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A BIM-based framework to integrate a sustainable end-of-life into the asset lifecycle towards the circular economy

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A BIM-BASED FRAMEWORK TO INTEGRATE A SUSTAINABLE END-OF-LIFE INTO THE ASSET LIFECYCLE

- TOWARDS THE CIRCULAR ECONOMY -

By

Rabia Charef

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Volume I

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Rabia Charef

Volume I

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Certificate of Ethical Approval

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A Framework to integrate the Deconstruction phase into the Asset Lifecycle in BIM - Towards the Circular Economy

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Dedication

To my Son, Mathis who has been affected in every way possible by this journey

To my Family, for their love.

Acknowledgement

"GOD Thank you for giving me the strength and encouragement especially during all the challenging moments in completing this thesis".

I sincerely appreciate the great support and guidance of my supervisors. Pr. Eshmaiel Ganjian has kindly accepted the challenge to be my Director of Study in a research field at the border of his expertise. He has always been very supportive throughout the research, and I had a great benefit from his vast experience as a PhD supervisor. I wish to thank him for his professionalism.

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Abstract

The construction industry is infamous for having a tremendous negative impact on the natural environment. This includes its excess contribution of construction/demolition waste to landfill and its massive consumption of raw materials causing resource depletion. These factors contribute to the degradation of the natural environment. The linear economic system, where resources are extracted, used and disposed of, will not be able to prevent the depletion of natural resources and the saturation of landfills. The construction industry must make a radical change by adopting the Circular Economy approach and managing the End-of-Life (EOL) of buildings more sustainably to close the material loop and reduce dependence on natural resource extraction.

Deconstruction or disassembly seems to be the most appropriate strategy for properly salvaging materials to be able to reuse or recycle them. This leads to designing the buildings with the additional objective of deconstructing them. However, the current most frequent definition of the asset life cycle goes from inception to in-use phases, including refurbishment, thereby leaving disposal as the main end of life option. This study aims to develop a BIM-based framework for integrating the sustainable End-of-Life phase into the asset lifecycle in the Circular Economy context.

A mixed-method was adopted for the research using several techniques (literature reviews, systematic review, survey questionnaire, Pre-Interview Questionnaire and semi-structured interviews with stakeholders involved during the asset lifecycle from France and the UK (20 interviewees, experts in SEOL and/or BIM). A descriptive statistical analysis and means comparison was performed for the questionnaire by using Statistical Package for the Social Science (SPSS) and Excel. The 20 interview analysis was performed by coding the transcripts through NVivo 12 software. Themes and concepts identified were based on the literature review findings. A BIM-based theoretical framework with Sustainable End-of-Life (SEOL) was drawn up based on the literature findings and was presented to the interviewees for improvements leading, as a result, to the creation of the conceptual framework.

BIM uses were also identified from the interviews, discussed and compared with the existing BIM uses available in the literature. Structured like the “RIBA Plan of Work – Designing for Manufacture and Assembly", Guidelines for implementing the SEOL approach were summarized in a table mentioning recommendations for each stage. The key research findings revealed that:

- There are several BIM dimensions having a different level of development. A consensus exists for 4D (planning) and 5D (costing), on what they refer to. However, there is a discrepancy between academics and practitioners for the 6D and 7D. More than 85% of practitioners allocated sustainability to 6D and Facility Management to 7D. No dimension is allocated to the EOL activities.
- Extending BIM to include EOL could help to move from the Linear economy to Circular Economy

- The design stage is a key phase where all the stakeholders, in the asset lifecycle, must be involved.
- The interviewees raised six categories of barriers: (1) economic barriers, (2) political barriers, (3) sociological barriers, (4) technical barriers, (5) Environmental barriers and (6) organizational barriers.
- BIM has the potential to help the management of EOL sustainability: Eight new BIM Uses were identified that can be added to eight other useful BIM uses found in the Literature review.
- The BIM-based framework has the potential to give an overview of who should be involved and when. It can be used by practitioners who want to adopt a SEOL or a Circular Economy approach.
- Detailed guidelines for practitioners, are proposed and explained in each stage (from 0 to 8) of the SEOL strategy. BIM tasks for Designing for a Sustainable End-of-Life (DfSEOL) and procurement tasks for DfSEOL are also suggested.

Keywords: Building Information Modelling (BIM), Sustainable End-of-Life, Asset Lifecycle, Building design, Construction & Demolition Waste, Barriers

List of publications

1. **Rabia Charef**, Hafiz Alaka, Stephen Emmitt, 2018. Beyond the third dimension of BIM: A systematic review of literature and assessment of professional views, *Journal of Building Engineering*, 19, pp.242-257.

2. **Rabia Charef,** Stephen Emmitt, Hafiz Alaka, Farid Fouchal, 2019. Building Information Modelling adoption in the European Union: An overview, *Journal of Building Engineering*, 25, pp. 100777

3. **Rabia Charef,** Eshmaiel Ganjian and Stephen Emmitt, 2019. Socio-economic and environmental barriers for a holistic asset lifecycle approach: a pattern-matching method, *Technological Forecasting & Social Chang (under review)*

4. Kambiz Rakhshan, Jean-Claude Morel, Hafiz Alaka, **Rabia Charef,** 2019. A systematic literature review of the factors affecting the reuse of building components, *Waste Management & Research* (Under Review)

5. **Rabia Charef,** Hafiz Alaka, Eshmaiel Ganjian, 2019. A BIM-based theoretical framework for the integration of the asset End-of-Life phase, *IOP Conference Series: Earth and Environmental Science*, 225, 1, pp. 012067

6. Jean-Claude Morel, **Rabia Charef**, 2019. What are the barriers affecting the use of earth as a modern construction material in the context of circular economy? *IOP Conference Series: Earth and Environmental Science, 225, 1, pp. 012053*

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List of Abbreviations and Acronyms

Abbreviation related to the asset lifecycle, in the order of apparition in chapter 2.

AC: Assembly Construction
AR: Adaptive Reuse
BL: Building Layers
By: Buildability
CE: Circular Economy
CDW Mana: C&D Waste Management
C&DWMini: C&D Waste minimization
C&DW: Construction & Demolition Waste
CL: Closed Loop Supply Chain
CLMCs: Closed-loop material cycles
CLMS: Closed-loop building material strategy
CLR: Closed-loop Recycling
CW: Construction Waste
Cy: Constructability
DB: Demountable Building
DC: Down-cycling
De: Deconstruction
Di: Disassembly-Demountable
Dis: Dismantling
Dy: Deployability
IFD: Industrialised, Flexible and Demountable
LCA: Life Cycle Analysis
LS: Linear System
MA: Manufacture & Assembly
OBS: Open Building System
Prefa: Prefabrication
Rcy: Recycling
Re: Reuse
RL: Reverse Logistic
SD: Selective demolition
SP: Salvage Performance
Sy: Sustainability
SB: Sustainable Building/Construction
TB: Temporary Buildings
TS: Transformable structures
WH: Waste Hierarchy
WHR: Whole House Reuse
WLP: Whole Life Performance
3Rs: Reduce, Reuse, Recycle

Abbreviation related to the design principles in order of apparition of chapter 2.

DFA: Design for Assembly
DfAdapt: Design for Adaptability
DfAR: Design for Adaptive reuse
DfCE: Design for Circular Economy
DfCh: Design for Change
DfCLMCs: Design for Closed-loop material cycles
DfCLR: Design for Closed-loop Recycling

DfD:	Design for Deconstruction
DfDis:	Design for Dismantling
DfDisa:	Design for Disassembly-Demountable
DfDur:	Design for Durability
DfIFD:	Design for Industrialised, Flexible and Demountable
DfM:	Design for Manufacture
DfMA:	Design for Manufacture & Assembly
DfMaint:	Design for Ease of Maintenance
DfMC:	Design for Modular Construction
DfPrefa:	Design for Prefabrication
DfRcy:	Design for Recycling
DfRe:	Design for Reuse
DfSA:	Design for Salvage Ability
DfRL:	Design for Reverse Logistic
DfSB:	Design for Sustainable Building/Construction
DfS:	Design for Simplicity
DfTB:	Design for Temporary Buildings
DfWHR:	Design for whole House Reuse
DoW:	Design out Waste
DS:	Design Standardization
Df3Rs:	Design for 3Rs

<u>General Acronyms, in alphabetical order</u>

AEC:	Architecture, Engineering and Construction
AIM:	Asset Information Model
AIR:	Asset Information Requirements
ATEx:	Appréciation Technique d' Expérimentation
BCF:	BIM Collaboration Format
BEP:	BIM Execution Plan.
BIM:	Building Information Modelling
BMS:	Building Management System
BRE:	Building Research Establishment
BREEAM:	BRE Environment Assessment Method
BSI:	British Standard Institution
BSLP:	Building Service Life Planning
CAFM:	Computer Aided Facility Management
CAPEX:	CAPital EXpenditure
CAWS:	Common Arrangement of Work Sections
CCC:	Convention on Climate Change
CDE:	Common Data Environment or Exchange
C&D:	Construction and Demolition
CDW:	Construction and Demolition Waste
CEO:	Chief Executive Officer
CFR:	Central Facility Repository
CIC:	Construction Industry Council
CIRIA:	Construction Industry Research and Information Association
COBie:	Construction Operation Building Information Exchange
CONQUAS:	Construction Quality Assessment System
CD&E:	Construction Demolition & Excavation
CPE:	Energy Performance Contract
CPIC:	Construction Industry Project Information Committee
CPIx:	Construction Project Information Exchange
CSC:	Construction Specification Canada

CSI: Construction Specification Institute
CSTB: Centre scientifique et technique du bâtiment
CWM: Construction Waste Minimisation
dPoW: Digital Plan Of Work
DIM: Deconstruction Information Model
EIR: Employer Information Requirements
EOL: End of Life
EPA: Environmental Protection Agency
EPBD: Energy Performance of Building Directive
EWC: European Waste Catalogue
FMs: Facility Managers
FDES: Fiche de déclaration environnementale et sanitaire
FM: Facility Management
HVAC: Heating, Ventilation and Air-Conditioning
HQE: Haute qualité environnementale
KPIs: Key Performance Indicators
IAI: International Alliance for Interoperability
IAQ: Indoor Air Quality
ICE: Institute of Civil Engineering
IFC: Industry Foundation Class
IFD: International Framework for Dictionaries
ISO: International Organization for Standardization
IDM: Information Delivery Manual
INES: Institut national de l'énergie solaire
LCA: Life Cycle Analysis
LOD: Levels of Model Detail
LOI: Levels of Model Information
LOFO: Last-On-First-Off
OIR: Organisational Information Requirements
OCCS: OmniClass Construction Classification System
OPEX: OPerational EXpenditure
O&M: Operation & Maintenance
PAS: Publicly Available Specification
PIM: Project Information Model
PIP: Project Implementation Plan
PIQ: Pre-Interview Questionnaire
PLQ: Plain Language Questions
PPD: Preliminary Project Descriptions
PQQ: Pre Qualification Questionnaire
PTM's: Project Team Members
MEP: Mechanical, Electrical, and Plumbing
MIDP: Master Information Delivery Plan
MPDT: Model Production and Delivery Table
MVD: Model View Definition
NIST: National Institute of Standards and Technology
QSs: Quantity Surveyors
RE: Resource Efficiency
RMP: Resource Management Plan
RIBA: Royal Institute of British Architects
RICS: Royal Institution of Chartered Surveyors
SEOL: Sustainable end of life
SMP: Standard Method and Procedure
STEP: STandard for the Exchange of Product
SOGED: Schéma d'Organisation et de Gestion des Déchets
SWMP: Site Waste Management Plan

TIDP:	Task Information Delivery Plan
TQM:	Total Quality Management
Uniclass:	Unified classification for the construction industry
WAC:	Waste Acceptance Criteria
WIP:	Work In Progress
WRAP:	Waste and Resources Action Programme

Definitions used for the Thesis

Sustainable End-of-Life (SEOL): An asset built with a sustainable approach to minimise its environmental impact at the end of its life. This excludes demolition.

Stakeholders: All the main actors involved in the entire asset lifecycle: Designers, Contractors, Quantity Surveyor, Technical controller, Structural Engineer, BIM Managers, Facility Manager

BIM Experts: All the actors involved in the entire asset lifecycle using the BIM process.

BIM Environment: Building Information Modelling (BIM) is a process used throughout the entire asset lifecycle from the programming phase to the EOL phase. The stakeholders, involved in the asset lifecycle generate and exchange digital information, in a collaborative environment. Working in that way, refer to "working in a BIM environment".

1 CHAPTER 1: Introduction

1.1 Background

The construction sector is one of the most vital industry in the whole world by producing the basics amenities for human beings such as creating homes as well as creating schools and hospitals to provide crucial services for the societal needs (Siddiqui 2019). It also enables nations to be kept connected through physical infrastructure. Without these, a human being cannot survive. For the sake of economic prosperity, the construction industry has to modernize, stay competitive and increase in efficiency (BIS 2013). The contributions made within the construction sector are vital for the world's environmental and societal targets. For example, the construction sector in the UK contributes nearly £90bn to the nation’s economy (Her Majesty’s Government 2013), nearly €110bn in France in 2016 (INSEE n.d.), and approximately €13000bn in the EU in 2015 (European Commission 2016). As a consequence of those activities, several issues and initiatives can be listed as follows.

1/ Energy consumption: The construction sector is “responsible for 42% of the total EU final energy consumption, with similar figure for the UK (Her Majesty’s Government n.d.) and France (KanopY n.d.). Regarding the greenhouse gases (GHG) emissions, the building sector is responsible for 35% of the emission in Europe. (COM 2011, 2007, Kylili and Fokaides 2017). Those impacts have led the European Commission to set up a number of policies (regulations directives, and initiatives) that are dealing with the sustainability of construction materials (Kylili and Fokaides 2017).

2/ Construction and demolition waste: One of the biggest concerns about the environment is the waste generated by the construction sector (Ge et al. 2017, Ajayi, S. O. and Oyedele 2017). The construction industry does not know how to reuse all its materials. The end-of-life of the asset is the process of removing the building due to its obsolescence. Those processes are primarily demolition that is responsible for 50% of the entire waste produced by the construction industry worldwide (Kibert 2016). In the UK, building demolition wastes contribute 30% of the waste sent to landfill (35% for France including construction waste (Notre-planette-info n.d.)); this costs the construction industry £200million annually, (Osmani 2012). Worse still, the Environmental Change Institute has shown that to meet the 2050 reduction targets of energy in use by the existing stock, around 14% of the current UK dwelling stock must be demolished (Power 2008). “This requires demolition rates to be increased to four times current levels, rising to 80,000 dwellings per annum by 2016” (Boardman et al. 2005). However, this will not happen because the latest rate (2017-2018) is 8050 dwellings per annum, that is representing only 10% of the target (Ministry of Housing 2018).

