregarding the challenges faced during localisation and appropriation of the technology. Social constructionism on the other hand gives primacy to the perceptions individuals and meanings that derive from social interaction and fail to account for structures and their impact in their analyses (Rex et al. 1998). Critical realism aims to explain empirical outcomes through revealing structures, powers and relations that work beneath the surface. The significance of this study lies in approaching EC considerations in BIM-enabled projects through this critical realist approach and considering not only technological capabilities but also social structures at both industry and project level that contribute to EC consideration inclusion and the contribution of BIM in communicating and addressing them.

This study revealed that two mechanisms 'position-practices' and 'dialectic of control' were manifested and brought new knowledge about the way these mechanisms relate to the power relations amongst actors and the inner and outer project structures. **Position-practice relations** between the client and the design team affect the way project norms such as the sustainability and BIM approaches (structures of legitimation) are defined for the project (section 7.5). These approaches relate to the incorporation of EC considerations to the project and their communication through BIM. Balanced position-practices between the client and the design team can facilitate the enhancement of the sustainability approach to include EC and a strong BIM approach that enables the communication of information requirements for the project. The significance of this study also lies in the revelation of **discrepancies in relation to position-practices** as expected by current policy and as observed in practice. The first discrepancy concerns the role of the client in setting the information requirements for projects (see section 8.2.3). Another discrepancy concerns the role of quantity surveyors (QS) in providing material quantity information for the LCA (see section 8.3.1). Existing studies on sustainable design and EC considerations in BIM-enabled projects have focused on the roles and responsibilities of professionals in the BIM-enabled building process (Zanni et al. 2017), the changes required in professional roles to address new environmental challenges such as EC (Bresnen 2013) and the role of professionals to act as middle agents to drive the low-carbon agenda for the building sector (Janda and Parag 2013). However, social systems and not formed by roles but of reproduced practices, which serve as points of connection between actors and structures (Giddens 1979). The notion of position-practices expands the concept of professional roles and enables insights about how situated actors and their relations shape structures that affect EC considerations in BIM-enabled projects. This situated approach also enables the revelation of discrepancies between role expectations and how these transpire in real-life contexts.

This study also contributed through revealing a relation between the **dialectic of control** over inner project resources and dependence on outer resources for the design team. The dependence of the design team on industry-wide resources is higher when their power over inner resources is low. This dependence is even greater when the design team professionals are novice to EC considerations and LCA (section 7.4). Another relation revealed was that of dialectic of control over the BIM model data input and information management requirement. The information management requirement was lower when the BIM model data input control of the professional conducting the LCA was higher (see section 8.3.3). The contribution of this relation extends and questions technological deterministic views about the requirement of BIM information management (cf. Cavalliere et al. 2019; Chen and Lu 2019) and debates over BIM model use for LCA that place their focus on lack of professional skills or software compatibility of the BIM model (cf. Soust-Verdaguer et al. 2017; Hollberg et al. 2020; Hollberg et al. 2022).

This study also contributes to new knowledge by highlighting **structures** at both industry and project level that affect EC consideration inclusions and how they are addressed. Capital cost of projects appeared an important factor influencing clients in relation to EC consideration inclusion, with clients prioritising decisions to reduce the cost of projects (see section 8.2.5). However, this study revealed that the relation of capital cost and incorporating EC considerations and LCA for projects is not clear. Although it was not the focus of this study, this study identified factors that can increase (such as higher costs for low EC impact materials compared to alternatives) and factors that can decrease (such as reduced overall material use for projects) a project’s capital cost in the effort to tackle EC impacts for projects. Whilst literature that have considered top-down measures for EC inclusion mostly focus on the requirement for EC legislation and standardisation of EC calculation and reporting (cf. Oluwole Akadiri and Olaniran Fadiya 2013; Pomponi et al. 2020) this study has highlighted that industry-wide structures in the form of financial initiatives are essential to influence clients and empower professionals that show leadership in driving EC inclusion. This research has also highlighted inner project structures such as the project schedule and contract as key factors to enable LCA to take place and safeguard design stage material specifications during construction. Whilst the incorporation of clauses that relate to EC in project procurement has been stressed in guidance documents available to the building industry (Anderson and Adams 2020; LETI 2020b), these have not been considered in studies that focus on barriers for EC inclusion that relate to industry and project level structures (cf. Akadiri 2015; Anand and Amor 2017; Pan and Teng 2021). On the other hand, studies that focus on information management and LCA at different design stages focus on what information is required and at which design stage, but have not considered the time required to be allocated in the project schedule for LCA to take place and inform the design development (cf. Cavalliere et al. 2019; Hollberg et al. 2022).

Finally according to Bryman (2001) identifying mechanisms has potential for proposing changes that can transform the status quo. This thesis has synthesised the empirical findings to propose two pathways to transform the industry status quo in relation to EC consideration inclusion in BIM-enabled projects. The two pathways consider the enabling conditions at industry and project level and the position-practice relations between the projects main stakeholders, namely, the client and the design team. The role of BIM in addressing EC considerations is considered in relation to information management requirement and the use of the BIM model to conduct the LCA. This provides a novel contribution to the topic that stems from the critical realist approach adopted which would have not been possible through determinism or constructionism approaches that previous studies have adopted (Pollock and Williams 2010).

8.5 Moving structuration theory forward

8.5.1 Integrating condition analysis and analysis of strategic conduct

This research used structuration theory to analyse and make sense of the empirical phenomenon under study as it was observed in case studies. This study contributes to theory through the synthesis of an analytical framework that combines ‘Conditions analysis’ with ‘Analysis of Strategic Conduct’ to analyse empirical outcomes. Drawing upon Giddens’ call for the study of the conditions in the organisation of social systems (Giddens 1979), the framework incorporates ‘Condition analysis’ to structuration theory's 'Analysis of strategic conduct'. The incorporation of 'Condition analysis' expands the analysis of contextually situated activities through the study of interactions between contextual conditions which enables a deeper knowledge of the hidden impacts of conditions on empirical outcomes. The 'Condition analysis' uses the intermediate dimension of modalities and considers industry and project levels to conceptually address the complexity of social systems. This way the framework introduces the analysis of interactions between elements that lie within the modality dimension, which is novel to the duality of structure diagram introduced by Giddens (1984). The developed framework uses conceptual terms that can be populated with empirical elements to analyse inquiries of contextual situated activities within complex social systems. As such, it can be used across different disciplines for a wide range of empirical inquiries. The framework presents a novel way to operationalise structuration theory in context, which addresses one of structuration theory's criticisms that relates to the difficulty of its application to empirical inquiry (Gregson 1989).

8.5.2 Role of visualisation in operationalising structuration theory

For the application of the theoretical framework to analyse the case studies, social network mapping was used to visualise the framework elements and the links of impact between them. Diagrams were created for the 'Conditions analysis' and the 'Analysis of strategic conduct' that enabled to visualise the network as a whole, isolate groups of elements for analysis and focus on specific elements or types of impact (direct/ indirect). The importance of visualisation in making sense of complexity has been advocated by many scholars such as Tufte (1990), Shneiderman (1996), Lima (2011) and Johnson (2006) with some also related to the use of visualisation for addressing complexity in architecture (Yaneva 2012). However, the novelty of this research lies in the visualisation of not only empirical data, but a visualisation of empirical data that incorporates theoretical concepts of the framework in the diagram's properties (ie. different colours of elements represent a different conceptual category). This enables both empirical and theoretical underpinnings to be studied alongside in the analysis undertaken.

Chapter 9 Conclusion

9.1 Introduction

This chapter presents a summary of the research conducted to address the research objectives and ultimately respond to the main research question. The key findings of this research are summarised along with the study's contributions to knowledge and their implications. The limitations of this research and future research recommendations are also presented, and the chapter ends with a final reflection.

9.2 Achievement of research objectives

The main research question of this research was *'How are Embodied Carbon (EC) considerations set and realised in a Building Information Modelling (BIM)-enabled building project?'.* To respond to the research question, five objectives were developed as presented in section 1.3.1. Table 9.1 lists the research objectives, the methods that were employed to achieve each objective and the chapters related to the respective objective in the thesis. The rest of this section presents a summary of findings that relate to each objective and where appropriate how these findings informed the research development.

9.2.1 Objective 1: Explore how EC considerations are set and addressed in a BIM-enabled project

The first objective was achieved by conducting the first phase of research which included Professional perspective interviews and an Exploratory Case study. The professional perspective semi-structured interviews were held with industry stakeholders to explore their views on the role of Embodied Carbon (EC) in building design, Building Information Modelling (BIM) application and its potential to facilitate the inclusion of EC in building design. These interviews were not related to a specific building project and informed the engagement with the ethnographic case study. Through the Exploratory case study, a deeper exploration relating to EC considerations and BIM application was enabled within the context of a building design process. The data collection included meeting attendance, project document analysis and interviews with the project stakeholders. The results of this research phase (phase 1) were analysed thematically; the themes were organised in three aggregate dimensions: *People, Process* and *Tools* informed by Leavitt's socio-technical diamond model and the links within and between these dimensions were identified (section 3.3.5).

Table 9.1 Research objectives, the respective methods used to achieve them and main finding summary.

Main research question: *How are Embodied Carbon (EC) considerations set and realised in a Building Information Modelling (BIM)-enabled building project?*		
Research objectives	Methods of achievement	Main finding summary
Phase 1: Exploratory phase		
1. Explore how EC considerations are set and addressed in a BIM-enabled project	-Professional perspective semi-structured interviews -Exploratory Case Study Ethnographic data collection that included meeting observation, project document analysis and interviews with project stakeholders.	- Importance of People dimension - client/ design team distinction as separate actor groups - Client control over project resources - Professional leadership importance - Structure division at industry and project level - Contribution to theoretical framework development (sections 4.2 and 4.3)
Phase 2: Explanatory phase		
2. Analyse the conditions and mechanisms that affect EC target setting and their communication through BIM	Analysis of three case studies; data collection included project document analysis and interviews with project stakeholders. Conditions analysis and Analysis of strategic conduct for 3 case studies	- Professional leadership down to individual - Information requirements by client problematic - Client power over inner resources - Team appointments importance - Position-practice relations mechanism between client and design team for setting project norms (sections 6.2, 6.3, 6.4)
3. Analyse the conditions and mechanisms that affect BIM use for addressing EC	Analysis of three case studies; data collection included project document analysis and interviews with project stakeholders. Conditions analysis and Analysis of strategic conduct for 3 case studies	- Team appointments and Government financial initiatives enabling conditions for addressing EC - Project scheduling importance for addressing EC - Contract importance for safeguarding material specifications during construction stage - Dialectic of control mechanism of design team over inner project resources impact on addressing EC - Position-practice relations mechanism expressed through new roles or expanded role of principal design team member (sections 6.2, 6.3, 6.4)
4. Analyse the impact of context on setting and addressing EC considerations in a BIM-enabled project	Cross-case comparison of the Condition Mechanism Outcome (CMO) configurations for the case studies.	- Client ambitions can be either a driver or a barrier for EC inclusion - The impact of EC reduction efforts on capital cost needs further exploration - Relation of control over inner project resources and dependence on industry-wide resources for the design team - Dependence on industry-wide resources is higher when professionals are novice to LCA - Relation of control over BIM model data input and information management requirement - BIM information management requirement are not deterministic for BIM model use for LCA. (sections 7.2-7.4)
5. Propose recommendations to facilitate EC considerations in a BIM-enabled project	Cross-case comparison of the Condition Mechanism Outcome (CMO) configurations for the case studies.	Two pathways proposed to facilitate EC considerations in BIM-enabled projects considering the enabling conditions and mechanisms identified through cross-case analysis. (section 7.5)

Through this analysis, the importance of the *People* dimension was identified. It was found that themes that related to the Process and Tools dimensions can become drivers or barriers to EC considerations and BIM application depending on how the relevant actors enact and use them. The themes in the *People* either related to the Client or the Design Team of the project, as such a separate consideration these two actor groups was warranted. The current OC focus of industry structures such as legislation and sustainability rating systems were found to influence the project's sustainability approach. The client was found to be the actor that controls project level resources required to facilitate EC considerations and BIM application. Professional leadership by the design team was identified as key to influence the client towards the inclusion of EC considerations and an enhanced BIM application. The analysis showed that Processes and Tools elements can be considered as industry or project level structures, and highlighted the need to further investigate how industry-wide structures affect the way project level structures are controlled through the actors engaged in the projects, namely the client and the design team (section 4.5).

The achievement of this objective contributed towards the development of the analytical framework that was used at the next phase of the research (phase 2) in two ways. Firstly, the findings of Phase 1 revealed the importance of structure and agency and highlighted the need of the development of an analytical framework for Phase 2 which considers both these theoretical constructs. Secondly, the themes that emerged during Phase 1 were used as empirical elements to inform the theoretical constructs of the Phase 2 analytical framework.

9.2.2 Objective 2: Analyse the conditions and mechanisms that affect EC target setting and their communication through BIM

To gain a deeper understanding on how EC considerations are set and the way they are communicated through BIM information management process, the conditions and mechanisms that affected EC target setting and the communication of EC information requirements were analysed for three case studies (Chapter 6). The analysis of this phase (phase 2) was theoretically driven and informed by the empirical findings from Phase 1 (Chapter 5). This deeper analysis enabled the revelation of enabling and constraining conditions as well as causal mechanisms that related to the outcomes. The outcomes were considered both at project level and contextual level, with the former considering how EC considerations were set and communicated in each case study and the latter considering how the project level outcome related to the industry status quo.

For CS1 outer conditions appeared as constraining EC target setting and information management through BIM. The client was the main actor influencing both these aspects for the project. The heavy focus of regulation and rating systems on OC influenced the project's sustainability approach and resulted in the lack of EC targets for the project. BIM standards that placed the responsibility of information management requirements on the client resulted in a poor BIM application with regards to information management for the project. The position-practice relations mechanism between the client and the design team was manifested by an overriding of the design team role by the client in relation to setting the sustainability and BIM approach for the project (section 6.2).

For CS2, the client was the main actor driving EC considerations and BIM application for the project; however, outer norms did not appear as a constraining condition for the project. The client's high sustainability aspirations and determination for a strong BIM approach acted as an enabling condition for the inclusion of EC considerations and their communication through BIM. To facilitate these aspirations, the client ensured that the appropriate expertise was available for the project through the appointment of BIM and LCA consultants. As such, team appointments were the main enabling condition for EC target setting and information management through BIM. The position-practice relations mechanism was characterised by a balance where the design team was empowered to actively contribute to how EC considerations were set and communicated for the project (section 6.3).

For CS3, professional leadership was the driving condition for EC considerations to be included for the project. The main actor driving this inclusion was the project architect, who saw the inclusion of EC considerations as their professional responsibility. Outer conditions for this case study included 'Government financial initiatives' which appeared as enabling conditions for EC inclusion. They enabled EC inclusion through incentivising the client to include EC considerations to secure government funding for the project. However, the lack of available EC benchmarks and the lack of experience in LCA by the architect led to lack of specific EC targets for the project. Position-practice relations mechanism for this project showed a power dynamic where the main architect led the sustainability approach for the project. As the project was at BIM level 1, no information management through BIM took place for the project (section 6.4).

9.2.3 Objective 3: Analyse the conditions and mechanisms that affect BIM use for addressing EC considerations

Similarly to objective 2, to gain a deeper understanding of how EC considerations are addressed and the use of BIM to address them, the conditions and mechanisms that affected the EC approach/ assessment and the use of the BIM model for these assessments were analysed for three case studies.

For CS1, although there was no EC target set for the project, professional leadership was shown by the principal design team through requesting experts to be appointed to enhance the project's BIM level 2 approach and facilitate LCA for the project. These appointments however were not facilitated by the client due to the additional cost they would incur. Another constraining condition that related to the BIM model and the design team coordination was the project's tight scheduling. The mechanism that was manifested was that of a low dialectic of control of the design team over project's resources which constrained the design team in their attempts to include LCA for the project and to have an enhanced BIM approach for the project (section 6.2).

For CS2, the appointment of the LCA and BIM consultants was the main enabling condition for LCA and a strong BIM approach for the project. However, industry-wide condition that related to the BIM model data complexity affected BIM model data input and resulted in lack of data in the BIM model required for the LCA. The BIM model in this CS was used to extract material quantity information and where the missing information was overcome though the use of spreadsheets. The positions-practice mechanism for this CS was manifested through the introduction of new roles to the design team introduced through the appointment of consultants. High dialectic of control of the design team was expressed through safeguarding of material choices made during the design stage carrying on during construction (section 6.3).