In the European Union, the Construction Demolition (C&D) and Excavation Waste represents 838Mt (C&D Waste + excavation) generated throughout Europe in 2016 (Eurostat n.d.). In other parts of the developed world, like in New Zealand or China amongst others, this is the dominant trend too (Zaman, A. et al. 2018, Akanbi et al. 2018, Cheng and Ma, L. Y. H. 2013).
These contributions of the construction industry to landfill have become a major contributing factor to the rapidly diminishing landfill space eventually leading to the issue of the shortage of landfill space (Poon et al. 1996, Du et al. 2011, Fatta et al. 2003). Also, the massive construction industry waste is contributing to environmental damage (Oyedele et al. 2013, Lu, W. et al. 2011, Nagapan et al. 2012) and a scarcity of land (Gavilan and Bernold 1994). There is an urgent need to put in place new strategies to reduce the demand for landfill (Oyedele et al. 2013) thus also reducing the cost of projects.
3/ Resource scarcity: The construction industry is also impacting the raw material resources of the earth as it consumes more than 50% of extracted raw materials (Lu et al. 2017). In the EU, 47% (equivalent to 6.2 tonnes per capita, 4.5 tonnes for UK and 6 tonnes for France) of all materials are consumed by the construction industry (European Commission 2015). For example, the largest consumer of steel products is the construction sector (Kylili and Fokaides 2017). Some EU countries like Sweden have already reported some scarcity for sand and gravel (EEA 2008) and the United Nations Environment Programme (UNEP 2014) has alerted the actual depletion risk that the continued trend in the consumption of aggregates could cause"(Robles 2016) (p.63). Among the main worldwide concerns, the growing of the population and the continent's inter-dependency between countries for raw material for construction materials' imports, lead to a high pressure on the planet resources becoming ineluctably scarcer (Gorgolewski 2008). For this reason, the construction sector has a great impact on the environment's degradation (Ding et al. 2018; Magalhães et al. 2017). The current linear system (opposed the Circular Economy) is defined by "make, use, and dispose of". The linear system based economy leads to the use of a massive amount of raw materials.

4/ EU Policies waste reduction: As the total of Construction & Demolition (C&D) waste has increased continuously; it has become a major concern for many governments. Some policies supported CDW management by providing financial support for CDW recycling projects (National Development and Reform Commission) (Huang, B. et al. 2018). In the same way, the EU goal is to address by 2020, the mandatory target of the EU Waste Framework Directive (2008/98/EC) that 70% of the C&D waste must be recycled (Kleemann et al. 2017, Dahlbo et al. 2015). In the UK, waste minimization initiatives were ambitiously set at "halving waste to landfill by 2012 relative to 2008" (Ajayi, S. O. et al. 2016), by 2020 the waste sent to landfill must come down to zero (Phillips et al. 2011).

The stakeholders must tackle various barriers to achieve the policies targets. One reason is the current solution proposed for the C&D waste issues, which are the “end-of-pipe” treatment after the generation of waste by proposing a recycling solution (Ajayi, S. O. et al. 2015). Recycling is usually down-cycling (Tebbatt et al. 2017), as opposed to up-cycling, with limited benefits in terms of embodied energy and reduction of pollution. That is why some authors start to think about waste reduction at the source before waste is generated. One of the key problems is the construction methods that do not enable buildings to be deconstructed easily. For example, to reduce waste, (e.g. up to 56% in a case study) prefabrication is proposed by various authors (Mália et al. 2013, Jaillon and Poon 2010, Mostafa et al. 2018) Another strategy to prevent waste is to work at the design stages, such as “design for deconstruction” to enable material reuse and recovery (Faniran and Caban 1998, Nelson et al. 2011, WRAP 2007, 2009). Few attempts address the role of design practice on waste issues (Osmani et al. 2008). However, the current thinking focuses on construction waste minimisation, based on guidelines, for on-site waste management improvement and recycling activities.

5/ Building Information Modelling: Meanwhile, the entire Architecture, Engineering and Construction (AEC) industry is facing the challenge of the implementation of Building information modelling (BIM). The BIM process is an improved method of management, requiring information exchange and cooperation between all stakeholders using a 3D digital model. BIM utilisation is now reinforced by a range of Public Policies aimed at increasing the effectiveness of the construction sector. For example, the European Union Public Procurement Directive (EUPPD) defines the following “28 European Member States may encourage, specify or mandate the use of BIM for publicly funded construction and building projects in the European Union by 2016” (Official Journal of the European Union 2014). The EUPPD recommended the use of electronic tools like BIM, stating that for “public works contracts and design contests, Member States may require the use of specific electronic tools, such as of building information electronic modelling tools or similar*”* (Zelles 2014).

1.2 Sustainable EOL method

When an asset is no longer usable, it is most often demolished (Figure 1). Reclaimed materials undergo recycling and waste goes to landfills. In the Netherlands, asset demolition is fading and instead replaced by deconstruction, which practises the approach of 'reuse and recycle', mostly through downcycling (Knecht 2004). Demolition is a purposeful dismantling or reduction of an asset, or part of it, without necessarily preserving the integrity of its components or materials. This is usually carried out mechanically, with a wrecking ball or bulldozer.

Some materials have been removed due to 3rd party copyright. The unabridged version can be viewed in Lancester Library - Coventry University.

Figure 1: Housing demolition (from www.24housing.co.uk

Opposed to the demolition, we will define in this thesis a Sustainable End-of-Life (SEOL) that implies methods to recover materials and to minimize the amount of the waste sent to landfills. Various concepts, such as the Deconstruction, Disassembling, Dismantling, and Decommissioning, are used amongst others. These processes refer to the "Last-On-First-Off" (LOFO) or "Construction in reverse"(Greer 2004). For instance, deconstruction is also defined as "the systematic disassembly of buildings in order to maximize recovered materials reuse and recycling" (Chini 2005). The SEOL requires processes of cautiously taking apart components of an asset. The main intentions are to recover the components for reusing, reconditioning or recycling them.

The SEOL methods may be used when a building needs to be refurbished to make it adaptable for its new use or in the case of deconstruction with the aim to salvage components when the building is not usable anymore due to its disrepair. The SEOL methods lead to a shift of the traditional linear to a circular process that can be achieved by planning upstream during the design of the management of EOL. In the SEOL methods, each building component has the capability to be demounted, reused and /or recycled. SEOL approaches can significantly increase construction sustainability. According to Falk & Guy (2007), "…if done right, deconstruction can extract thousands of dollars' worth of reusable materials from a house that would otherwise be knocked down, crushed and planted in a landfill" (Falk and Guy 2007). Indeed, as highlighted by Akbarnezhad et al. (2014:131), "…if designed properly, at the end of the building service life, building components may be reusable for the same or similar applications as the original components" (Akbarnezhad et al. 2014). Ajayi et al. (2015) mentioned that proper design coordination could be real preventive measures for improving rate waste generated during construction activities, including deconstruction (Ajayi, S. O. et al. 2015). The SEOL approaches aim to increase the rate of salvaged materials that is to say that they will be either reused or recycled.

1.3 BIM environment

Since its origins, in 1978 (Eastman et al. 2011), the Building Information Modelling (BIM) process has been progressively implemented worldwide in the AEC sectors resulting in fundamental transformations of the world of construction, one of the most important, since the industrial revolution (Eynon 2016, Underwood and Isikdag 2011) and the CAD revolution in 1990s (Tulenheimo 2015, Cerovsek 2011). This new technology has shaken the traditional "ways to work" in AEC processes (Khosrowshahi and Arayici 2012, Gledson and Barry 2016, Murphy 2014). In fact, the digital revolution leads to a paradigm shift (Lu et al. 2017) when compared to the move from paper to computer. BIM process is based on a multidisciplinary collaboration approach that necessitates changes in the roles of the stakeholders that are involved in the project (clients, architects, contractors) (Sebastian 2011, Lea et al. 2015, Alreshidi et al. 2017). Construction players need to move from a "silo process" to collaborative work and share a huge amount of data generated from design to completion (Fadeyi 2017, Zhu et al. 2017). The thinking process towards an overall view of a building lifecycle will have to be modified.
BIM process "is not only a single, large database; it is also an information management tool" (Xu et al. 2014). A BIM model is an electronic repository containing organised 3D data. The data is related to both physical and dynamic functional features of a building. The BIM process works like a living database putting the resources embodied into the asset in their spatial and temporal context. It can cover the entire lifecycle of a facility (Skandhakumar et al. 2012) and stores data for all aspects of the building (Umar et al. 2016).

BIM was first used in the design phase where the 3D BIM model is a virtual mock-up model expressing visually, among other ways, the design concepts. The three primary spatial dimensions used are width, height and depth. This allows increasing collaboration (Eadie et al. 2013) and improvement in the design and construction processes (Azhar 2011) by enabling visual controls during design and construction phase (Charehzehi et al. 2017, Chong, H. Y. et al. 2014, Schultz et al. 2013, Bråthen and Moum 2016). To date, BIM has been widely used in the design phase whereas in construction and Facility Management phases, BIM is significantly used less (Bråthen and Moum 2015). Due to its capability to improve the productivity, to reduce the project duration and to allow better control of the project cost through all the design and construction process, the BIM technology is increasingly adopted in the AEC industry (Cavka et al. 2017, Akinade et al. 2017). And basically, the simple 3D visualisation before the "hammer meets nails", dramatically reduces the errors generating waste and cost, and rules out misunderstandings and disputes between the stakeholders involved in the project. Then, the overall design quality is enhanced.

3D BIM visualisation has not achieved faster delivery; the "time" factor became the 4th dimension of BIM (Zhang, J. P. and Hu 2011, Lopez et al. 2016). Indeed, many other dimensions needed to be added for BIM to fulfil its potential. These activities, include sustainability, asset management, accessibility, safety management, energy saving, acoustic among others (Yung and Wang, X. 2014, Ding, L. et al. 2014, Kiviniemi, M. et al. 2011, Nicał and Wodyński 2016, Davtalab 2017, Aouad et al. 2005, Fu et al. 2006, Yi et al. 2015). However, the current design decision-making tools don't support designers efficiently, during the design phase, for the evaluation of construction waste (Liu et al. 2015). The contemporary software for waste management are limited, and they cannot support stakeholders in their tasks and willingness to control waste(Bilal et al. 2016). The increasing adoption of BIM within the AEC industry necessitates a holistic rethink of entire construction activities (Akinade et al. 2015). According to Kim et al. (2017), the use of BIM could cover all the asset lifecycle phase from design to demolition. But the use of BIM for the demolition phase suffers from a research' insufficiency in that area (Kim, Y. C. et al. 2017). However, a review of the currently limited approaches for waste management with BIM reveals that new tools are emerging for waste minimisation during the design phase and waste management throughout the demolition stage. Akinade et al.(2016:5), identified five categories of tools, (i) waste management plan templates and guides, (ii) waste data collection and audit tools (iii) waste quantification models, (iv) waste prediction tools, and (v) geographic information system (GIS)-enabled waste tools (Ajayi, S. O. et al. 2015, Akinade et al. 2016).

The effort put at the beginning of the design phase for embodying the 3D model with a huge amount of data should be continued throughout the asset life cycle, for construction management (Bargstädt 2015)(Gbadamosi et al. 2019) and Operation and Management phases (Patacas et al. 2015, Kiviniemi, A. and Codinhoto 2014)(Lucas 2012, Edirisinghe et al. 2017, Couto, J. P. and Couto, A. 2009) and end-of-life management (Akanbi et al. 2019). To be able to use BIM for End-of-Life management, the asset lifecycle must be reconsidered and the EOL activities incorporated. BIM technology is more than a 3D model and the use of the software. It shakes the way projects are designed, constructed, managed, and the way the assets' End-of-Life will be managed optimally. This PhD study will focus on the insertion of a SEOL process into the asset lifecycle in a BIM environment. This research work will take into account a holistic approach to fulfil the full BIM potential, and will, therefore, consider the entire lifecycle of the asset.

1.4 Asset lifecycle

The current most frequent definition of the asset lifecycle goes from inception to in use phases, including refurbishment. For instance, the UK construction sector is governed by several professional bodies, inter alia, the Royal Institute of British Architects (RIBA) stages, the RIBA Plan of Work. The Plan of Work is a guide setting the scene without being a contractual document and representing how the construction process should be organized (Hughes 2003, Kassem et al. 2014). As mentioned by Dawood and Iqbal (2010), the "RIBA has a distinct process for organising and managing building design projects through a number of key work stages". It is a framework used by all UK project teams to gather information quickly on required deliverables at each stage. An updated version of the RIBA 'Outline Plan of Work' has been edited to include a 'BIM Overlay' (Dawood, N. N. and Vukovic, Vladimir 2015) conjointly with the Green Overlay (Sinclair 2012). That Outline plan of work assists architects by providing stage-by-stage guidance for designing and managing construction projects through the use of BIM. The Green Overlay aims is to provide a process to help project stakeholders to lead sustainable design strategies in their projects (Gething 2011). The RIBA Plan of Work (Sinclair 2013), the BIM Overlay to the RIBA Outline Plan of Work (Sinclair 2012), the Green Overlay (Gething 2011)and the RIBA Guide to Sustainability in practice (Bordass et al. 2012) are discussed in Chapter 4.

In this linear system, eight phases are linked, starting with "strategic Definition" and end with the "In Use" phase (phase 0 to 7). Both the RIBA plan of work and Green overlay do not take into consideration the EOL (Liu et al. 2015). This study aims to consider a SEOL stage (and generally the End-of-Life) of the asset as a part of the asset lifecycle that needs to be included into construction processes, as a phase, in the same way as "design", "construction", and "In use" phases. The asset process will be deemed as a whole. All the phases of the asset lifecycle are linked together and in interaction, working as a holistic system. For doing that, the study will rely on the construction process in the UK and its BIM implementation.

The analytic vision is replaced by a holistic view leading to a collaborative work where all the stakeholders involved in an asset lifecycle are connected. The loop of the asset lifecycle is closed, enabling the construction system to become circular. SEOL procedures lead to recover building materials and re-introduce them into the loop by reusing or recycling them. Therefore, asset fate is linked to the design and construction processes. Several papers raised the importance to have a holistic view of sustainable construction (Crowther 2005). Having a holistic view consist of taking into account the SEOL during the design stage (Ajayi, S. O. et al. 2015, 2016). However, the asset lifecycle needs to be considered as a holistic system from inception to SEOL management. The AEC digitalisation, fostered by several policies, can give the means to shift from a linear system to a circular one due to its ability to produce and manage an enormous amount of data related to the asset lifecycle. The major reason for the huge amount of waste in the construction industry is the ineffectiveness of current waste management strategies. Indeed, waste is not tackled holistically but in static steps (Ajayi, S. O. et al. 2015). To reinforce the argument, some authors think that to achieve the project objectives successfully; the construction industry must move to a more holistic philosophy and consider the phases as interconnected (Kifokeris and Xenidis 2017). This brings the question of the relationships that exist with those who design the building, those who build and those who deconstruct. This opens the new vision of "design with the end in mind"; a critical notion in the extended BIM process.

By moving from the Linear Economy to the Circular Economy, the asset lifecycle needs to be considered as a holistic system and the BIM implementation extended throughout the whole lifecycle of the building, from design to End-of-Life management. In a BIM environment, the BIM model is an intelligent and object-oriented model embodying rich parametric data aiming to represent the asset. A great amount of data is collected from various activities throughout the lifecycle of the asset (Lu, Q. and Lee, S. 2017, Zeng and Tan, J. 2007, Umar et al. 2016). Even if its use in post-construction is still late (Giel and Issa 2015), various academics have recently acknowledged that BIM technology can cover the entire life span of a building, from planning to demolition (Ustinovichius et al. 2017) (Kim, Y. C. et al. 2017).