For CS3, the main enabling condition for LCA for the project was the Government financial initiative which incentivised the client to include these assessments for the project as they were a requirement to secure the funding. It also enabled the selection of locally sourced timber frame construction by covering for the increased cost of the material compared to alternatives. The Government funding also enabled the safeguarding of design stage material choices during the construction stage resulting in a clause related to this in the project contract. No expert appointments were made for the project, the LCA for the project was undertaken by the project lead architect. The architectural practice saw this project as an opportunity to expand their services to include LCA, as such there was a learning curve for the architect in performing the assessments for the project. This was facilitated by the project's flexible scheduling which enabled both skills building and the assessments to take place. The BIM model was used directly for LCA and as the project was a BIM Level 1, coordination of information by the respective design team professionals was not done through BIM. Instead, information from the respective professionals was collated by the architect who then updated the BIM model with the collated information. The position-practice relations mechanism for this CS did not include expert roles, but rather an expansion of the architect role to include the LCA task and information coordination for the project (section 6.4).

9.2.4 Objective 4: Analyse the impact of context on setting and addressing EC considerations in a BIM-enabled project

An analysis of the impact of context on setting and addressing EC considerations in a BIM-enabled project was conducted through a cross-case comparison of the three case studies (Chapter 7). The case studies were compared in relation to their outer (industry-level) and inner (project level) contextual conditions, the mechanisms that were triggered and the case study outcomes. This enabled the development of Condition-Mechanism-Outcome (CMO) configurations for the two main outcome categories: 'How EC considerations are set and communicated' and 'How EC considerations are addressed'. The driver/ barrier and the enabling/ constraining conditions along with the mechanisms that were triggered were compared against the outcomes achieved by each case study.

The inclusion of EC considerations to projects was found to be influenced either by the client or by the design team professionals. When it was influenced by the client, this could lead to either the inclusion or the exclusion of EC considerations for the project, as such, the client can be a barrier (CS1) or a driver (CS2) for EC consideration inclusion. Professional leadership can also be a driving condition for EC considerations inclusion as observed in CS3. This was enabled by the available outer condition ‘Government financial initiative’ which the project lead architect used as an incentive for the client to agree on the inclusion of EC considerations for the project. Further to this, leadership was found to be down to the individual rather than practice level for CS3, where the project architect pushed for the inclusion of LCA for the project and for the practice to invest and upskill so that they would provide it as a service for future projects.

With regards to setting a target for EC, for all case studies there was lack of available industry-wide EC benchmarks during the early design stage, which is when project targets are set. However, this had a different impact on the two cases that included EC considerations. For CS2, the lack of available EC targets did not have an impact on setting an EC target for the project as the appointed LCA consultants had the required professional knowledge and experience to establish a target for the project. For CS3 however for which the architect led the EC consideration inclusion and LCA expertise was not available, the lack of available EC benchmarks resulted in lack of an EC target for the project. As such, dependence on industry-wide resources was higher when professionals are novice to EC considerations.

The use of BIM as an information management tool through which EC information requirements can be communicated was also affected by industry-wide resources. BIM standards that give power to client to set the project information requirements rather than reinforce the design team power over establishing these requirements which as above, had adverse impacts for different case studies. For CS1 and in lack of an appointed BIM information manager, this resulted in lack of establishing information requirements for the project and a delayed BIM execution plan. For CS2 however, the appointment of a BIM consultant enabled the establishment of information requirements for the project and an enhanced information management through BIM.

Professional skills played a crucial role in addressing EC considerations; however, these were brought by different professionals for each case study. For CS1, the principal design team lacked the professional skills for LCA and the client did not appoint experts to address this skills gap due to the additional cost this would incur. As such, client ambitions and cost appeared as the main barriers for addressing whole lifecycle impacts for the project. Further to this, the carbon approach by the respective principal design team professionals differed with regards to the extent of the EC impacts considered for material selection. For CS2, professional skills were brought for the project through the appointment of LCA consultants which was secured due to the client high sustainability aspirations. For this project, the capital cost reduction of the project as a consequence an effort to reduce the project's EC impacts through reduced material use was greater than the cost of the fee of the LCA consultants. As such, the overall capital cost was reduced because of the LCA consultant appointment. For CS3 however, the use of lower EC impact materials caused an increase of the capital cost of the project. For CS3 the professional skills were brought by the upskilling of the architect

The use of the BIM model for addressing EC considerations was also different for the two case studies that performed LCA (CS2,CS3). For CS2, although information management through BIM was enhanced, the BIM model was only used for material quantity information and not directly for LCA. The BIM model in this case study was a model federated of the BIM models by the respective professionals of the design team and despite the enhanced BIM approach of the case study, the model still missed some information required for LCA. The complexity of BIM model data which is an industry-wide level context condition resulted in fragmented BIM model data input. Fragmented data or inaccurate data input to the model can lead to lack of trust in the BIM model for its use in LCA. For CS3, the BIM model was used directly for LCA by the project architect. The project was at BIM level 1 and the architect was the one who collated the required information from the respective professionals of the design team and inputted the data in the BIM model. As such, BIM model data input was solely controlled by the architect, who ensured that the data was complete and reliable. Information management requirement through BIM was therefore found not to be deterministic for the use of the BIM model for LCA. Control over BIM model data input was found to be linked to the information management requirement, with a lower information management requirement when BIM model data input control was high.

With regards to industry-wide resources that relate to EC such as secondary databases and guidelines, a higher dependence on them by the design team was found when professionals were new to LCA (CS3) than when experts were appointed for the LCA (CS2). Project level contextual conditions that were found to have an impact on addressing EC was the project schedule and contract. In both CS2 and CS3 where LCA took place, the project schedule had either accounted for or was flexible to include time for LCA to take place and alternative material options to be assessed. The project contract is crucial for safeguarding material specifications made in the design stage during the construction stage. This is particularly important for Design and Build procurement where the responsibility of the project passes to the contractor after novation.

9.2.5 Objective 5: Propose recommendations to facilitate EC considerations in a BIM-enabled project

Through the Condition-Mechanism-Outcome (CMO) configuration comparison of the three case studies two pathways to facilitate EC considerations in a BIM-enabled project were suggested for the two outcome categories (section 7.7). For each pathway the enabling conditions and mechanisms that relate to position-practice relations and dialectic of control were highlighted to facilitate EC considerations in BIM-enabled projects.

For *How EC considerations are set and communicated* the pathways relate to the project stakeholder who drives EC considerations to the project and can be either client or design team driven. For the Client driven pathway, the main enabling condition is Team appointments to ensure the required professional skills are available for projects. This includes the appointment of consultants or the principal design team, which leads to different pathways in addressing EC considerations. For this pathway the position-practice relations between the client and the design team are balanced, which leads to the establishment of a sustainability and BIM approach for the project that is informed by both the client and the design team. With the client ‘on board’ for EC inclusion, the design team has high dialectic of control over project inner resources which leads to a lower dependence on industry-wide resources (outer conditions) such as financial initiatives, guides, and databases. For the Design team driven pathway, the main enabling condition is government financial initiatives that facilitate the incentivisation of the client. For this pathway, the position-practice relations show an enhanced role for the design team in establishing the sustainability and BIM approach for the project. The dialectic of control over inner project resources is however low for the design team in this pathway, and as such, they have higher dependence on industry-wide resources (outer conditions).

For *How EC considerations are addressed* the pathways relate to the way that required professional skills are brought to the project, which can be either through the appointment of consultants or through the principal design team professionals. For both pathways, scheduling and contract are enabling conditions to safeguard the required time for LCA to take place and material choices made in the design stage during construction respectively (see Objective 4 for more detail on this). For the pathway where professional skills are brought by an LCA consultant, team appointments are the main enabling condition. The position-practice relations amongst the design team are characterised by the introduction of new roles to the design team, with consultants bringing their expertise to the project. For this pathway, however, as more professionals are involved in information exchanges through the BIM model, the dialectic of control over the BIM model data input is low for the professional conducting the LCA. As such, a higher level of coordination is warranted which leads to a higher information management requirement. For the pathway where professional skills are brought by one of the design team professionals, the enabling condition is government financial initiatives which can facilitate by covering for costs such as the purchase of required LCA software. The position-practice relations are characterised by the expansion of the role of the principal design team professional who has immediate control over the BIM model data input. As such, the information management requirement for this pathway is low.

9.3 Contribution and implications

This study has a range of contributions that include theoretical, methodological and empirical contributions. The contributions of this study were extensively described in the Discussion chapter (sections 8.4 and 8.5); a summary of the study's contribution is presented in the following paragraphs.

The **theoretical contribution** of this study lies in the synthesis of an analytical framework that combines structuration theory's concepts and expands on the contextual conditions analysis (section 8.5.1). The framework enables the revelation of interactions between contextual conditions at the meso-level of modalities whilst considering industry and project level impacts. This presents a novel way to operationalise structuration theory in context which addresses one of structuration theory's criticisms. As the framework uses conceptual terms that can be populated by empirical elements, it presents a way to analyse contextually situated activities within complex social systems. This has implications to research as the framework could be used across different disciplines and for a wide range of contextually situated empirical inquiries.

The **methodological contribution** of this study was made through the use of social network mapping to visualise the framework elements and the links of impact between them (section 8.5.2). The visualisation of the framework enabled different levels of analytical focus and facilitated addressing the network complexity. The novelty, however, does not lie in the use of social network mapping, which has extensively been used to represent empirical information. The methodological contribution lies in the representation of both empirical data as well as theoretical concepts in the social network diagrams. This has potential research implications that relate to the enhancement of the use of social network diagrams for qualitative studies that are theoretically informed.

The **empirical contributions** of this study relate to the area of focus of the study and the study's philosophical approach. The first contribution lies in exactly this, the study of EC considerations through a socio-technical approach that seeks to reveal the conditions and mechanisms that work beneath the surface to explain EC consideration inclusion and the way they are addressed in BIM-enabled projects. Through this approach, 'position-practices' and 'dialectic of control' were the two theory informed mechanisms found to affect setting and addressing EC considerations in BIM-enabled projects. The study brought new knowledge on how these mechanisms relate to power relations between the client and the design team and to industry and project level structures. The empirical contributions of this study is presented in Table 9.2, Table 9.3 and Table 9.4 according to their relation to the mechanisms and structures. The contributions' implications on practice, policy and education are also presented alongside the respective contributions.

Table 9.2 Empirical contributions relating to position-practices and their implications about EC considerations.

Key takeaways	Contribution	Implications
Balanced position-practice relations crucial	- Position-practice relations between the client and the design team affect the way project norms such as sustainability approach including EC considerations and BIM approach are defined for projects (section 8.2.4)	- Inform practice and policy on the importance to ensure a balanced contribution of both the client and the design team to project norms that relate to sustainability and BIM approaches.
Professionals as middle agents for embodied carbon considerations	- Professional leadership is important to drive EC considerations and operates not only at practice but at individual level. The responsibility and response to climate emergence starts with the individual. (section 8.2.2)	- Inform practitioners of the importance to take act as middle actors and take leadership in driving the incorporation of EC considerations for projects as a bottom-up approach to address climate emergency. - Inform educational institutions of the need to ensure that sustainability is a value distilled to professionals who can drive change from the individual level and that leadership is part of the soft skills developed by their graduates.
Developing new and expanding existing professional skills	- To address EC considerations a shift in position-practice is required for the design team, to either include new expert roles or to expand the role of one of the principal design team members. - In the absence of LCA and BIM expert role appointment, the profession that expanded their role in the project was the architect. This presents an important finding that relates to the architect profession and how this profession is evolving in a construction industry that needs to respond to and address climate emergency demands. (section 8.3.1)	- Inform practice and policy on the way to secure the required professional skills for addressing EC considerations, either through expert appointments or the expansion of the role of a principal design team member. Project costs may need to be revised to enable new roles and required expertise (BIM manager, LCA consultant) to be appointed. - Raise awareness of a potential need of a re-definition of the role of the architect profession in addressing EC considerations. This not only relates to policy and practice but could also have implications on higher education and curriculum design for architecture schools.
Expected versus actual position-practices	- There are discrepancies between position-practices as expected by standards and as observed practice. These relate to the role of the client in setting the project's information requirements through BIM routes The lack of expertise by the clients restricts them in establishing these requirements which results in either being compiled by the design team or not being complied at all. (section 8.2.3) - The other discrepancy concerns the role of quantity surveyors (QS) in providing material quantity information as part of the LCA of projects. Although QS are mentioned as the profession best positioned to provide this information, their involvement has been found limited to non-existent in the case studies. (section 8.3.1)	- Inform practice and policy about expectations of the client role in setting information requirements and the need re-distribute this responsibility to design team professionals that have the required expertise to address this. - Inform practice and policy about expectations of the QS role in providing material quantity information for LCA. This has implications to higher education and curriculum design to ensure that QS expected contribution to LCA is reflected in practice. Further familiarisation of the QS with the BIM model would also facilitate their involvement in coordinating this information with the design team.

Table 9.3 Empirical contributions relating to dialectic of control and their implications about EC considerations.

Key take-aways	Contributions	Implications
Interdependencies between inner and outer resources	- There is a relation between the dialectic of control of the design team over inner project resources and their dependence on industry-wide resources. The dependence of the design team on industry-wide resources is higher when their power over inner resources is low. (section 8.2.5)	- Inform practice and policy to set a BIM model checking process where BIM model data input requirements by different professions at different design stages are clearly established to ensure BIM model can be used for LCA.
Relation between BIM model data input and information management requirement	- There is a relation between the dialectic of control over the BIM model data input and information management requirement. The information management requirement is lower when the BIM model data input control of the professional conducting the LCA is higher. On the other hand, BIM model data input becomes more complex when it is made by all design team professionals, as would be the case in BIM level 2 projects. In this case, a higher level of information management is required to ensure the required information is inputted in the model for it to be used in LCA. (section 8.3.3)	- Inform practice and policy to address the lack of trust in the BIM model due to fragmented or missing data in the BIM model according to the information requirements of projects. Information management through BIM to be established for larger teams and BIM level 2 projects where a greater coordination requirement is required to ensure the BIM federated model can be used for LCA.

Table 9.4 Empirical contributions relating to structures and their implications about EC considerations.

Key take-aways	Contributions	Implications
Project cost and top-down financial initiative impact on EC considerations	- EC reduction efforts impact on capital cost is not clear. Although it was not the focus of this study, this study identified factors that can increase (such as higher costs for low EC impact materials compared to alternatives) or factors that can decrease (such as reduced overall material use for projects) a project's capital cost in the effort to tackle EC impacts for projects. Further research is required to establish the impact and further factors that contribute to the increase or reduction of capital cost as a result of EC reduction efforts in projects. - Just as professional leadership is essential to drive EC considerations as a bottom-up approach, industry-wide structures in the form of financial initiatives are also essential as top-down approaches to incentivise clients on the inclusion of EC considerations to projects. (section 8.2.6)	- Further research on the impact of EC reductions on capital cost could better inform practice and policy on the impact of EC reduction efforts of capital cost. As cost was found to be an important factor for clients, research that can identify the factors that facilitate capital cost reduction as a result of addressing EC could act as incentives for clients to include EC considerations to projects. - Inform policy that financial initiatives such as funding available to projects that address whole-life carbon impacts and tax relief for companies to upskill their staff and invest in software to address LCA could greatly facilitate industry to address this new challenge of addressing whole-life carbon impacts for building projects.
Including EC considerations in project management and procurement contract processes	- Project scheduling and project contract are key inner project structures for the facilitation of LCA during the design stage and for safeguarding design stage material specifications during the construction stage. (section 8.3.4)	- Inform practice and policy to ensure that project scheduling accounts for design optimisation stages that not only relate to OC reduction, but for whole life carbon considerations through LCA. - Inform practice and policy that clauses for safeguarding design stage material specifications during construction are required in contracts.

Finally, this study proposes two pathways for the facilitation of EC considerations to BIM-enabled projects which highlight the enabling conditions and mechanisms that are required to facilitate EC considerations in projects and enhance the use of BIM as an information management and software tool to address them. The two pathways have implications on policy and practice as they can provide useful guidance to facilitate EC considerations in BIM-enabled projects.