1.5 From Linear System to Circular Economy

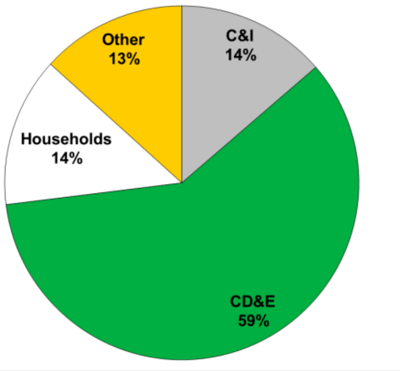
The willingness of the AEC industry to leave the linear system for a circular system exists in various countries which had set up a plan to move towards the Circular Economy (CE), (Chang et al. 2016). In China, the government has set up a five-year plan to shift the growth model towards a Circular Economy (Menegaki et al. 2018). Japan is trying to achieve a Circular Economy since 1991(Ministry of Economy 2003). In 2000 a pioneering law for the Promotion of Efficient Utilization of Resources was launched, considering materials as circular goods (Morioka et al. 2005). The Japanese government developed a "comprehensive legal framework for moving towards a recycling-based society" (p.215) (Su et al. 2013).

Interest started to raise up among researchers. Indeed several papers presented the benefits of the Circular Economy for the built environment. For instance, Ghisellini et al. (2016), make available an extensive review of the literature aiming to facilitate the understanding of the CE approach covering the micro, meso, and macro levels (Ghisellini et al. 2016). Other authors focus on the CE approach for the built environment. They propose a critical literature review with the goal to offer a better understanding and emphasize the crucial importance of interdisciplinary research (Pomponi and Moncaster 2017). Su et al. (2013) also reviewed the current practices, the concept and the assessment of the Circular Economy approach to identify issues and challenges for the China strategy. Some recommendations were proposed to improve CE development (Su et al. 2013).

Likewise, the European Union has proposed to move towards a Circular Economy model to transform the production chains and consumption habits by means of turning waste into resources to close the production loop (Robles 2016) Additionally, the European Directive CEN TC 350 requires "member states to legislate so that all new buildings are designed from a whole-life perspective, which takes into account both operational and embodied carbon emissions. As such, designers will have to complete whole-life assessments, which take into account emissions associated with the production of all materials used in a building's construction, including their manufacture, transport to site, and possibly also their subsequent maintenance and end of life disposal or recycling" (Eurostat n.d.).

1.6 The justification for construction industry adaptation

By consuming more than 50% of the total global resources, the construction industry is the biggest resource consumer' sector in the world (Iacovidou and Purnell 2016) (Figure 2). With rapid economic development, the consumption of resources becomes more serious (Shy 2017).
The construction sector generates the largest percentage of total waste all over the world (Clark et al. 2006). In the UK alone, the Construction industry produces an average of 100 million tonnes of construction, demolition and excavation waste for the year 2012. This represents more than 1/3 of all waste arising in the UK (Deloitte 2016). Concrete is the largest amount of material generated during demolition. The other components coming from demolition are brick, clay, wood and metals (Douglas et al. 2016). Over 75% of the construction industry waste has a residual value enabling them to be salvaged and recycled or reused (Yeheyis et al. 2013).



Source: Defra Statistics

Percentages may not sum to exactly 100% due to rounding
C,D&E figures include excavation waste and dredging
Household figures are based on the WfH measure, but also include End of Life Vehicles

Figure 2: The CD&E waste in the U (Source: Defra Statistics)

The current linear way resources are consumed, from their extraction, utilisation and disposal is damaging the environment (section 1.2). Companies cannot follow the linear system anymore if they want to reach to government goals, like the EU target of zero waste to landfill by 2020. Companies need, therefore, to rethink the asset lifecycle by moving from the Linear Economy to the Circular Economy and moving from demolition to deconstruction. Adapting Circular Economy principles enables to stop aggravating the depletion of the natural resources by injecting back into the economy the salvaged materials as "secondary raw materials".
In this context, designers would work "hand in hand" with the EOL contractors to tackle waste through an efficient deconstruction or disassembly at the EOL of the asset. In some cases, adopting a SEOL has a positive impact in term of cost of the project. For example, for six buildings (up to two-storey types), it is 37% cheaper to use deconstruction, rather than demolition (Gorgolewski 2008). Compared to similar new asset built, deconstruction can lead to an average

of 1.7% marginal profit. (Coelho and de Brito 2011). However, deconstruction cost differs according to the building types and the value of salvaged materials (Couto, J. and Couto, A. 2010). According to Rios et al.(2015), it is possible offsetting the labour cost using financial incentives provided by the government and by reducing costs from equipment used to deconstruct (Cruz Rios et al. 2015).

As the main hurdle that is the lack of confidence in C&D waste quality, waste management strategies play a critical role in the quantity and quality of the materials retrieved. In this manner, Design for SEOL such as Design for Deconstruction (DfD) or Design for Disassembly will reduce further waste and increase material recovery and reuse. DfD also has the potential to raise the cost-effectiveness of material salvage (Densley Tingley and Davison 2012).

In the United Kingdom, researchers have investigated the capability of using BIM for driving out construction waste during the design phase through a questionnaire survey. Additionally, follow-up interviews were conducted (Liu et al. 2015). The findings enable them to develop a waste minimisation framework aiming to help designer for designing out waste. Another study conducted among UK experts by using semi-structured focus group discussions reveals that waste management tools should be compliant with BIM (Ajayi, S. O. et al. 2015).

1.7 The gap in knowledge

Design and EOL: Despite the undeniable usefulness of the abovementioned studies and the BIM-based deconstruction tool for the AEC industry, the set of studies are focussing on the design and the deconstruction or disassembly phases only. They are not considering the entire disruptions generated in the asset lifecycle, as a holistic system, when the SEOL, whether deconstruction or dismantling are inserted in it, in a BIM environment. The interplays between phases and stakeholders are not yet adequately explored. There is a lack of studies producing a holistic approach considering all phases from design to EOL management in the Circular Economy context.

CDW management: All these approaches are focused on waste management tools without addressing the challenges and consequences of insertion of the SEOL phase in the asset lifecycle, in a BIM environment. By discussing the link between the design phase and EOL, the loop is closed. It becomes obvious that the construction process should be considered as a holistic system where all the phases are bound together. The need was supported by Hakkinen et al. (2011) and Matar et al.(2011:261) who raised up that "one of the major technical barriers for Sustainable Buildings (SB) is "the absence of a common framework that integrates the aspects and tasks of SB with construction practices at an operational level*"* (Matar et al. 2010, Häkkinen and Belloni 2011). Akinade et al.(2016) concluded, based on a literature review that even if the existing tools are promising, "…they are not holistic enough to tackle the challenges of waste management" (p.17) (Akinade et al. 2016).

Filling the gap of knowledge: In consequence, this study aims to consider the SEOL of the asset as a part of the Asset Lifecycle that needs to be integrated into construction processes in the same way as the "design", "construction" and "in use" phases. The study will propose a framework for integrating the SEOL phase into the asset lifecycle in the BIM environment. When you add something to a holistic system, it will disturb it, and some adaptation should be made. The impacts of adding the SEOL into the asset lifecycle will be investigated through stakeholders' perspective. What is this adaptation, and what are the main barriers to incorporate the SEOL processes into the asset lifecycle in a BIM environment?

The research will enable to offer to the stakeholders involved in the asset lifecycle a BIM-Framework designed from feedback of experienced professionals working to minimize the impact of their project on the environment. The BIM-Framework can be used as guidelines to the construction supply chain willing to move towards a more circular approach. Barriers to moving towards the new asset lifecycle concept were also reported and discussed.

1.8 Aim & objectives

The aim of the research is **to develop a BIM-based framework for integrating the sustainable End-of-Life phase into the asset lifecycle in the Circular Economy context**. The following research objectives have been set to reach this aim:

1. **To investigate** the current elements assigned to BIM Dimensions beyond the third dimension to reveal if a BIM dimension is linked to the EOL phase by using systematic review and survey.
2. **To explore** the various SEOL approaches and **identify** the barriers to their adoption by conducting an extensive literature review.
3. **To create** a theoretical BIM-framework to incorporate the asset SEOL phase into BIM environment based on a literature review.
4. **To identify** the barriers of integrating the SEOL phase into the asset lifecycle and to improve the theoretical BIM-based framework through the stakeholder's perspective engaged in using Eco-friendly material approaches, in France and in the UK.
5. **To draw** the conceptual BIM-based framework, **identify** the BIM uses and **propose** guidelines for the implementation of a SEOL approach.

1.9 Research Questions

The study will answer four research questions

1. What is the BIM dimension assigned to the End-of-Life activities?
2. What are the various sustainable construction approaches, and what are the barriers to their implementation?
3. What are the stakeholders' views on the barriers of incorporating the sustainable End-of-Life phase into the asset lifecycle?
4. What are the stakeholders' opinions on the BIM-based theoretical framework integrating the SEOL phase into the sustainable asset lifecycle and how it can be improved?

1.10 Methodology

The research will adopt various techniques and approaches for collecting and analysing data. For each objective, specific techniques will be used to achieve them. The techniques used were literature review, systematic review, survey questionnaire and face-to-face interviews, as shown in Figure 3.

1.10.1 Objective 1 methodology

To investigate the current elements assigned to BIM Dimensions beyond the 3rd dimension to reveal if a BIM dimension is linked to the EOL phase by using a systematic review and a survey*.*

As a preliminary study, the elements assigned to the current BIM dimensions were investigated, first to be able to insert those dimension properly in the framework and, second to identify the current use of BIM for the asset End-of-Life concerns. For both, two methods were used:

- **Systematic Review** of extant literature was carried out to determine the current BIM dimensions and to what they refer to. It also enabled to check if a BIM dimension exists for the End-of-Life management.
- **Online Questionnaire Survey**: Based on the systematic review findings, the questionnaire survey was set up to study the current BIM dimension used by European practitioners to clarify a lack of consensus beyond the 5th dimension. The questionnaire was structured in four sections:
    - (i) The informed consent section,
    - (ii) A set of four questions on the respondent identification,
    - (iii) Two questions for the company description section,
    - (iv) A set of three closed questions regarding BIM to determine the awareness, understanding and utilisation of BIM dimensions by the practitioners, across Europe.

  The survey was designed, distributed and collected through the Bristol Online Survey (BOS). The questionnaire was reachable via a link emailed to potential respondents. To ensure potential respondents from all the 28 EU countries were contacted, the purposive sampling method was used. The selected sample was purposely targeting position with a high level of responsibilities in the companies, and knowledge in BIM. A total of 51 respondents filled the questionnaire. The response rate of this study was about 46%. The questionnaire was then analysed with Excel using descriptive statistics and Statistical Package for the Social Science (SPSS). The survey process is discussed in detail in Chapter 3, and the results are reported in Chapter 7.

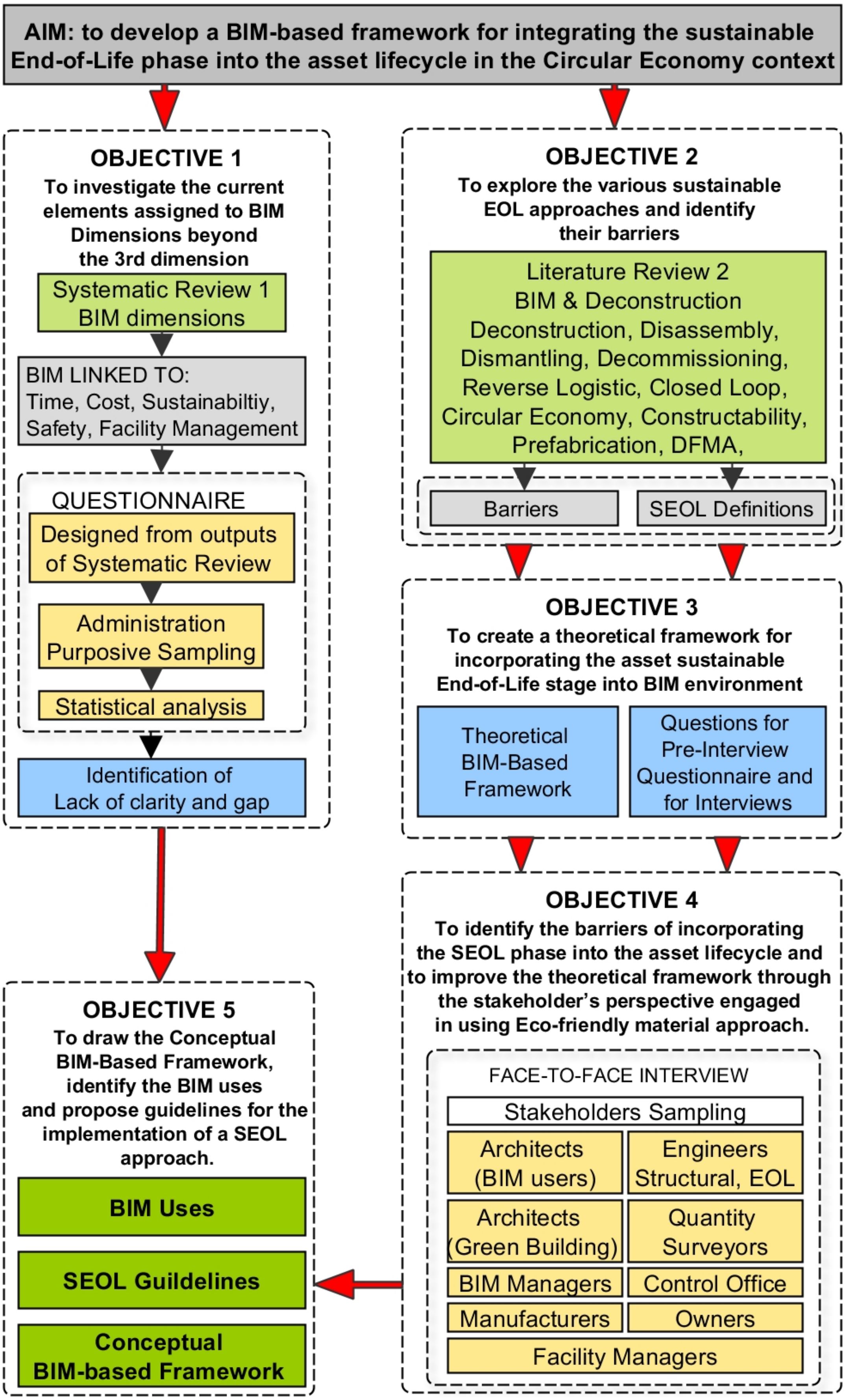


Figure 3: Methodological flowchart for the study (Source: Author)

1.10.2 Objective 2 methodology

To explore the various sustainable EOL approaches and identify their barriers by conducting an extensive literature review.

Extant literature was reviewed about the potentially SEOL approaches. The words used for the search were: Barriers OR Drivers OR Factors AND Deconstruction, Disassembly, Dismantling, Decommissioning, Reverse Logistic, Closed Loop, Circular Economy, Constructability, Prefabrication, DFMA. The aim of the extant literature was to determine what the barriers for the use of a SEOL are and how the SEOL can be managed through the BIM process are?