9.4 Limitations and further research recommendations

This research provided some theoretically informed explanations of the topic under study and contributed with the development of new questions. However, there are a number of limitations to this research which relate to the nature of this research, the availability of resources to the researcher and the length of the study.

This research included a small number of cases for data collection and analysis. Although this is pertinent for the nature of this research where a small number of cases is used to enable ‘rich’ data collection, the explanations and understandings that were reached are contextually bounded to the case studies that were considered. As such, there are limitations in relation to generalisability and reproducibility of the research results. Further to this, the selection of the case studies followed some sampling criteria to ensure that useful interpretations could derive from the analysis of the independent cases and the cross-case comparison. However, to a certain extent, the case studies have a geographical limitation that relates to accessibility of cases to the researcher. This also contributes to the restriction of generalisability of the results. As the scope of the research was within the geographical boundaries that the cases fell within, this does not pose a significant drawback for the research. However, for reaching generalisability, the findings of the research could be tested against a wider sample to include a wider range of building typologies and sizes and expand the geographical area of focus. Finally, the data collection of this study has predominantly focused on the perspectives and views of architects. However, considering that a wider range of professionals is involved decisions that affect EC impacts, further research that considers in more depth the views of all professionals involved in the design and procurement of building projects could enhance a collaborative and coordinated approach for EC reduction efforts.

The adopted qualitative case study approach of this research has the strength of analysing a socio-technical system in depth and considering both the technological as well as the social aspects of the system that affect the phenomenon under study. However, qualitative studies investigate wider and complex problems and the implications of their results may be less precise than implications made by quantitative research approaches. Further to this, the qualitative methods used in this study enabled the collection of 'rich' data that considered contextual impacts and as such generated findings that reflect in-practice realities. The methods used to analyse the large amounts of data were diverse and informed by literature and theory to ensure a robust approach to analysis. However, there is an inherent level of subjectivity involved in all qualitative research as the researcher is the main instrument of data interpretation and analysis. As such, it is inevitable that observation and analysis would have been different for any number of different researchers.

Another limitation of the study relates to the length of time during which this research took place. This research was undertaken at part-time study mode, during which some necessary interruptions of study caused the time length of the study to be further extended. As such, the initial stages of this research took place over 5 years prior to the completion of the research. As both EC and BIM use are evolving matters in the construction industry, the perceptions and views gathered from research participants during the initial stages of the research may not reflect current views on these topics. This is an inevitable limitation of studies that have a span of several years. However, this limitation does not pose a threat to the contribution of this research as EC considerations are still far from becoming mainstream in the construction sector, and studies that investigate the use of BIM for addressing EC have so far only focused on the technological aspect of BIM. As such, this research still addresses a gap in knowledge and provides empirical contributions that can be useful to both policy and practice.

Although this research span through several years, as it was done part-time, the time limitations that pertain all postgraduate research studies were pertinent. The time allocated for the research enabled thorough analyses to be conducted and new knowledge to emerge, but some aspects had to be left out of the scope of the study, such as the examination of institutional and cultural contexts. However, these can be considered as areas of future research.

9.4.1 Future research directions

Considering the limitations as well as the results of the study, future research recommendations to further expand the knowledge of the topic is presented below.

This study revealed two relations of dialectic of control. The first concerned the design team control over project resources and their dependence on industry-wide resources where, a higher outer resource dependence was observed for a lower control over inner resources. The second concerned control over the BIM model data input and BIM information management requirement where, a higher information management requirement was observed for a lower control over the BIM model. These dialectic of control relations could form hypotheses that could be tested through subsequent qualitative and quantitative research for a wider sample of projects. An industry-wide survey would address the limited generalisability of the relationships of dialectic of control that were revealed in this study.

As part of the data collected for CS3, which was a residential project, it was mentioned that BIM level 2 is not common for residential projects. As this was not in the scope of this research, this finding was not considered in for this study. However, future research could firstly statistically explore this finding to verify if this is true for this building typology, and secondly explore the reasons and implications of this finding for the projects, including how this affects addressing EC for residential building projects.

This research highlighted the importance of adding clauses to building contracts to secure design stage material specifications during the construction stage. Further research could focus on the stage of novation for different types of building contracts and the relationship amongst factors that may cause discrepancies between the building design and the building as constructed.

Cost was found to have an impact on clients for the inclusion of EC considerations to projects. The impact of tackling EC for projects on capital cost, however, was found to be unclear with some factors causing an increase and others reduction of the project capital cost. As such, this research showed that there is more to be understood on how EC reduction efforts impact project capital cost. Further research of the impact of tackling EC on capital cost could further explore the factors that that contribute to the increase or reduction of capital cost as a result of EC reduction efforts in projects.

The importance of incorporating optimisation stages to project time scheduling that consider whole-life carbon impacts of building projects was highlighted in this research. Further research could be conducted to establish the time required to test design and material use iterations through LCA. As this study showed that LCA could be conducted either by LCA consultants or by members of the principal design team, further research on this topic could be inclusive of this to consider time requirements for experts as well as novel LCA assessors.

At the beginning of this research industry-wide benchmarks for EC impacts of buildings were not available. Benchmarks that relate to EC emerged during the course of this research, but the these were not available during the time that targets were being set for the case studies considered in this study. Further research could look into the impact of the newly introduced benchmarks on EC inclusion to project targets and investigate their impact on practitioner perceptions with regards to the meaningfulness LCA results of projects.

Finally, the role of client ambitions and professional leadership were highlighted as the driving conditions for EC consideration inclusion to building projects. Further research could focus on these two actors and could incorporate institutional and cultural impacts that affect their prospects of developing leadership for driving change. This topic could also be explored further at a micro-level by using cross-disciplinary research to consider psychological aspects of leadership building and professional responsibility towards tackling climate emergency.

9.5 Final reflections

At offset of research in 2015, BIM was gaining more and more attention with the UK government BIM level 2 mandate for all public sector works about to be implemented in 2016. Both the literature and my own perception of BIM was that it was a game changer for the construction industry, bringing both technological and information management capabilities that would revolutionise the way EC information requirements would be communicated and that would present the industry with a software tool to facilitate LCA. As such, the initial case study sampling that was considered was one that would only include BIM level 2 projects. However, due to availability of cases for data collection, this was not feasible and a BIM level 1 project was added as a case study for this research. The inclusion of this case study gave unforeseen insights that related to the use of BIM for information management and as a tool for LCA. The relatively technological optimistic views that BIM would be a 'holy grail' that lifts the barriers for tackling EC were replaced with an understanding that no technology can bring the required mindset change. Incorporating EC considerations as well as the application of BIM as an information management and software tool mainly depend on the actors involved in projects, their aspirations, their sense of professional responsibility and skills. At the final stages of this research, it became clear that there is no one-size fit all solution, but rather, that each project has its unique composition of actors which results in different ambitions, leadership and professional skills brought to the project. This study has shown that there are dynamics that relate to position-practices and dialectic of control that need to be considered for the inclusion of EC considerations and for a use of BIM that responds to the project requirements. By considering these relations and making necessary adjustments according to the different requirements of each project, a step toward changing the construction industry's status quo in relation to tackling EC may become feasible. And BIM could help, provided that the actors use it 'wisely'.

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Appendix

Professional Perspective interviews – Consent form

Cardiff University

Welsh School of Architecture

Consent Form - Confidential data

I understand that my participation in this project will involve answering to questions that relate to my work expertise in an audio-recorded interview, which will require an approximate time of 45-60 minutes.

I understand that participation in this study is entirely voluntary and that I can withdraw from the study at any time without giving a reason.

I understand that I am free to ask any questions at any time. I am free to withdraw or discuss my concerns with Dr. Vicki Stevenson, the supervisor of this study.

I understand that the information provided by me will be held confidentially, such that only the Principal Investigator can trace this information back to me individually.

I understand that the information provided by me will be used for Postgraduate Research and will be published as part of the results of this research.

I understand that I can ask for the information I provide to be deleted/destroyed at any time and, in accordance with the Data Protection Act, I can have access to the information at any time.

I, ________________________________ consent to participate in the study conducted by Ms Amalia Banteli, Welsh School of Architecture, Cardiff University with the supervision of Dr. Vicki Stevenson.

Signed:

Date:

<u>Contact information:</u>

Amalia Banteli: email: bantelia1@cardiff.ac.uk, phone number: +44 (0)29 2087 6515

Dr. Vicki Stevenson: email: stevensonv@cardiff.ac.uk, phone number: +44 (0)29 2087 0927

Case Study – Consent form

Cardiff University

Welsh School of Architecture

Case Study Consent Form

This consent form refers to a building project that is going to be used for data collection for Postgraduate Research (PhD). The aim is to analyse the project design development in relation to the PhD topic (please see project information document for further information on the PhD topic).

Through this form, consent is given to the reseacher to analyse the building project using mixed methods such as interviews, observation, document analysis. Further information about the case study engagement specifications are available in the *'Case Study Engagement Specification'* document (available to ethics application and project stakeholders).

Participation in this study is entirely voluntary and the project stakeholders can withdraw from the study at any time without giving a reason. The form is signed by an individual in a leading project role on behalf of all involved in the case study, however, any individual involved can independently withdraw or decline to provide information (eg. in the form of an individual interview) without giving a reason.

Stakeholders responsible for this project are free to ask any questions at any time and free to withdraw or discuss any concerns with Dr. Vicki Stevenson (contact details below), the supervisor of this study.

Information provided to the researcher will be held confidentially, such that only the Principal Investigator can trace this information back to the project or the stakeholders involved in it.

The information provided will be used for Postgraduate Research and will be published as part of the results of this research.

The information provided can be deleted/destroyed at any time upon request from the stakeholders responsible for this project and, in accordance with the Data Protection Act, access to the information is available at any time to the stakeholders responsible for this project.

I, ______________________________________ consent that this project can be used as a case study in the research conducted by Ms Amalia Banteli, Welsh School of Architecture, Cardiff University with the supervision of Dr. Vicki Stevenson.

Signed:

Role in project:

Date:

<u>Contact information:</u>

Amalia Banteli: email: bantelia1@cardiff.ac.uk, phone number: +44 (0)29 2087 6515, 07914433975

Dr. Vicki Stevenson: email: stevensonv@cardiff.ac.uk, phone number: +44 (0)29 2087 0927

Information Sheet

Welsh School of Architecture
PhD degree programme

Researcher name: Amalia Banteli email: bantelia1@cardiff.ac.uk

Research supervisor: Vicki Stevenson email: stevensonv@cardiff.ac.uk

Title: An analysis of embodied carbon considerations in a Building Information Modelling (BIM)-enabled building design process through structuration theory

Aim:

The main aim of this research is to analyse the design decision process in relation to Embodied Energy and Carbon (EEC) and Building Information Modelling (BIM). The overarching question that this research aims to address is: 'How can BIM facilitate EEC calculation inclusion to design decisions of building projects?' Under this wider scope, this research also aims to reveal the current methodologies used by built environment professionals to calculate EEC for new projects and its role in building design.

Whilst looking at current practice and EEC methodologies, the professions that provide information that is required for EEC calculations will be revealed as well as when during the project design this information is provided and in what way (who/when/how).

Research questions

- **What** are the barriers to include EEC calculations in building design?
- **What** is the current role of EEC in design decisions?
- **How** do built environment practices professionals calculate the EEC of their projects? (what are the current methodologies?)
- **Who** are the professionals involved in the delivery of information?
- **When** information exchanged?
- **How** information exchanged (processes)?
- **What** information is required by BIM and how can that be used for EEC calculation?
- **How** does BIM application in action compare to the assumptions held by the BIM contractual documents in relation to EEC information?

Research methods:

This research has an ethnographical approach, where the researcher is immersed in the research setting and observes the phenomenon as it happens. This research approach includes semi-structured interviews, project meeting observations and project document analysis of specific building projects that are used as case studies.

Contribution aim:

Making known the professions and timing of information required in order for EEC calculations to be included in design stage enables better informed agreements at initial project stage. This also contributes to minimising miscommunications and fragmentation of Industry. The contribution aim of this research is to inform practice and policy to enable the inclusion of EEC reduction in order to meet overall carbon targets.

Professional perspective Interview guides

Interview Guide - Architects

Introduce self

Purpose of study (Information sheet)

Consent form to be signed

Permission to record

Date/ Time
Setting
Respondent (m/f)
Observations

Topics	Questions
1.Participant background info	Profession Years of work experience in this field Role in company Type of company Size of company Types of project (ie office building, educational…) Types of client (public, private…)

2. Role of Embodied Energy/ Carbon (EEC) in design decisions
 	
- Procurement routes
- Environmental/ impact design considerations? (general/ materials)
  ○ What are they?
  ○ Prioritise
  ○ What drives them?
- EEC considerations
  ○ Existent? Clients?
  ○ prioritisation
  ○ What motivates them?
	What kind of procurement methods are used in your projects? (eg. Traditional, Design and Build)
	Provide a brief description of client/ Designers and contractors responsibility/ involvement
	Please talk about the one that is used most frequently,
	
	When designing a building what are the main considerations in terms of environmental design?
	How do you prioritise these considerations?
	What drives your environmental design considerations?
	
	Do clients request for low EEC for the projects?
	If client doesn't request EC part of considerations, do you try to influence that decision?
	Do you believe it is the client's role or your role to push for this as a design consideration?

○ How this changes for different procurement/ project/ client - Future importance of EEC	Is embodied energy/ carbon a consideration? *(If yes)* Where does it fall in the prioritisation of the considerations? What motivates you to consider EEC/ materials impact? From your experience, does the inclusion of EEC in the design process tend to change for: a) different procurement routes? b) Different types of projects? c) Different clients? Do you think that tackling it is important? *(Then continue to 3A)* *(If no)* Do you think that tackling it is important? *(If yes go 4)* *(If no:)* At the moment there is a lot of policy focus/regulation focus on addressing the operational performance of buildings, do you think that in coming years as operational energy will be lower therefore, as a proportion of energy, EEC will become more significant? (either 4 or 3B depending on participant – assess if there is any benefit in asking about barriers to EEC calcs or if not go to 3B)
3. A. How is EEC calculated ○ Outsourced or in-house?	Who makes the calculations and comes up with results? Outsourcing or in-house? (do they hire an external expert company for embodied energy calculations? or they do it within the company? When do EC considerations come into the design? (first and iterations) When is it revisited (iterations) Who provides information/ data for embodied energy calculations? How is the information exchanged? (BIM model, CDE, COBie)? Only Material options considered or design options as well? *(If in-house and they are involved continue with questions.)* *(If outsourced/ in-house but not involved in calcs, go to 4)*

	What boundary conditions are considered? (do you consider the entire life cycle of the building?) What are the sources of information (give examples - EDPs (Environmental Product Declaration), manufacturers' info etc)? What databases do you use? Any particular standard/ guidance you use? What software/ tool do you use for the calculations? (Developed in house?, BIM compatibility?)
4. Challenges/ barriers to include EEC	Where do you find challenges in including/ estimating embodied carbon? What could be changed to reduce these challenges?
3. B. Material impact	(only if EEC is not a consideration – no cals) Since EEC is not taken into account during the design, do you take any steps to reduce the impact of construction materials through design, construction, maintenance and repair? Do you try to address BREEAM Material points that focus on issues that relate to the procurement of materials that are sourced in a responsible way and have a low embodied impact over their life including extraction, processing and manufacture and recycling? How do you address them?
5. A BIM and EEC	
Only if EEC is consideration	Do you use BIM? *(if no go to 5B)* *(If yes continue)* What BIM level have your projects reached? Do you have a BIM Manager appointed in the practice? What contractual documents do you complete? Who are those completed by? Do you complete Employer's Information Requirements document (EIR)? Who compiled this doc? In the Levels of Model definition in the EIR, are there any information requirements for EEC? Do expected information exchanges that relate to EEC happen as expected? Through BIM model? How has BIM use helped with the EEC consideration in design? What is the potential of BIM to facilitate even more EEC consideration in the future?

5. B. BIM potential for EEC inclusion to design	Do you think that BIM use could facilitate EEC consideration design? In what way?/ How? Do you think that BIM facilitates information management and collaboration in the project? In what way?
6. Further research	Would you be happy to be contacted again for a follow up interview/ phone talk for further clarification once the initial data analysis has started taking place? Do you have any suggestions about relevant people that could be contacted to be interviewed about this topic? Would you be able to provide case studies for the later stages of this research within your company?