1.10.3 Objective 3 methodology

To create a theoretical framework for incorporating the asset SEOL phase into a BIM environment, based on the findings of the review of the second objective.

The literature review findings were used as a basis for drawing the BIM-based theoretical framework and for the questions used for the interviews. The theoretical framework represents the main stages in a project, such as the design, construction and "in use" phases. The SEOL phase was added to extend the asset lifecycle until its EOL management. The BIM-based framework also considers the Circular Economy approach and incorporates the processes enabling to close the materials' loop.

1.10.4 Objective 4 methodology

To identify the barriers of integrating the SEOL phase into the asset lifecycle through the stakeholder's perspective engaged in using Eco-friendly material approach and to improve the theoretical BIM-based framework.

The qualitative face-to-face interviews were used to investigate barriers related to the integration of the SEOL phase in the BIM environment. The goal was to get all the stakeholders' perspective (from the owner to the deconstruction engineer). The SEOL phase involved a set of stakeholders throughout the asset lifecycle. The phases considered were the design phase (designers, Quantity Surveyors, Engineers, owners), the construction phase (contractors) the Operation & Maintenance phase (Facility Managers) and the EOL phase (demolishers, deconstruction contractors). Interviews were conducted with 20 experts in BIM or in sustainable construction. The interview process is explained in Chapter 3 (section 3.4). The interviews were set up according to several steps. First, a pre-interview questionnaire was filled by the interviewees. Then, during the interviews, a set of questions were used to semi-structured the interview. The theoretical BIM-based framework was presented to the interviewees. One question was how to improve the theoretical BIM-based framework to make it more useable for practitioners.

The results are presented in Chapter 5, Chapter 6, and Chapter 7. The types of interviews used were Semi-structured Face-to-face interviews (reel face to face and virtual via Skype and by phone).

1.10.5 Objective 5 methodology

***To draw the conceptual BIM-based framework, identify the BIM uses and* propose *guidelines for the implementation of a SEOL approach*.**

The theoretical BIM-based framework was re-drawn according to the interviewees' feedback. BIM uses for the SEOL approach were identified. Guidelines for implementing the SEOL approach were summarized in a table mentioning recommendations for each stage. The table from the "RIBA Plan of Work" was used as an example to present the guidelines.

1.11 Unit of Study

According to Hopkins, the "Unit of study" singles out to the major entity that would be explored or analysed in a study (Hopkins 1982). Various type of "unit of study" exists, such as individuals, groups, organisations, projects, among others. This will be presented in the methodology chapter. As reported by Trochim and Donnelly (2008), the "unit of study" must be designed appropriately (Trochim and Donnelly 2008). This enables us to avoid ecological and exception fallacies (Bless et al. 2006). A unit of analysis" must be chosen, appropriately before data collection.

The purpose of the research is to investigate the barriers for the implementation of a SEOL and to improve the theoretical BIM-based framework. The unit of analysis of the research is a social artefact: the sustainable End-of-Life incorporation into the asset lifecycle. The unit of observation of the research is the group of the AEC stakeholders involved in a construction project and having a sustainable approach.

1.12 The significance of the research

Closing the loop of materials is considering C&D waste as a resource that would help the industry to reduce resource extraction. It would also decrease the amount of waste and environmental impacts.

Among the construction professionals, new roles would appear, and needs for skilled workers would increase. The supply chain would be completely reorganised, giving to site workers more importance. Blue collars would be revalued and the overall construction would gain in quality in various aspects. For instance, buildings would have a lower environmental impact, and healthier material will be used. The overall cost of buildings would be shared differently and would be lower due to the reclaimed material resale.

1.13 Scope and limitation

- In a nutshell, the overall aim of the research is to develop a BIM-based framework for integrating the SEOL phase into the asset lifecycle**.** Due to time, limitations should be set up. The study will be based on publically available reports and published literature in English. Data will also be collected from AEC stakeholders involved in a construction project such as designers, BIM Managers, Quantity Surveyors, Structural Engineers, and Deconstruction Engineers, Manufacturers, among others.
- According to the asset lifecycle phase, the scope of this research covered building Design stages, Construction stage, Operation & maintenance and EOL stages. The research

concentrated on what are the main barriers to overcome for the adoption of a SEOL approach to be able to move towards the Circular Economy.

- In addition, construction industry activities are divided into two categories, building construction and infrastructure. The research is restricted to buildings' construction. Those limitations and delimitation aimed to shape the research scope and boundaries.
- Within the scope of this research, the thesis will focus on what are the consequences of incorporating the SEOL stage in the asset lifecycle in a BIM environment. Information about the BIM process will be given, but it will not address the process of BIM tools implementation.
- The developed framework was based on the literature review and improved by the Interviewees' feedback. However, due to the limited time for a thesis, it was not validated by a worldwide range of AEC experts.
- Another limitation is geographic. For the assessment of the use of BIM, Europe was considered. Then, for the interviews, the focus of the research was the UK and France. The aim was not to compare both countries. However, the research will highlight, if necessary for some data, specificities for France or the UK.

1.14 Thesis structure

The thesis is organised into eight chapters:

Chapter 1: is an overview of the research, methodology used and the thesis structure. It discusses the background, the SEOL, asset lifecycle and the Circular Economy concepts, and the BIM process. It also points out the research gap and sets the aims and objectives of the research, research questions, the justification of the study and its novelty. The methodology used is only presented briefly in this chapter.

Chapter 2: This chapter reviews the literature associated with the research aim and objectives. It provides a background for the research and structures the collection of the data. Several domains were explored to set up the research. First, the BIM level of adoption by the AEC industry and BIM dimensions were explored to find out what are the several activities linked to BIM and if the EOL management is already made with BIM. Then, the various Sustainable End-of-Life approaches were explored according to their definitions and the barriers for their adoption. Lastly, a theoretical BIM-based framework, integrating the SEOL as a phase, was drawn based on the literature review findings.

Chapter 3: The chapter discusses the research methodology, including research philosophy, research strategies/approaches and research design and methods. Thereafter, the adopted research methodology is discussed and covers: the systematic review, data collection through interviews and questionnaire survey, data analysis and the development and improvement of the framework.

Chapter 4: This chapter sets up the BIM bases of the research. First, the RIBA Plan of work, the architects' profession and the construction industry framework were presented and compared with the French framework for the project organisation. Then, the asset lifecycle was discussed. And lastly, the background of the interviewees and their various strategies to reduce their impact on the environment were presented.

Chapter 5: The chapter presents the findings, analysis and discussion of the data collected from the exploratory interviews undertaken with the construction project stakeholders. The barriers highlighted by the 20 interviewees were structured according to the themes and sub-themes identified. The results were compared and discussed with the literature review findings. The discussion was also alimented with the drivers suggested by the interviewees to overcome the barriers.

Chapter 6: The chapter presents the findings, analysis and discussion of the data collected from the interviews carried out to improve the framework. Suggestions by the interviewees were structured according to the project phases or actors involved in a SEOL project. An improved framework was drawn, the conceptual BIM-based framework and Guidelines for the SEOL implementation are summarized in a table.

Chapter 7: The chapter presents the research findings and the data analysis collected through questionnaires. BIM Dimension understanding and use are presented. The chapter is also explaining the various models generated throughout the asset lifecycle. The emerged model for Sustainable End-of-Life (SEOL) management is presented.

Chapter 8: This chapter proposes the research conclusion and recommendations. It presents the accomplishment of the aims and objectives of the research summarily. The research's contribution to knowledge is also identified. Further research is suggested.

1.15 The motivation of the candidate

After my graduation in the School of Architecture of Lyon, I have spent 15 years in the industry as a designer of a variety of buildings from multifamily residential buildings to more complex assets like hospitals. For some projects, I was in charge of the design and construction of the asset. This experience convinced me that the day-to-day work of an architect had two main flaws: a lack of efficiency due to the poor cooperation among the stakeholders and a lack of sustainability concerns.

That is why I took the opportunity to engage in 2014 in the newly launched master in Building Information Modelling (BIM) in Ecole des Ponts ParisTech (France). After being graduated, I wanted to deepen my knowledge in the field. I also wanted to drive my researches to be as useful as possible for practitioners. I was seeking to understand the important link between the design, sustainability and a holistic view of the asset lifecycle and to confront my practical skills with the research methodologies. I was also interesting in studying the potential link of digitalisation with buildings sustainability. To do so, I designed the PhD topic to deal with the management of the end of life of assets as a step in the life of the building and not as the end, in the context of the circular economy

2 CHAPTER 2: Literature Review

2.1 Introduction

Some definitions of BIM are already given in the introduction chapter, and here in the literature review, we expatiate more on BIM because our aim is to develop a BIM-based framework. In section 2.2, systematic literature reviews are performed on two crucial topics related to BIM: in 2.2.1, the level of BIM usage and adoption and in 2.2.2, the current BIM Dimensions usage. The research is restricted to the EU due to the limitation of time and means.

Then, section 2.3 is dedicated to the study of the barriers to incorporate the SEOL in the asset life cycle. In 2.3.1, the concepts and principles potentially related to the thesis aim are clarified. Indeed there is not yet any definition of what an asset sustainable life cycle is. In 2.3.2, the barriers related to those concepts that may be related to our objectives are assessed.

In section 2.4, the supporting secondary data that helped the design of the research are presented. Subsection 2.4.1 is dedicated to the design of the theoretical framework and subsection 2.4.2, to the elaboration of the questions to drive the semi-structured interviews of the stakeholders for the qualitative data collection used to improve the theoretical framework.

2.2 Overview of BIM adoption and usage in the European Union

Only a summary of the research on the overview of BIM adoption and usage in the European Union is given here because the full work is already published in two articles that are given in Appendix 1 and 2. That is why only the systematic review method with a summary of the findings is given in the two following subsections.

For both subsections, the secondary data were collected through two systematic reviews that also helped to design the questionnaire for primary data collection (see chapter 3 and 7).

2.2.1 An overview of BIM adoption in the European Union

A. The systematic literature review

The author has chosen the systematic review because it is the “most reliable and comprehensive statement about what works” (Petrosino and Lavenberg 2007). The systematic literature review was conducted in the peer-reviewed journals, conference papers and books, but also included official documents from the European Commission and reports/projects dealing with BIM implementation in the EU (EU n.d.)(Figure 4).

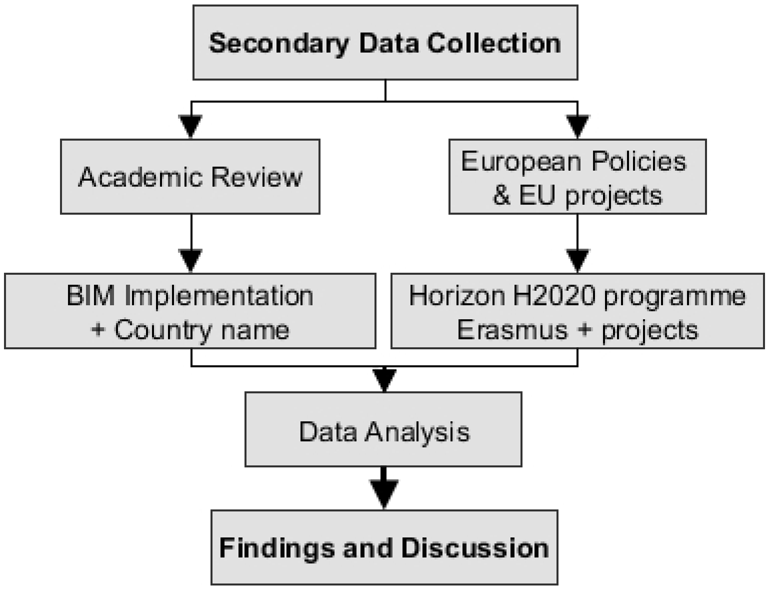


Figure 4: The process of collecting the secondary data for BIM adoption in the EU (Source: Author)

Secondary data came from a systematic literature review where journals papers, conferences papers and book chapters written in English were collected using Scopus as a search engine. Scopus was used because it is the largest abstract and citation scientific database of peer-reviewed literature, and it offers the highest reliability in comparison with other databases (Adriaanse Leslie and Rensleigh, 2013; Chadegani et al., 2013).

The search field type was the “Article Title, Abstract, Keywords”. The method used for the systematic review, split into six stages, was based on the PRISMA statement flowchart (Lutz 2015) summarised in Figure 5. Stage 0 is related to search questions definition. A generic search was conducted using the keywords method. Two search criteria were used to be consistent with the aim and objectives (see Figure 5 stage1). The keywords used for the first criterion were “BIM AND (Country name)” OR “BIM” AND “Europe” OR “World” AND “Implementation” OR “Adoption.” For the second search criteria, “BIM” AND “Adoption” AND “Barriers” were utilized. Stage 1 focused on setting the search criteria and removing duplicates, which left 187 outputs for research first criterion and 49 for the second one.

During the stage 2, documents titles were assessed, and 120 papers in total were found to be ineligible because they are related to “infrastructures” or out of topic, (Outside Europe, or just cited the name of the country used as a search word). For example, the titles “Using BIM for the last planner system: Case studies in Brazil” (Garrido et al. 2015) and “BIM bamboo: A digital design framework for bamboo culms”(Lorenzo et al. 2017).