Interview Guide – Sustainability/ LCA Consultant

Introduce self

Purpose of study (Information sheet)

Consent form to be signed

Permission to record

Date/ Time
Setting
Respondent (m/f)
Observations

Topics	Questions
1.Participant background info	Profession Years of work experience in this field Role in company Type of company Size of company Types of project (ie office building, educational…) Types of client (public, private…)

2. Role of Embodied Energy/ Carbon (EEC) in design decisions
 	
- Procurement routes
- Environmental/ impact design considerations? (general/ materials)
    o What are they?
    o Prioritise
    o What drives them?
- EEC considerations
    o Existent?
    o What motivates them?
    o How this changes for different procurement/ project/ client
- Future importance of EEC
	What kind of procurement routes are used in projects that you are involved in? (eg. Traditional, Design and Build)
	Please talk about the one that is used most frequently,
	
	What do you think motivates practitioners to consider EEC/ materials impact?
	
	From your experience, does the inclusion of EEC in the design process tend to change for:
	d) different procurement routes?
	e) Different types of projects?
	f) Different clients?
	
	(If no:)
	At the moment there is a lot of policy focus/regulation focus on addressing the operational performance of buildings, do you think that in coming years as operational energy will be lower therefore, as a proportion of energy, EEC will become more significant?

3. A. How is EEC calculated ○ Outsourced or in-house?	When does your involvement with projects usually start? What does your consultation involve? When do EC considerations come into the design? (first and iterations) Who provides information/ data for embodied energy calculations? Who do you contact to provide consultation about EC options/ materials? How is the information exchanged? (BIM model, CDE, COBie)? Only Material options considered or design options as well? What boundary conditions are considered? (do you consider the entire life cycle of the building?) What are the sources of information (give examples - EDPs (Environmental Product Declaration), manufacturers' info etc)? What databases do you use? Any particular standard/ guidance you use? What software/ tool do you use for the calculations? (Developed in house?, BIM compatibility?)
4. Challenges/ barriers to include EEC	Where do you find challenges in including/ estimating embodied carbon? What could be changed to reduce these challenges?
5. A BIM and EEC	
	Have you been involved in projects that use BIM? *(if no go to 5B)* *(If yes continue)* What BIM level had the projects reached? How has BIM use helped with the EEC consideration in design? What is the potential of BIM to facilitate even more EEC consideration in the future?
5. B. BIM potential for EEC inclusion to design	Do you think that BIM use could facilitate EEC consideration design? In what way?/ How?
6. Further research	Would you be happy to be contacted again for a follow up interview/ phone talk for further clarification once the initial data analysis has started taking place?

	Do you have any suggestions about relevant people that could be contacted to be interviewed about this topic? Would you be able to provide case studies for the later stages of this research within your company?

Case Study engagement specification

Welsh School of Architecture
PhD degree programme

Researcher name: Amalia Banteli email: bantelia1@cardiff.ac.uk

Research supervisor: Vicki Stevenson email: stevensonv@cardiff.ac.uk

Title: An analysis of embodied carbon considerations in a Building Information Modelling (BIM)-enabled building design process through structuration theory

Case Study Engagement Specification

Questions

How long will data collection from this case study last?

From the start of the project and all the design stage (mostly 0-4 RIBA stages unless part of the design continues during stage 5).

What will the engagement include?

During the initial phase, when the researcher will start their involvement, some exploratory interviews will be held to make research arrangements for access and to obtain the initial information about the case studies.

During the data collection phase (immersion period)

- Observation of meetings that relate to design decisions and shadowing of team work that relates design decisions (with special focus on embodied energy and carbon)
- Project information / document analysis. Project documentation that relates to information/ BIM model requirements and embodied energy and carbon is the focus.
- Routines of work (working practices, communication channels and tools used)
- Informal routines (rules of thumb, conversations, interdisciplinary feedback)
- Formal system (how data and information is shared within the company and with their collaborators)
- Interviews with the team (frequency to be decided once the project starts, but probably at the start/ end of each RIBA stage)

During this period contact time will be approximately every two weeks, but will depend on project progress and meetings that could be attended by the researcher.

During the final phase when the data collection will have finished, the researcher will keep in contact with the participants to collect any additional information required for the analysis of the data/ any clarifications required.

Ethical Considerations:

Anonymity

The case studies will all be anonymised so that the specific project, the company and the individuals involved in the project cannot be identified.

All information collected will be held confidentially, such that only the researcher can trace this information.

Publication of results

The Data collected (and anonymised) will be used for Postgraduate Research and will be published as part of the results of this research.

Further questions concerns can be communicated:

Researcher: Amalia Banteli email: bantelia1@cardiff.ac.uk Phone: 07914433975

Supervisor: Dr.Vicki Stevenson email: stevensonv@cardiff.ac.uk Phone: 029 2087 0927

Case Study Interview questions and respective professions.

Case Study Info General <Client OR lead architect>

Project use, size, location

Contract type – Novation

Type of client

Teams appointed and expertise

BIM Level

EEC Process

What <Client AND lead architect AND sustainability consultant>

EEC a specific consideration? Compliance only or performance-driven?

Contract type and when teams change/ responsibilities?

Targets for EEC? If yes, define.

Assessment standards and calculation methodology

EC considerations refer to material options only or building design options as well?

Specification for building/ element level?

Challenges with EC?

How/ where <sustainability consultant>

Where are EC requirements stated? What document are they included in? Which stage was this document compiled? Are EC requirements also considered for the project's tender and procurement process?

Calculation Tools used? Standards used? Carbon data Sources?

BIM model used? Does it have information on material quantity and mass? Transport distance information from where?

If BIM model not used, how was above information found?

When <Client AND lead architect AND sustainability consultant>

What stages do EC requirements refer to? Starting point, iterations and frequency of EC assessments.

Who <Client AND lead architect AND sustainability consultant>

Who decided on the target? Was this from the client? Did the design team/ any other consultant influence the target?

Who drafted the documents that these requirements are stated in?

Who decided on frequency of EC assessments?

Who conducted the assessment/s?

Who else was involved to provide information for assessments?

Client Design Team appointments – were they based on sustainability expertise? Who is responsible for them? Which professions? Did this affect appointment of entire design team or just sustainability/ carbon consultant?

EC considerations **-** Outsourcing or within the design team? (When were they involved?)

Why <Client>

What was the driver for sustainability target? What was the driver for EC target? Which professions influenced the target?

BIM Process <Client AND lead architect>

What

Establishment of the project's information requirements (EIR) completed?

Are information requirements or levels of information for EC included?

What is the BIM model level of detail and information at each stage for the different building elements? Can the model be used for LCA?

Challenges with BIM?

Did BIM facilitate EC info management?

BEP completed?

Who

Has a BIM information manager been appointed?

Who has decided and compiled EIR? Client only? Did consultation from third party/ architects take place? Was the sust/carbon consultant consulted?

Ethics Approval Forms and confirmation

EC1709.334

WELSH SCHOOL OF ARCHITECTURE
ETHICS APPROVAL FORM FOR STAFF AND PHD/MPHIL PROJECTS

Tick one box:	☐ STAFF ☒ PHD/MPHIL
Title of project:	Whole building embodied energy and carbon calculation potential and its inclusion to early-stage design through Building Information Modelling
Name of researcher(s):	Amalia Banteli
Name of principal investigator	Supervisor: Vicki Stevenson
Contact e-mail address:	Bantelia1@cardiff.ac.uk
Date:	02/06/17

Participants		YES	NO	N/A
Does the research involve participants from any of the following groups?	• Children (under 16 years of age)		x	
	• People with learning difficulties		x	
	• Patients (NHS approval is required)		x	
	• People in custody		x	
	• People engaged in illegal activities		x	
	• Vulnerable elderly people		x	
	• Any other vulnerable group not listed here		x	
• When working with children: I have read the Interim Guidance for Researchers Working with Children and Young People (http://www.cardiff.ac.uk/archi/ethics_committee.php)				x

Consent Procedure	YES	NO	N/A
• Will you describe the research process to participants in advance, so that they are informed about what to expect?	x		
• Will you tell participants that their participation is voluntary?	x		
• Will you tell participants that they may withdraw from the research at any time and for any reason?	x		
• Will you obtain valid consent from participants? (specify how consent will be obtained in Box A)[1]	x		
• Will you give participants the option of omitting questions they do not want to answer?	x		
• If the research is observational, will you ask participants for their consent to being observed?	x		
• If the research involves photography or other audio-visual recording, will you ask participants for their consent to being photographed / recorded and for its use/publication?	x		

Possible Harm to Participants	YES	NO	N/A
• Is there any realistic risk of any participants experiencing either physical or psychological distress or discomfort?		x	
• Is there any realistic risk of any participants experience a detriment to their interests as a result of participation?		x	

Data Protection		YES	NO	N/A
• Will any non-anonymous and/or personalised data be generated or stored?			x	
• If the research involves non-anonymous and/or personalised data, will you:	• gain written consent from the participants			
	• allow the participants the option of anonymity for all or part of the information they provide			

Health and Safety	YES
Does the research meet the requirements of the University's Health & Safety policies? (http://www.cf.ac.uk/osheu/index.html)	x

Research Governance	YES	NO	N/A
Does your study include the use of a drug? You need to contact Research Governance before submission (resgov@cf.ac.uk)		x	
Does the study involve the collection or use of human tissue? You need to contact the Human Tissue Act team before submission (hta@cf.ac.uk)		x	

[1] If any non-anonymous and/or personalised data be generated or stored, *written consent* is required.

Prevent Duty	YES	
Has due regard be given to the 'Prevent duty', in particular to prevent anyone being drawn into terrorism? https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/445916/Prevent_Duty_Guidance_For_Higher_Education__England__Wales_.pdf http://www.cardiff.ac.uk/publicinformation/policies-and-procedures/freedom-of-speech	x	

If any of the shaded boxes have been ticked, you must explain in Box A how the ethical issues are addressed. If none of the boxes have been ticked, you must still provide the following information. The list of ethical issues on this form is not exhaustive; if you are aware of any other ethical issues you need to make the SREC aware of them.

Box A The Project (provide all the information listed below in a separate attachment)

1. Title of Project
2. Purpose of the project and its academic rationale
3. Brief description of methods and measurements
4. Participants: recruitment methods, number, age, gender, exclusion/inclusion criteria
5. Consent and participation information arrangements - please attached consent forms if they are to be used
6. A clear and concise statement of the ethical considerations raised by the project and how is dealt with them
7. Estimated start date and duration of project

All information must be submitted along with this form to the School Research Ethics Committee for consideration

Researcher's declaration (tick as appropriate)	
• I consider this project to have **negligible ethical implications** (*can only be used if none of the grey areas of the checklist have been ticked*).	x
• I consider this project research to have **some ethical implications**.	
• I consider this project to have **significant ethical implications**	

Signature [redacted] **Name** [redacted] **Date** 24/7/17
Researcher or MPhil/PhD student

Signature [redacted] **Name** [redacted] **Date** 25/7/17
Lead investigator or supervisor

Advice from the School Research Ethics Committee

STATEMENT OF ETHICAL APPROVAL

This project had been considered using agreed Departmental procedures and is now approved

Signature [redacted] **Name** [redacted] **Date** 20/9/17
Chair, School Research Ethics Committee

EC1711.347

WELSH SCHOOL OF ARCHITECTURE
ETHICS APPROVAL FORM FOR STAFF AND PHD/MPHIL PROJECTS

WS

Tick one box:	☐ STAFF ☒ PHD/MPHIL
Title of project:	Whole building embodied energy and carbon calculation potential and its inclusion to early-stage design through Building Information Modelling
Name of researcher(s):	Amalia Banteli
Name of principal investigator	Supervisor: Vicki Stevenson
Contact e-mail address:	Bantelia1@cardiff.ac.uk
Date:	07/11/17

Participants		YES	NO	N/A
Does the research involve participants from any of the following groups?	• Children (under 16 years of age)		x	
	• People with learning difficulties		x	
	• Patients (NHS approval is required)		x	
	• People in custody		x	
	• People engaged in illegal activities		x	
	• Vulnerable elderly people		x	
	• Any other vulnerable group not listed here		x	
• When working with children: *I have read the Interim Guidance for Researchers Working with Children and Young People* (http://www.cardiff.ac.uk/archi/ethics_committee.php)				x

Consent Procedure	YES	NO	N/A
• Will you describe the research process to participants in advance, so that they are informed about what to expect?	x		
• Will you tell participants that their participation is voluntary?	x		
• Will you tell participants that they may withdraw from the research at any time and for any reason?	x		
• Will you obtain valid consent from participants? (specify how consent will be obtained in Box A)[1]	x		
• Will you give participants the option of omitting questions they do not want to answer?	x		
• If the research is observational, will you ask participants for their consent to being observed?	x		
• If the research involves photography or other audio-visual recording, will you ask participants for their consent to being photographed / recorded and for its use/publication?	x		

Possible Harm to Participants	YES	NO	N/A
• Is there any realistic risk of any participants experiencing either physical or psychological distress or discomfort?		x	
• Is there any realistic risk of any participants experience a detriment to their interests as a result of participation?		x	

Data Protection		YES	NO	N/A
• Will any non-anonymous and/or personalised data be generated or stored?			x	
• If the research involves non-anonymous and/or personalised data, will you:	• gain written consent from the participants			X
	• allow the participants the option of anonymity for all or part of the information they provide			x

Health and Safety	YES
Does the research meet the requirements of the University's Health & Safety policies? (http://www.cf.ac.uk/osheu/index.html)	x

Research Governance	YES	NO	N/A
Does your study include the use of a drug? You need to contact Research Governance before submission (resgov@cf.ac.uk)		x	
Does the study involve the collection or use of human tissue? You need to contact the Human Tissue Act team before submission (hta@cf.ac.uk)		x	

[1] If any non-anonymous and/or personalised data be generated or stored, *written consent* is required

Prevent Duty	YES	
Has due regard be given to the 'Prevent duty', in particular to prevent anyone being drawn into terrorism? https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/445916/Prevent_Duty_Guidance_For_Higher_Education__England__Wales_.pdf http://www.cardiff.ac.uk/publicinformation/policies-and-procedures/freedom-of-speech	x	

If any of the shaded boxes have been ticked, you must explain in Box A how the ethical issues are addressed. If none of the boxes have been ticked, you must still provide the following information. The list of ethical issues on this form is not exhaustive; if you are aware of any other ethical issues you need to make the SREC aware of them.

Box A **The Project** (provide all the information listed below in a separate attachment)
1. Title of Project 2. Purpose of the project and its academic rationale 3. Brief description of methods and measurements 4. Participants: recruitment methods, number, age, gender, exclusion/inclusion criteria 5. Consent and participation information arrangements - please attached consent forms if they are to be used 6. A clear and concise statement of the ethical considerations raised by the project and how is dealt with them 7. Estimated start date and duration of project **All information must be submitted along with this form to the School Research Ethics Committee for consideration**

Researcher's declaration (tick as appropriate)	
• I consider this project to have **negligible ethical implications** (*can only be used if none of the grey areas of the checklist have been ticked*).	x
• I consider this project research to have **some ethical implications**.	
• I consider this project to have **significant ethical implications**	

Signature [redacted] **Name** [redacted] **Date** 29/11/17
Researcher or MPhil/PhD student

Signature [redacted] **Name** [redacted] **Date** 17/11/17
Lead investigator or supervisor

Advice from the School Research Ethics Committee

STATEMENT OF ETHICAL APPROVAL
This project had been considered using agreed Departmental procedures and is now approved

Signature [redacted] **Name** [redacted] **Date** 28/11/17
Chair, School Research Ethics Committee

Table of professionals interviewed during the two research phases (including case study stakeholders and professionals that participated in professional perspective interviews):

	Phase 1		Phase 2	
Roles	Professional Perspective Interviews	Case Study 1 Stakeholders	Case Study 2 Stakeholders	Case Study 3 Stakeholders
Client		x	x	
Architect	x	x	x	x
Structural Engineer		x		
Mechanical Engineer		x		
Sustainability Consultant	x	x		
LCA Consultant	x		x	