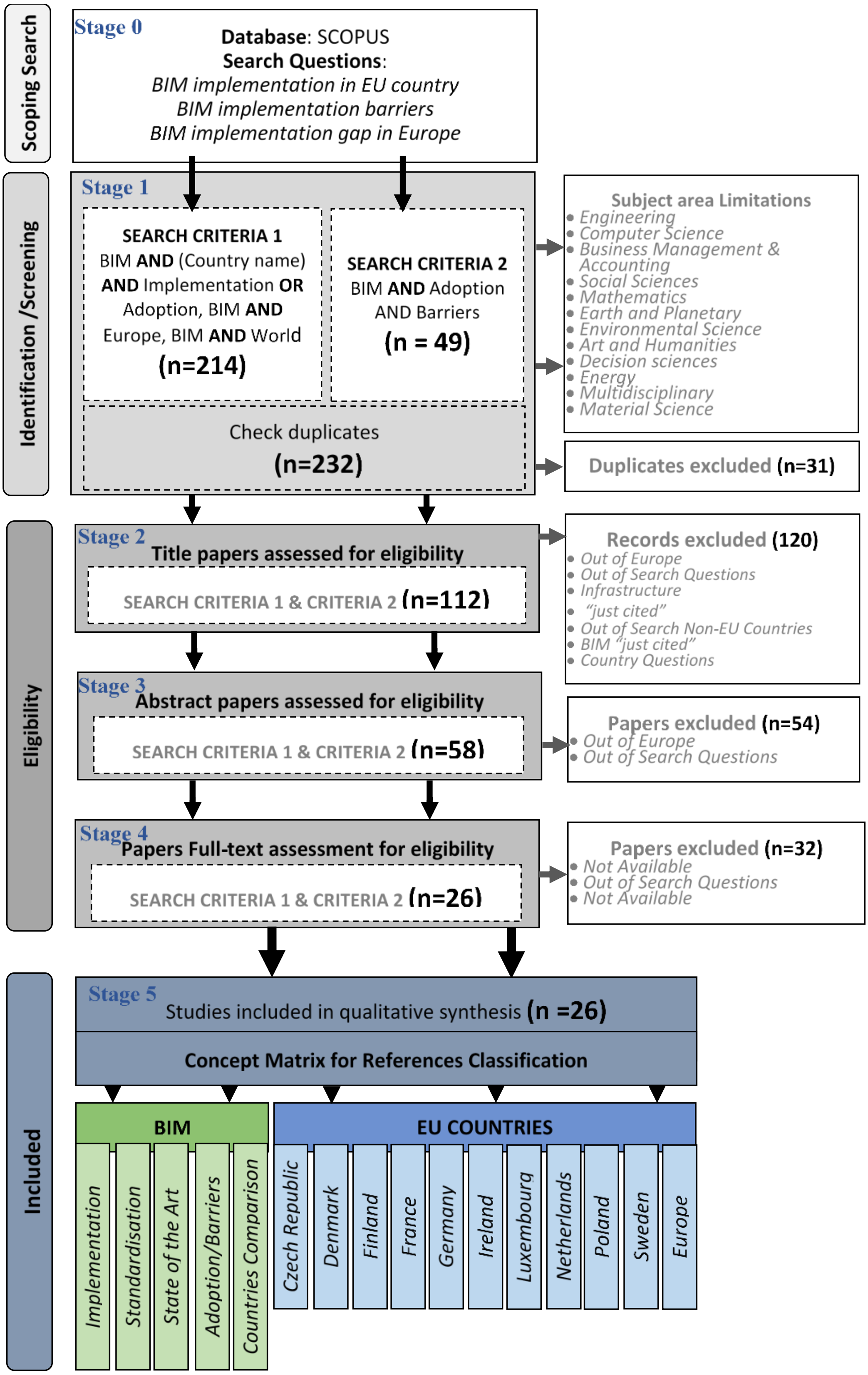


Figure 5: Prisma Flowchart for the systematic literature review (Source: author)

At stage 3, for both criteria, one hundred and sixteen abstracts were read for the eligibility assessment, and fifty-four documents were excluded because they were found to be out of search questions established in phase 0. For example, due to their focus, such as the use of BIM on heritage buildings (Gigliarelli et al. 2016) or the analysis of risk and rewards of adopting BIM for SMEs in the UK (Thanh LAM et al. 2017).

For stage 4, from sixty-two papers, two were dismissed for their unavailability (Hjelseth and Mêda 2017, Jeffrey 2012) and the remaining sixty assessed by full-text reading. Because of this, thirty-two papers were excluded due to their irrelevance. For example, the paper “Changing roles of the clients, architects and contractors through BIM” was excluded because it's focused on the use of BIM for hospitals only (Sebastian 2011). Another example is the paper “Building information modelling: the UK legal context” excluded because it deals only with the legal context of BIM adoption in the UK (McAdam 2010). Finally, twenty-six publications addressed the BIM implementation in various European countries (11 Journals papers, 10 Conferences papers, 5 Review papers and one book chapter).

In Table 1, papers selected as relevant to the topic were analysed, and a matrix was set up aiming to classify the 26 documents according to the European countries and BIM. The classification was made using six categories that were directly sourced from the content of the papers reviewed: (i) Implementation, (ii) Standardisation, (iii) State of the Art; (iv) Country comparisons; (v) Adoption Assessment and (vi) Barriers/Challenges. For the European countries, results show that 11 countries had a minimum of one paper related to one category (Table 1).

The UK has a total of 16 documents including five Journal papers addressing BIM implementation in the UK (Eadie et al. 2013, Rezgui et al. 2013, Dainty et al. 2017, Alreshidi et al. 2017), barriers associated with BIM adoption, and BIM standardisation (Maradza E. et al. 2013). Furthermore, three review papers were in the search area, among them. One paper has developed a roadmap for BIM implementation, and one has addressed specifically costs related to BIM implementation. Table 1 summarised the journal and conference papers addressing BIM implementation in EU countries. Kassem et al. (2014) went further and compared BIM publications (guidelines, protocols and requirements) from eight countries aiming to organize the knowledge and facilitate their access (Kassem et al. 2014). In addition to that, Khosrowshahi and Arayici (2012) proposed to set up grounds for BIM implementation assessment via a thematic framework (Khosrowshahi and Arayici 2012). Sweden, Finland and Denmark counted 5 papers each. Sweden totalled three Journal papers related to, IT technology adoption (Samuelson, Olle and Björk 2014) and organisation in the construction sector (Gustavsson et al. 2012) and BIM standardisation (Hooper 2015). Two Journal papers were found for Denmark (Jensen and Johannesson 2013).

Table 1: The papers addressing BIM implementation in EU countries (Source: author)

Type of Documents	Paper's Number	AUTHORS	BIM: Implementation	Standardisation	State of the art	Countries Comparisons	Adoption assessment	Barriers /Challenges	Countries: Czech Republic	Denmark	Finland	France	Germany	Ireland	Luxembourg	Netherlands	Poland	Sweden	UK	Europe	Outside EU
Journals Papers (11)	(1)	Wong et al. (2010)	✓			✓				✓	✓										✓
	(2)	Gustavsson et al. (2012)			✓													✓			
	(3)	Jensen & Jóhannesson (2013)	✓			✓				✓											✓
	(4)	Eadie et al. (2013)	✓																✓		
	(5)	Rezgui et al. (2013)	✓					✓											✓		
	(6)	Maradza et al. (2013)	✓	✓		✓													✓		
	(7)	Samuelson & Björk (2014)			✓													✓			
	(8)	Hooper (2015)		✓														✓			
	(9)	Young & Lee (2016)	✓			✓														✓	
	(10)	Alreshidi et al. (2017)	✓					✓											✓		
	(11)	Dainty et al. (2017)	✓					✓											✓		
Review (5) Book Chapter	(12)	Khosrowshahi & Arayici (2012)	✓			✓		✓			✓								✓		
	(13)	Cheng et al. (2015)	✓			✓														✓	
	(14)	Grimes et al. (2015)	✓																✓		
	(15)	Abdirad (2017)	✓				✓												✓		
	(16)	Kassem et al. (2015)	✓			✓				✓	✓					✓			✓		✓
Conference Papers (10)	(17)	Kouider et al. (2007)	✓					✓											✓		
	(18)	McAuley et al. (2012)	✓											✓							
	(19)	Maradza et al. (2013)		✓															✓		
	(20)	Smith (2014)	✓			✓				✓	✓								✓	✓	✓
	(21)	Kiviniemi & Codinhoto (2014)	✓					✓											✓		
	(22)	Kubicki & Boton (2014)	✓			✓				✓	✓				✓			✓			✓
	(23)	Davies et al. (2015)	✓									✓						✓	✓	✓	
	(24)	Juszczyk et al. (2015)			✓				✓								✓				
	(25)	Aibinu & Papadonikolaki (2016)	✓													✓					
	(26)	Bekr (2017)	✓			✓		✓					✓								✓

B. **Summary**

The complete analysis of the review is given in Appendix 1. The conclusion is that a real BIM awareness dynamic has started to be observed worldwide and across Europe. The economic, societal, cultural and political variations that affect BIM implementation cannot be synchronically implemented in all EU countries. However, we have not found a clear picture of the heterogeneity of the BIM uptake in the EU. This question was partly answered in Appendix 1 where primary data give an overview in the EU context.

2.2.2 Overview of the current BIM Dimensions usage

In this section, the assessment of how far BIM is currently used is summarised because the author has to push forward its use, beyond the current dimensions in order to develop the aim to integrate the asset EOL in the full asset lifecycle. The details of the method of the literature review and the findings are given in Appendix 2.

To summarise, various dimension linked to 3D BIM exists. There is a consensus about 4D BIM and 5D BIM, where the fourth dimension is linked with time, and the fifth dimension is linked with cost. However, for the 6th and the 7th, there is no real establishment in the literature. The results of the systematic review show that these two areas are still in their infancy, illustrated by some ambiguities on what these BIM dimensions refer to. Following this systematic review, a questionnaire survey will be conducted to verify if the BIM dimensions are in agreement with the practitioner's knowledge (in section 7.3).

2.3 Overview of the alternative approaches to the "design for construction"

2.3.1 Literature review method used in this section

In the following sections of this chapter, the literature review performed is called qualitative evidence synthesis by Grant et al. (2009). Some authors also name this type of review meta-synthesis (Ang et al. 2019). This method was chosen because the aim of this chapter is to understand and integrate the current management of the sustainable buildings life cycle from qualitative studies. The research conducted is interpretative in broadening understanding of how the SEOL was taken into account in the literature. Purposive sampling was used (as defined by Grant et al. (2009)) where the keywords (such as Deconstruction, Dismantling, Disassembly, Demountable, amongst others) were searched in different databases (Scopus, google scholar, Coventry University Library).

Before researching the current management of the sustainable buildings life cycle, it is necessary to clarify the definitions that will be used in this thesis.

2.3.2 Definitions related to the asset sustainable End-of-Life (SEOL)

Similarly to the concept of a Circular Economy that was first developed in the manufacturing industry, the concept of "sustainable end of life" is becoming more common in the industry, especially in the car manufacture industry (Gehin et al. 2008). However, in the AEC industry, the notion of "sustainable end-of-life" is not yet common. In Scopus, the search of the words "sustainable end of life" in the field of titles, abstracts or keywords resulted in 22 documents, 21 being in the field of the manufacturing industry. Only one reference was within the AEC industry (citing EOL once, only in the abstract of the chapter on "Sustainable Deconstruction of Buildings" (Schultmann 2005). The book chapter is focused on material flow management in the case of deconstruction. Its limitation is that it does not take into account other types of end-of-life management and is only focused on the end of life phase, whereas in the approach of this thesis, it is sought to take into account the whole life cycle of the building in a circular approach. Moreover, since a decade, some papers have dealt with other concepts (e.g. dismantling and disassembling) than deconstruction to manage the end of life of assets, so that it is needed to explore the meanings of those terms.

Some labelling systems have been developed to support sustainable approaches in marketing. For example, from the oldest to the newest there are amongst others: “Minergie” (1998) in Switzerland, “Haute Qualité Environementale” (HQE), (2004) in France, “BRE Environmental Assessment Method” (BREEAM), (2010) in the UK and “Leadership in Energy & Environmental Design” (LEED) (2010) in the USA. But there is no consensus on those labels, each of them not being designed to address all the components of the building sustainability. For example, LEED awarded homes in the United States have indoor air chemicals’ concentrations exceeding available risk-based screening levels for at least one chemical in the case of all the 30 homes studied, which is not sustainable (Dodson et al. 2017). In the case of HQE, it can also be found a review of the shortcomings of the label in the document released by the “réseau écobatir” (Ecobatir 2004).

In the following, some definitions of concepts more or less in relation with the sustainable end of life are investigated, with the whole life cycle of the asset in mind to achieve a cradle to cradle (C2C) cycle. It is not in the scope of this thesis to study in-depth all those concepts. However, clarification of those terms is necessary. That is why some of the definitions found in the literature will be given without listing all of them in the next subsections. Those concepts, listed in a separate list in the nomenclature, have to be understood through the holistic essence of the sustainable building lifecycle. Figure 6 is designed to help to understand the different concepts with a simplified map of the construction project.

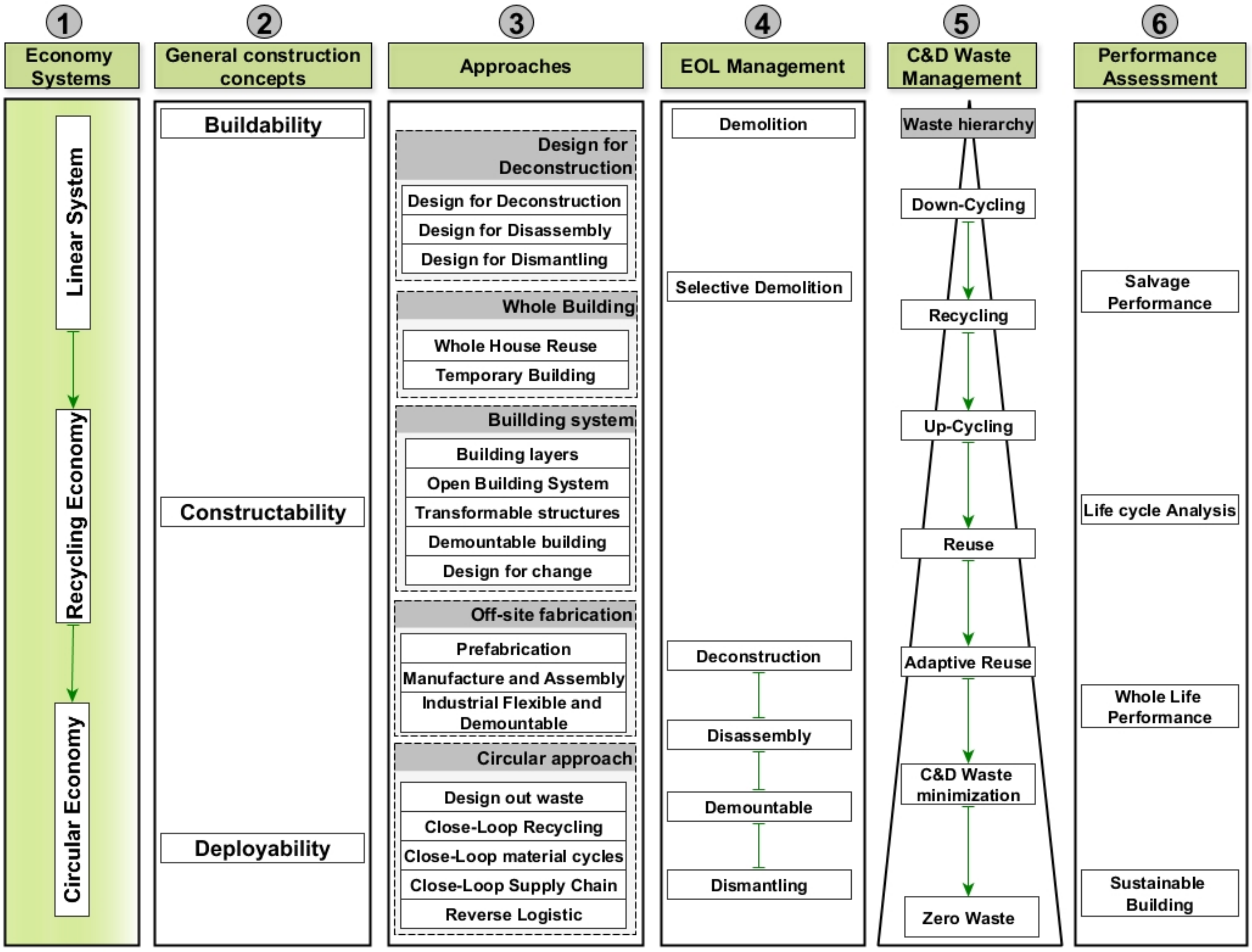
Figure 6 can be read from left to right and from top to bottom and is divided into six boxes vertically: (1) the general economy followed (linear or recycling or circular), (2) the general building concepts, (3) the approaches, (4) the end of life management, (5) the CDW management with the waste hierarchy that gives a vertical lecture of the figure from the bottom (the best) to the top (the worst), (6) the assessment tools.

A. **Sustainability applied to buildings Principle Definitions**

There is a consensus on the broad definition of “sustainable development” because it was adopted by the United Nations Conference of Rio de Janeiro in 1992, with the meaning sourced from the Brundtland Report (1987): “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland 1987). However, when sustainable development (or sustainability) is applied to the field of architecture, it becomes difficult to find an accurate definition with any consensus.

The topic is still under research (Häkkinen and Belloni 2011, D'Amato et al. 2017, Loiseau et al. 2016).

Figure 6: A simplified overview of the concepts related to construction project sustainability (Source: author)



B. Definitions related to the economy of the system

The mainstream economy is also called linear economy, or linear system (LS) or process**.** Some authors have specified that the linear life cycle is single-use and disposal of materials (Crowther 2014, Sanchez and Haas 2018). In that case, all the materials end up in landfills (Hosseini et al. 2014). The life cycle phases are extraction, processing, manufacture, assembly, use, demolition, and disposal.

The Circular Economy (CE) is opposed to the concept of a linear system. CE implicitly included in sustainability (Akanbi et al. 2018, Sanchez and Haas 2018) is promoted by the Ellen MacArthur Foundation (2015). Following the E. McArthur Foundation, the CE fundamental principle objectives are the preservation and enhancement of "natural capital by controlling finite stocks and balancing renewable resource flows; it optimizes resource yields by circulating products, components, and materials in use at the highest utility at all times in both biological and technical cycles; and it fosters system effectiveness by revealing and designing out the negative externalities" (Ellen MacArthur Foundation 2015). There is the will to restore the utility of products when possible or maintain their utility, their components, and materials and retain their value. If the CE basement relies on reducing the use of raw materials by a better management of resources (Lacy and Rutqvist 2016, Geissdoerfer et al. 2017, Pomponi and Moncaster 2017), the E. McArthur Foundation also specifies that the aim of CE is to reduce the negative externalities of the economy, Geissdoerfer et al. (2017) also talks about "narrowing energy loops".

The recycling economy (RE) was developed by developed countries by the 1990s. According to Liu (2009:211), based on Zhu Guohong (1995) reported that a recycling-oriented society is an important way for sustainable development (Liu, H. 2009). "Recycling economy mainly uses the bionomics law to guide socio-economic activities, taking clean production and comprehensive utilization of resources, ecological design and sustainable consumption and so on to be integrated, to achieve the in-house recycling of material and energy". Compared to the traditional linear economy, "take-make-dispose", "the recycling economy is an economic development model on the basis of a continuous cycle of the material". The linear economy changes resources into waste while the recycling economy promotes economic growth by recycling resources to have little or no waste (Liu, H. 2009). Cretu et al. (2019) define the recycling economy model as a "reuse-recycle" model opposed to the "take-to-throw" model (Crețu, et al. 2019).

C. **General construction concepts**

The box 2 of Figure 6 contains three construction methods that are buildability, constructability, deployability. The widely accepted definition of buildability (Crowther 2002) is that of the Construction Industry Research and Information Association (CIRIA), which states that 'buildability is the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building'. Crowther (2002) adds that buildability allows for ease of progress from materials to building and that it is within a holistic vision of the building project. This method is associated with the mainstream linear economy and design for construction.

Constructability can be defined as a holistic methodological approach to project management, primarily up to project delivery, with dynamic individual characteristics and various developed tools (Kifokeris and Xenidis 2017). Constructability analysis during building design simplifies the construction process and can be extended to address deconstruction issues. If a building is constructed with simple processes, it probably can be deconstructed easier as well. Examples of relevant constructability principles include prefabrication, modularisation, and simplification of connections and building systems (Pulaski et al. 2004).

According to Brancart et al. (2017), “deployability allows the instantaneous opening or closing of a structure to transform it from a compact configuration to an expanded, functional space enclosure” that is a way to design transformable structures (Brancart et al. 2017). It becomes that constructability and deployability have the potential to achieve a project in the Circular Economy.

D. Different Approaches in the management of the construction process

As said previously, most of the existing buildings were only “designed to be constructed”, and this has led to a huge problem of sustainability for the assets built after World War II because the prime materials (earth, stone, bricks…) were substituted by industrially manufactured materials. In the framework of a sustainable circular life cycle, it is obvious that the management of EOL (box 4) of the building will depend on all the previous phases, and especially the design of the building. That is why most of the concepts cited in box 4 have their counterpart as “design for”. The box 3 of Figure 6 cites different approaches that have logically similarities amongst them. For example, some authors consider that design for deconstruction (DfD) is equal to design for disassembly (DfDisa) (Kibert 2003a, Nordby et al. 2009). Nordby (2009) has been using DfDisa, DfD, design for recycling (DfRcy), design for reuse (DfRe) and design for salvage ability (DfSA) interchangeably (Nordby et al. 2009).

To discuss those “Design for”, the simplified order of 3Rs hierarchy (see box 5, Figure 6), Reduce, Reuse and Recycle is followed.

Brancart et al., (2017:359) have defined Design for change (DfCh) that “is a systemic design approach aimed at developing structural and building systems that can be adapted with a minimum of expert intervention, giving the user the control to perform changes according to their needs. This is a participatory process enabling spontaneous and instantaneous changes” (Brancart et al. 2017). DfCh uses simple systems that can be manually erected, demounted and reconfigured. An example is a case for temporary structures for temporary activities (transformable or deployable structures).

Many authors have studied the following approaches: DfD (Jaillon and Poon 2014, Carvalho Machado et al. 2018) , DfDisa (Crowther 2002, 2005) and Design for Reverse logistic (DfRL) (Nordby et al. 2009, Sassi 2008). Those terms have the same aim that is the use of design principles that ensure an easy deconstruction/disassembly/dismantlement of the building to maximise the reuse and optimise the recycling of materials. The design out waste (DoW) with the aim of waste prevention, is also in this category (Faniran and Caban 1998, Liu, Z. et al. 2011, Ekanayake and Ofori 2004).All the concepts classified in “reuse” are also designed to ease the recycling process.

The Design for Manufacture and Assembly (DfMA) is not directly linked to the end of life of the building in its definition but Iacovidou and Purnell (2016), state that the process has the same potential as DfD and DfRe in the sense that the assembly process is smart enough to allow a simple disassembly (Iacovidou and Purnell 2016). Most authors give a definition that links DfMA with prefabrication, manufacture and assembly (Bogue 2012, Emmatty and Sarmah 2012, Sanches Da Silva et al. 2014, Ng, L. X. et al. 2013). DfMA is described as being a design of prefabricated building components in an organic combination of Design for Manufacture and Design for Assembly (Martínez et al. 2013, Barbosa and Carvalho 2014).

A similar approach is the design standardisation described by Polat (2008) as a design of prefabricated buildings according to a uniform architectural design criterion including "precast component standardisation and building design process standardisation" (Polat 2008).

For the other approaches, box 3 of Figure 6, from top to bottom, the scale is changing from the whole structure to a part of the structure (a building system) to the material scale. The second set of approaches is dealing with the whole building reuse. For Brancart et al. (2017:358), a transformable structure is “designed to anticipate future changes and allow adaptation in a much more efficient way" (Brancart et al. 2017). Those authors distinguish deployability and design for disassembly as the two principles for the design of transformable buildings.

According to Gorgolewski (2008:176), temporary buildings are “designed with a view to relocation. Other temporary structures are taken down, and the material reused in more permanent buildings” (Gorgolewski 2008). Zaman et al., (2018:3432) have studied a case of whole house reuse that implies a deconstruction of the asset “coupled to the aspiration of entire material reuse”(Zaman, A. et al. 2018).

The other close definition is given by Jaillon and Poon (2010:1026), who have reported that the concept of demountable buildings was first established in the Netherlands in 1976 by John Habraken, who promoted “the use of demountable connections with precast concrete building systems. Those systems were based on standard precast columns and floors series to be bolted in place”. John Habraken has developed in the sixties, an alternative to mass housing, suggesting to separate “the ‘support’ (building base) from the ‘infill’ (fitting out) in the design and construction of residential buildings to encourage the participation of inhabitants in the design process” (Jaillon and Poon 2010). Kendall and Teicher, (2000), have developed this concept that was already used for a commercial building at that time, defining the subsystems order and combination to minimise the interference between subsystems (Kendall and Teicher 2000).

This notion of open building systems relies on the concept of building layers also defined by John Habraken (1998), who identified two layers in a building: the structural frame and the elements of partitioning the space as said before. The first has a long life where the second may be removed and reused over time as the end-users may change (Habraken 2000). Another author defines more precisely the building layers dividing them into: “Structure, Skin, Services, Space plan, and Stuff, and also adds the layer of the Site on which the building stands" (Brand, S. 1994). The idea is to separate the layers that do not have the same longevity to ease the optimum management of the building over time.

The fourth set of approaches for construction in box 3 of Figure 6 is gathering the offsite construction strategies. The industry has developed the prefabrication process to reduce the price and duration of the construction process. In this process, the precast components are produced in a factory and transported to the construction site for assembly (Hong, W.-K. et al. 2014, Kim, S. et al. 2012, Kim, M. K. et al. 2015)). Another author complements by noticing it is the first degree of industrialisation followed by mechanisation, automation, robotics and reproduction (Yuan et al. 2018). Other authors have also noticed that prefabrication is often used with the modular design approach enabling to increase the buildability and accelerate the construction process. Prefabrication has the same meaning as manufacture and assembly (Jaillon and Poon 2010, Chan, D. W. M. and Chan, A. P. C. 2002, Tam, Vivian W.Y. et al. 2007)**.**

Another industrial strategy is called IFD (industrialised, flexible, and demountable) that enables “possible changes in design layout over time and disassembly of components for repair or reuse in another location or form" (Quah et al. 2004). IFD building systems use dry construction method (dry joint) to avoid entire or partial demolition of the asset. IFD is based on modular dimensioning and adjustability for all parts, with flexibility and adaptability (Hendriks and Vingerling 2000, Hendriks 1999, Van Gassel 2002).

At the scale of the material, the CE approach is related to the concept of closing the loop of material cycles to decrease the use of new resources and increase the use of secondary raw materials. Ayries et al. (1996) defined Closing the Loop of Material Cycles (CLMC) as "a construction constituting materials and building elements that can be recovered from buildings and infinitely recycled through natural or industrial processes" (Ayres, R. U. and Ayres, L. . 1996). Sassi (2008:512) adds that CLMC should be performed without significant pollution emissions (Sassi 2008). Kibert 2000 links CLMC to green buildings (Kibert et al. 2000). The other related concept is Closing the Loop of the Supply Chain (CLSC), also first developed in the manufacturing industry before its use in the construction sector (Sassi 2004). The CLSC involves a perfect supply chain wherein the loop of materials is closed (Chini and Bruening 2003, Jaillon and Poon 2014, Sassi 2004, 2008, 2009, Shakantu, W. M. and Emuze 2012, Shakantu, W. et al. 2003). CLSC aims at moving towards closing the material loop, which is another important sustainability strategy, according to Tingley and Davison (2012) (Densley Tingley and Davison 2012). Some authors also associate both concepts to zero waste (Kibert 2003b, Ayres, and Ayres . 1996).

Reverse Logistic (RL), has a similar historical development as CE, first developed by the manufacturing industry with the first publications in Google Scholar in the nineties. Later applied to the building sector, with more than 1000 occurrence in Google scholar in the last decade (search with “reverse logistic” and building). Reverse logistics has the same meaning as CLSC according to (Mulder et al. 2007, Schultmann and Rentz 2002, Kibert et al. 2000, Van Dijk et al. 2014, Shekdar 2009, Guide and Van Wassenhove 2009). The latter gives the following definition for RL: "process of planning, implementing and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin to recapture value or proper disposal". RL is opposed to “Forward Logistics” associated the materials' movements from extraction towards consumption (Rogers and Tibben-Lembke 2001). RL is sometimes associated with Green Logistic, but some authors agreed that the two concepts are different with only some overlaps linked to environmental concerns (Walker et al. 2008, de Brito, M. P. and Dekker 2004, Rodrigue et al. n.d., van Hoek 1999).

E. EOL management

The box 4 of Figure 6 lists the different methods to manage the EOL from the demolition to process are by deconstructing, dismantling or disassembling**.** Some authors define demolition as a “building EOL management primarily aimed at disposal to landfill with little consideration for material recovery” (Akinade et al. 2015, Zaman, A. et al. 2018). This broad definition does not specify the technique of removing/destroying the asset. That is why other terms become more popular because more accurate.

Deconstruction, also called selective demolition, is opposed to conventional demolition (Coelho and de Brito, J. 2011, Kourmpanis et al. 2008). Deconstruction is also seen as reversing the steps of a construction (Kourmpanis et al. 2008). It is, therefore, a labour-intensive manual method (Couto, A. and Couto, J. P. 2010). Deconstruction is opposed, or an alternative to traditional demolition (Gorgolewski 2006, Kibert 2016) and is a pillar for RL (Coelho and de Brito, J. 2011) and CE when associated with reuse (Akanbi et al. 2018, MacArthur 2013, Seadon and Griffin 2016).

If the deconstruction’s definition is consensual, it is different for dismantling definition. Some authors explain that the dismantling process is the last stage of a building’s lifecycle, with activities resulting to enormous quantities of waste that until recently has been the discarded and sent to sanitary landfills (Aidonis et al. 2008, Xanthopoulos et al. 2009). For those authors, dismantling is the process of removing the building at its end of life either by demolition or deconstruction. Contrarily, Volk et al. (2018:227), use deconstruction synonymously with dismantling, describing “the reverse construction process of buildings and facilities with a high degree of material separation and recycling” (Volk et al. 2018). In this thesis, the latter definition will be used, that is dismantle equal deconstruct.

The assembly process is “a system in which the building gains mass through the conversion of materials into components, components into sub-assemblies, and subassemblies into buildings" (Crowther 2002) p.3. Some authors suggest that deconstruction is the partial or systematic disassembly of assets with minimum damage to maintain original properties and maximize recovered materials reuse and recycling (Schultmann 2005, Chini and Bruening 2003, McDonough and Braungart 2003, NAHB Research Centre 2001, Addis and Schouten 2004, Diyamandoglu and Fortuna 2015, Yeang 2006, Kibert 2003a, Guy and Gibeau 2003, Steward et al. 2004, Endicott et al. 2005).

The previous definition is in line with, several authors who consider that deconstruction is the reverse of assembling, therefore equivalent to disassembly (Guy and Mclendon 1999, Leigh and Patterson 2006, Crowther 1999, Smith et al. 2007). Chini (2005) complement the previous definition by adding that deconstruction is “carefully taking apart portions of building or removing their contents with the primary goal of reuse in mind" (Chini 2005).

F. The C&D waste management

One of the main obstacles against the delivery of a sustainable building is the massive production of waste due to the current AEC industry working processes. So it is necessary to go through the description of those C&D waste. Skoyles and Skoyles (1987) have defined the construction waste as "...a material or product which needs to be transported elsewhere from the construction site or used on the site itself other than the intended specific purpose of the project due to damage, excess or non-use, or which cannot be used due to non-compliance with the specifications, or which is a by-product of the construction process” (Skoyles, E. R. and Skoyles, J. R. 1987). The author believes that there should be a consensus on this definition. Then demolition waste is trickier because the demolition process has no clear boundaries; therefore, the process of demolition can generate waste with a wide range of quality.

CDW minimisation is often classified into Reduction, Reuse, and Recycling collectively called the 3Rs (Won and Cheng 2017). The Waste Hierarchy is determined by the European Commission (EC) Framework Directive on Waste (Council Directive 75/442/EEC) stating that "in addition to recycling and composting, reuse is an environmentally acceptable, and indeed preferable, waste disposal option".

At the asset EOL, if the materials are not dumped in a landfill, the most popular management is recycling, that means the waste materials are remanufactured to achieve a new life (Gorgolewski 2008, Chini and Bruening 2003, Sassi 2008). Hosseini et al. (2015) give a more accurate definition of recycling that only applies if the recycled material has the same quality and purpose of the previous (Hosseini et al. 2015). In the case of processing of the building material that produces a lower grade material, the term down-cycling is used. Conversely, up-cycling leads to higher grade applications (Chini 2005, Adjei 2016, Loiseau et al. 2016).

Reuse is opposed to recycling because It "...refers to putting the building component or material to new use after extraction from the obsolete building with no or trivial processing. A building component or material is reusable if it can be reused but not necessarily recycled" (Hosseini et al. 2015) p.501. Between components reuse, materials reprocessing and materials recycling, some authors explain that reuse is the best because there is no additional energy needed

(McDonough and Braungart 2003, Crowther 2005). Gorgolewski (2008) define adaptive reuse when the modification of the building is due to its obsolescence (Gorgolewski 2008).

Due to the huge amount of waste generated by the AEC industry, Waste management and waste minimisation are crucial. Hosseini et al. 2014 oppose waste management that deals with products at their end of life, to RL that has the aim to extend the life of materials and products (Hosseini et al. 2014). That is why the industry is focused now on Waste Minimisation (Osmani et al. 2008, Osmani 2013, Baldwin, A. et al. 2009, González-Torre et al. 2010, Guthrie and Mallett 1995, Crittenden and Kolaczkowski 1995, Ekanayake and Ofori 2004). Those authors have defined waste minimisation as a process that prevents (at the early design stage), eliminates or reduces waste at its source or permits to reuse or recycle the waste. This definition is related to the fact that a significant proportion of construction waste occurs during the early design stages (Bossink and Brouwers 1996).

G. Method to assess the performances related to sustainability

In box 6 of Figure 6, another concept defined by Akanbi et al. (2018:176) is Salvage performance which "is the value of building at a particular time, in terms of quantity of structural materials (in tons) that is obtainable when the building is demolished or deconstructed". This is the basic assessment at the scale of the material, of the flux of materials. The term whole life performance assessment is also used by Akanbi et al. 2018. Those authors have developed a "BIM-based Whole-life Performance Estimator" for the structural components of the asset. This tool goal is to assist designers during the design phase for the assessment of buildings' salvage performance. (Akanbi et al. 2018).

As it is crucial to assess the level of sustainability for any industry, assessment tools are being researched and developed based on Life Cycle Assessment (LCA) which is a method not specifically dedicated to the AEC industry. The LCA is focused on the environment, defined by the ISO 14040:2006, is also called Environment life cycle assessment (E-LCA) by some researchers (Zheng et al. 2019). The method expatiated to the life cycle cost analysis (LCCA) (Kshirsagar et al. 2010) and social life cycle assessment (SLCA) Dong et al. (2015) to target the whole dimensions of sustainability (Dong and Ng, S. T. 2015).

Applying the concept of sustainability, particularly to the AEC industry is crucial as its negative impact on the environment and human health must be reduced. Since 2008 the International Organization for Standardization (ISO 2008) gives the general principles of sustainability in building construction. The sustainable building (SB) process is defined as the process' quality allowing the delivery of the sustainable asset, and it applies to the life cycle of buildings from their inception to the end of life. The last assertion explicitly states that it is necessary to deal with a sustainable asset end of life management. To deliver sustainable building, three main prerequisites are, i/ the availability of SB technologies, ii/ the availability of methods and knowledge for sustainable target setting, design, procurement, monitoring and management of buildings, iii/ the development of SB processes and the adoption of the new SB technologies, methods and working models (ISO 2008).

H. **Limitations of SEOL concepts used in this research**

In the literature, there is an awareness of the design's impacts on the asset's sustainability and the sustainable management of its EOL. However, there is no consensus on the concepts that would ensure the sustainability of the asset life cycle, from its inception to its EOL. On the other hand, most of the “design for” concepts (except *design for construction*) would have the potential to achieve a SEOL according to the definition given before. That is why, in this thesis, the definition of SEOL will include the *“*design for*”* found in the literature (except design for construction) and listed in the box “recycling and reuse economy” of Figure 7. All of them have the potential to be in the scope of the PhD, in line with its aim and objectives. The approaches in the Circular Economy, a more recent concept (Figure 7) are also in the scope of the thesis.

The “design for” and CE concepts have only a “potential” to be sustainable or circular (in the CE) because they face limitations. Indeed, to stay in the CE context, “design for” linked to reuse (Design for Reuse, Salvage Ability, Adaptive reuse, Industrialised Flexible and Demountable) may not be circular because reusing is not ensuring an infinite use of the materials. Indeed, construction materials have limited durability, steel is rusting, wood is rotting, bricks are decaying, and even the glass experiences creep after decades. In 2008, Sassi (2008) had noticed this idea and had given examples of products that can be reused (once or few times and not infinitely) but not recycled: ceramic sanitary ware, composite laminated boards, electrical plugs, concrete tiles, amongst others (Sassi 2008). “The useful life of such products may be extended through reuse, sometimes significantly, but remains a linear rather than cyclical life” p.510 (Sassi 2008). In other words, simply because they cannot be infinitely reused or recycled, they don’t fit in the Circular Economy. For the same reason, the “design for” linked to changes at the building scale (Design for Change, Temporary Buildings, whole House Reuse, Modular Construction, Adaptability) may not be reach the CE expectations, as well.

The other limitations deal with designs focussing on the construction phase only (such as Design for Manufacture & Assembly, Assembly, Standardization, Manufacture, Prefabrication, Simplicity, Durability, and Ease of Maintenance) because the deconstruction is not planned and may be difficult depending on the assembly process.

I. **Summary**

A definition of the SEOL of a building is not yet given by the literature, probably because the notion of sustainability in the building industry is not as mature as sustainability in the manufacturing industry. Also, buildings are very different from manufactured products in terms of use and fabrication process:

- Each owner (private, public or company) is willing to have a bespoke building, not a standard one.
- The management of the building from its construction to its fates involves a wide range of stakeholders with different skills and stakes.
- The lifespan of buildings is particularly long.

The awareness of design for specific architecture/purpose ("design for") is relatively new and still far from being the mainstream in the AEC industry. It means that in Europe, most of the buildings that currently attain their EOL phase were "designed for construction". That is why there is a lot of work done on down-cycling because recycling is more difficult for those buildings.

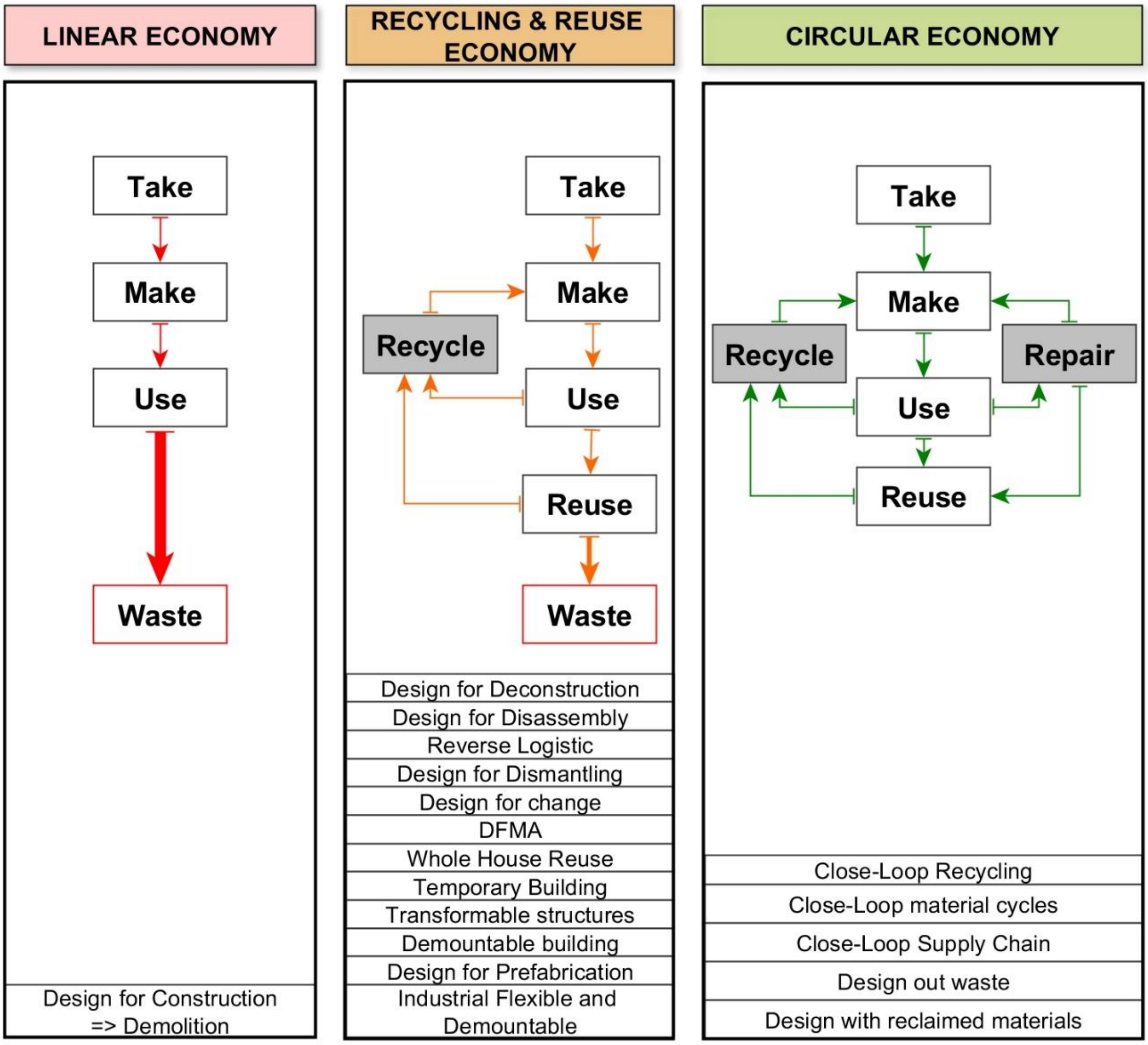


Figure 7: The three types of economy and their design approaches (Source: Author)

In this research, the “design for” related to the deconstruction and prefabrication concepts will be included. Similarly, the concepts classify under the CE category are included as well (Figure 7). Most of the new design strategies are focused on the building process from the manufacture, assembly and disassembly. Those strategies would be perfect if the materials had an infinite lifespan. However, this is not the case because modern materials have shorter lifespans for many reasons (composites, cost, and new materials with lack of durability knowledge). Due to the time limitation for this research, the concepts are not deeply studied and are categorized as having a potential SEOL due to the uncertainty of their components. However, in order to simplify the reading, all the aforementioned concepts are grouped into the SEOL or CE approach.

In conclusion, those relatively new concepts will encounter obstacles for their effective use. Therefore, it is important to explore what are the barriers to the adoption of those new concepts.

2.3.3 Different barriers categories found in the literature

Before going through the numerous barriers found in the literature, it is relevant first to classify them by categories (or classification) and sub-categories to facilitate the analysis and the discussion in the following chapters. First, articles focusing on barriers for the implementation of alternative building processes are sought. Mostafa et al. (2018) have studied the barriers to BIM integration within prefabrication construction, which were explored in the Australian context through a survey and a literature review (Mostafa et al. 2018). They did not classify those barriers (Business change practices to support BIM, Replacing CAD technologies with BIM, Investment required in software, training and hardware Legal concerns with fabrication and multiple designs, Challenges with collaborating and sharing information among project team members). Hurley and Hobbs (2004) respectively Pitt et al. (2009) have listed the main barriers in the UK without giving any classification, to the increased use of deconstruction methods, respectively, the barriers to the move towards sustainable construction (Pitt et al. 2009, Hurley and Hobbs 2004).

Although the articles of the previous paragraph give only a list of barriers without classification, most authors are classifying the barriers in categories (Table 2). Three main types of categories were found, those linked to:

(i) A discipline (economy environment, culture, among others),

(ii) Specific stakeholders (owners, designers…)

(iii) A construction phase (design, in use).

For this study, in order to take into account the whole range of data found in the literature review, six main classifications will be used (Economic, Sociological, Political, Organisational, Technological, and Environmental). Within those categories, some subcategories related to specific stakeholders or phases were added when necessary.

Table 2: The different types of barriers' classification found in the literature (Source: Author)

Authors	Classification
(Hosseini et al. 2014, Chileshe et al. 2016)	Authors have chosen to classify the barriers into external (reusing the category given by Walker et al (2008) and internal (to the manufacture and building industry)
(Chileshe et al. 2015a)	Authors split the external barriers into two sub-categories: "environmental barriers" referring to barriers imposed by the governing business environment in the industry, and barriers due to the nature of construction products (e.g. buildings) and its activities
(Abdulrahman et al. 2014)	Authors grouped the RL implementation barriers relevant to the Chinese context into the four categories: (i) management, (ii) financial, (iii) policy and (iv) infrastructure
(Bouzon et al. 2018)	Authors have classified the barriers against their multi-perspective framework for RL into three categories: (i) governmental perspective, (ii) organizational perspective and (iii) costumers' perspective
(Häkkinen and Belloni 2011)	(i) Steering mechanisms: (Informative regulatory instruments (mandatory labelling) - Economic and market-based instruments (certificate schemes), Fiscal instruments and incentives (taxation and support) - Voluntary action (public leadership programmes) **(ii)** Economics, (iii) Client understanding, (iv) Process: procurement and tendering, timing, cooperation and networking) (v) Underpinning knowledge: knowledge and common language, availability of methods and tools, Innovation: Normative regulatory instruments (building codes)
(Huuhka and Hakanen 2015)	Authors have classified the barriers for reusing load-bearing building components in Finland in four categories (i) economics, (ii) social, (iii) ecological and (iv) technological barriers.
(Kifokeris and Xenidis 2017)	Authors have classified the barriers for constructability implementation in five categories (i) General barriers, (ii) Owner barriers, (iii) Designer barriers, (iv) Contractor barriers and (v) Project-specific barriers.
(Park and Tucker 2017)	Authors have chosen to classify the barriers by stakeholders (end users, developer, etc.)

2.3.4 Barriers for the adoption of the various sustainable approaches

As pointed in section 2.3.2, there are no specific studies on the SEOL. Logically there are no studies on the integration of the SEOL into the asset lifecycle in the Circular Economy context either. That is why it is provided here some insights from studies on barriers for sustainable buildings. When possible, a focus will be made on the management of the asset's end of life (in the BIM environment or not). The researcher believes that those barriers found in the literature may be related to the thesis aim because it is within the broad field of sustainability in construction.

A. **Economic barriers**

a. Economic Context

For the economic barriers (as for all tables for each of the six categories), Table 3 outlines the type of barriers found under that category. The first row specifies the context (which principle is involved) in which the barrier was cited (related to Figure 6 and defined in section 2.2). The principles gathered in the first row are dual, with the principle or the design for the principle (e.g. RL and DfRL). The comments about the tables will specify only the principle and not both the principle and its associated design (e.g. simply RL, not RL-DfRL) to simplify the reading. One cross means that at least one journal paper cites that barrier. Full tables of barriers are provided in Appendix 2.3 of the thesis.

The obstacles arising from factors related to the economic context (Table 3) demonstrate that there is a lack of market around sustainable buildings. For example, the marketing plan of IFD is found inappropriate by (Jaillon and Poon 2014). For SB, the lack of client demand is a barrier (Häkkinen and Belloni 2011). Those shortcomings include the lack of demand for second-hand materials, reused and recycled products (Xanthopoulos et al. 2009, Hosseini et al. 2014). The other side is due to the search for profitability that does not permit any risk to innovate or change the current processes (Chileshe et al. 2015b, Kifokeris and Xenidis 2017, Xanthopoulos et al. 2009).

b. SEOL versus demolition

SEOL is more expensive than demolition because more time and labour are needed and because of the construction materials market. The obstacle spotted by Gorgolewski (2008) is the low **cost of construction materials**, compared to recovered materials (Gorgolewski 2008). Several authors have identified that the low cost of construction materials compared to recovered/recycled materials is the problem in the cases of Deconstruction (De) and 3Rs (Knecht 2004, Gorgolewski 2008, Nisbet et al. 2012, Forsythe 2011).

Moreover, the standard construction and demolition practices are focused on the **fastest and most economical way** to get the job done in the cases of 3Rs (Gorgolewski 2008). Lastly, obstacles are due to the shortcomings of the recycling processes of conventional materials. For example, the building aluminium scraps are difficult to recover economically (Nisbet et al.

2012).The recycled aggregates have a considerably lower price compared to the natural materials, due to their poor quality.

The relatively low cost of C&D waste disposal materials to landfills is also cited as a barrier by many authors, in the cases of De, RL, 3Rs, and PFS (Chileshe et al. 2015a, Jaillon and Poon 2014, Zaman, A. et al. 2018, Hosseini et al. 2014, 2015, Xanthopoulos et al. 2009, Nisbet et al. 2012).

Deconstruction equal labour intensive process: In the cases of De, RL, 3Rs, some authors have noticed the labour intensive process of deconstruction and reuse processes (Bouzon et al. 2015, Hosseini et al. 2015, Couto, J. and Couto, A. 2010, Nisbet et al. 2012, Huuhka and Hakanen 2015). Moreover, additional time was necessary in the cases of SD, De, 3Rs, compared to conventional processes. This extra time is resulting in extra costs (Jaillon and Poon 2014) (Bouzon et al. 2015, Hosseini et al. 2015, Couto, J. and Couto, A. 2010, Nisbet et al. 2012, Huuhka and Hakanen 2015).

Table 3: Outline of the economic barriers found in the literature (Source: Author)

Economic Barriers	CE-DfCE	Cy	CL-CLSC	RL-DfRL	TB-DfTB	MA-DfMA	IFD-DfIFD	PFA-DfPFA	De-DfD	Disa-DfDisa	Dis-DfDis	SD	CDW Mana	3Rs-Df3Rs	AR-DfAR	CDW Mini	LCA	SB-DfSB
A-Economic context		x		x			x		x				x	x				x
a-Market		x		x					x									x
b-Market of recovered materials				x					x				x	x				
c-Market supply/demand				x					x				x	x				x
d-Marketing plan	x						x											x
B-Sustainable EOL versus demolition				x	x				x			x	x	x				
a-Cost of materials					x				x					x				
b-Low cost of disposal				x					x				x	x				
c-EOL duration and labor cost				x					x			x		x				
C-Additional cost for SEOL				x	x			x	x	x			x	x		x		x
a-Cost of the approach																		
1-Design phase																		
2-New approach adaptation costs				x	x			x	x	x			x	x		x		
1-Attractiveness of conventional recycling														x				
2-Initial cost for principle adoption/True cost of the process				x	x			x	x					x				
3-Additional cost for principle adoption				x	x			x	x	x				x		x		
4-Cost for hazardous components				x									x	x				
3-Insurance cost														x				
4-for new roles, missions, tasks														x				x
b-Client readiness to pay the new concept				x								x						

c. Additional cost for SEOL

1. Cost of the approach

The first types of cost listed are attributed to the approach. The design phase embodies additional cost due to more work to be done in the case of RL, 3Rs, PFA, (Jaillon and Poon 2014, Bouzon et al. 2015, Hosseini et al. 2015, Couto, J. and Couto, A. 2010, Nisbet et al. 2012, Huuhka and Hakanen 2015). No additional cost attributed to the construction phase was found, but some cost were found due to necessary adaptations to a new approach (or to adopt new principles). Several authors have identified such additional cost for adopting the following principles: De, RL, TB, Dis, 3Rs, CDWmini, PFA (Chileshe et al. 2015b, 2015a).

The additional cost is also due to the management of hazardous components, for example, the existence of lead and asbestos in old buildings makes the process of deconstruction costly and time-consuming because the cost of separating the material to be recycled from contaminating materials is high (Hosseini et al. 2015, Río Merino et al. 2010, Nisbet et al. 2012). The last costs to adopt a new approach are additional initial cost (higher cost of the initial investment in the project) cited by (Chileshe et al. 2015a, Jaillon and Poon 2010, Chileshe et al. 2016, Jaillon and Poon 2014, Zaman, A. et al. 2018, Hosseini et al. 2014, 2015, Ajayi et al. 2015, Couto, J. and Couto, A. 2010) in relation to following principles: De, RL, and PFA. Lastly, a barrier cited once is about the additional costs due to higher insurance fees (Huuhka and Hakanen 2015) in the case of 3Rs.

Four authors have spotted barriers linked to the quantification and sale of the approaches. In the case of De, (Jaillon and Poon 2014) have noticed that the economic benefits are not well established and (Xanthopoulos et al. 2009), that the economic and environmental benefits from the C&D waste management are not well established. In the case of SB, (Häkkinen and Belloni 2011) have noticed the lack of business case understanding and finally, (Chileshe et al. 2015a) have noticed that the distribution of the construction budget was completely different in the case of Adaptive Reuse.

2. Client willingness to pay for new concept

Another type of obstacle is the necessity to plan and pay upfront in the asset life cycle that is not possible without a willingness of the client to pay upfront according to (Gorgolewski 2008) in the case of 3Rs. At this stage, the contractor is often not appointed yet, so the client has to spend money upfront purchasing materials, which many clients will not be willing to do.

B. Sociological barriers

Sociological barriers deal with social issues, focusing on cultural, psychological and personal characteristics. Table 4 outlines the barriers found in the sociological category.

a. Societal trend

Some barriers are related to the "consumer society behaviours". For example, the fear of additional cost for better waste management (Häkkinen and Belloni 2011, Ajayi et al. 2015), or the belief that waste is inevitable (Ajayi et al. 2015), or the disbelief in the potential utility of a constructability program (Kifokeris and Xenidis 2017). Some authors have added that the consumer's culture and attitude towards the quality of salvaged and used items are also an obstacle (Chileshe et al. 2015a, Hosseini et al. 2014). The bad image of salvaged materials is noticed by many authors in the cases of RL, 3Rs, and PFA (Jaillon and Poon 2010, Hosseini et al. 2015, Huuhka and Hakanen 2015).

b. The Lack of awareness, understanding and demand

Some authors have noticed the lack of awareness for SB, 3Rs, and CDW minimization (Häkkinen and Belloni 2011, Río Merino et al. 2010, Huuhka and Hakanen 2015). Then, regarding deconstruction, there is an issue with the demolition contractor's culture (Couto, J. and Couto, A. 2010). The lack of concern for De, RL, and SB approaches is spotted by (Häkkinen and Belloni 2011, Jaillon and Poon 2014, Zaman, A. et al. 2018, Bouzon et al. 2015). The lack of understanding of deconstruction is identified by (Zaman, A. et al. 2018) and for SB by (Häkkinen and Belloni 2011). Other authors have noticed the unawareness of the benefits of using Cy, RL, CE, (Chileshe et al. 2015a, Sanchez and Haas 2018, Pulaski et al. 2004, Hosseini et al. 2014).

Table 4: Outline of the sociological barriers found in the literature (Source: Author)

Sociological Barriers	CE-DfCE	Cy	CL-CLSC	RL-DfRL	TB-DfTB	MA-DfMA	IFD-DfIFD	PFA-DfPFA	Disa-DfDisa	Dis-DfDis	SD	De-DfD	3Rs-Df3Rs	AR-DfAR	CDW Mini	CDW Mana	LCA	SB-DfSB
A-Societal trend		x		x				x					x		x	x		x
a-Consumer society		x		x											x	x		x
b-Bad image				x				x					x					
B-Lack of awareness and demand	x	x		x								x	x			x		x
a-Deconstruction not a hot topic												x						
b-Awarness of the decontruction approach												x						
c-Awarness of the SB approach																		x
d-Lack of concern and awareness				x									x			x		x
e-Lack of understanding deconstruction and SB												x						
f-Do not see the benefits os using this approach	x	x		x														
C-Human behaviour		x		x				x	x			x	x		x	x		x
a-Cultural believes															x			x
b-Lack of global vision				x					x									x
c-Lack of trust				x								x	x			x		
d-Impatience want a ROI quikly				x														
e-Resistance to change		x		x				x				x	x					x

c. Human behaviour

The cultural beliefs are involved in the case of sustainable buildings, notably with the low-risk culture (Häkkinen and Belloni 2011) and similarly in the case of CDW Minimization, (Ajayi et al. 2015). The lack of global vision is also noticed in the cases of RL, SB, Disa, and CE, (Häkkinen and Belloni 2011, Hosseini et al. 2015, Crowther 2005). Those authors have found linear thinking and a lack of lateral thinking and ignorance of life-cycle thinking. The lack of trust in De, RL, 3Rs, CDW management is described by (Chileshe et al. 2015a, Densley Tingley and Davison 2012, Hosseini et al. 2015, Ajayi et al. 2015, Nisbet et al. 2012, Huuhka and Hakanen 2015). Those authors have noticed a lack of acceptance of reclaimed materials. In particular, an impatience to get a Return on Investment (ROI) quickly, which is an unfavourable business culture in the case of RL is spotted by (Chileshe et al. 2015a). The last but not least of the social barriers is the resistance to change, identified by (Häkkinen and Belloni 2011, Chileshe et al. 2015a, Sanchez and Haas 2018, Kifokeris and Xenidis 2017, Jaillon and Poon 2010, Gorgolewski 2008, Chileshe et al. 2016, Jaillon and Poon 2014, Hosseini et al. 2015, Couto, J. and Couto, A. 2010) against the use of Cy, De, RL, SB, 3Rs, PFA. Those authors have highlighted the industry scepticism and tradition, leading to a natural resistance to change, from the manufacturers, builders, and owners. That resistance to change is also seen within the organisations alongside with an excessive effort necessary to innovate. The barriers of the resistance to change is common to 6 techniques/concepts, then the lack of experienced, skilled workers and insufficient knowledge are common to 5, which is not surprising for new techniques and concepts.

C. **Political barriers**

Table 5 outlines the barriers found in the political category. In the first two rows, one author is noticing that building inspectors discourage the use of salvaged materials in the case of RL (Hosseini et al. 2015) and another author citing that regional governments are slow to apply CDW management plans which have been approved (Río Merino et al. 2010).

The lack of appropriate standards is cited in the cases of Cy, De, CL, RL, SB, 3Rs, CDW management, and PFA by (Häkkinen and Belloni 2011, Chileshe et al. 2015a, Kifokeris and Xenidis 2017, Jaillon and Poon 2010, Knecht 2004, Gorgolewski 2008, Jaillon and Poon 2014, Zaman, A. et al. 2018, Hosseini et al. 2015, Ajayi et al. 2015, Couto, J. and Couto, A. 2010, Nisbet et al. 2012). Those lacks include shortcomings on standardised processes, on the share of the best practices, on clear information and on guidance for designers about the design and procurement procedures to adopt when reusing components. The lack of guidance for sustainability in public facilities for FM is reported by (Häkkinen and Belloni 2011).

The lack in the Re-certification, legal warranties and residual performance of recovered building materials is spotted by (Häkkinen and Belloni 2011, Jaillon and Poon 2014, Akanbi et al. 2018, Couto, J. and Couto, A. 2010) in the particular cases of De, SB, and 3Rs, compared to conventional processes. Then the lack of fiscal incentives or support from governments are cited by (Häkkinen and Belloni 2011, Chileshe et al. 2015a, Zaman, A. et al. 2018, Hosseini et al. 2014, 2015) for De, RL, SB. Lastly, the lack of appropriate assessment procedures of architectural competitions, or the assessment process done late during the design phase, or the lack of labelling/measurement standard, are shortcomings spotted by (Häkkinen and Belloni 2011) for SB.

Some authors have listed the barriers related to the current regulation being too strict to allow innovation, cited by (Häkkinen and Belloni 2011, Chileshe et al. 2015a, Kifokeris and Xenidis 2017, Zaman, A. et al. 2018, Hosseini et al. 2015, Río Merino et al. 2010, Ajayi et al. 2015) for Cy, De, RL, SB, CDW minimization, and CDW management.

Table 5: Outline of the political barriers found in the literature (Source: author)

Political Barriers	CE-DfCE	Cy	CL-CLSC	RL-DfRL	TB-DfTB	IFD-DfIFD	MA-DfMA	PFA-DfPFA	Disa-DfDisa	Dis-DfDis	SD	De-DfD	3Rs-Df3Rs	AR-DfAR	CDW Mini	CDW Mana	LCA	SB-DfSB
A-Slow regulation application and Inspectors' behaviour				x												x		
a-Slow regulation application																x		
b-Inspectors behaviour				x														
B-Lack of appropriate standards and policies		x	x	x				x				x	x		x	x		x
a-Lack of policies-regulation				x				x				x	x					x
1-Lack of standard Building standar / guidance				x				x				x	x					x
2-Lack of standard for recoved materials				x								x						
3-Lack of certification and re-certification												x	x					x
4-Lack of incentives				x														x
5-Lack of support				x								x						x
6-Lack of assessment procedures																		x
b-Policies weaknesses		x	x									x	x			x		
1-Lack of specific constructability requirements		x																
2-Lack of Building code for dissassembly			x															
3-Lack of standard for DfD												x						
4-Lack of legislation for CDW reduction													x			x		
c-Policies absurdity and complexity		x		x								x	x		x	x		x
1-Regulation complexity and strictness		x		x									x					x
2-Regulation absurdity and failure				x								x	x		x	x		x
3-Liabilities for recovered materials use				x														

D. **Organisational Barriers**

Organizational barriers refer to the hindrance in the flow of information among stakeholders, phases that will impact the efficiency of a project negatively. The organizational barriers include the extra time, resources and effort necessary for the consideration of sustainability throughout the asset lifecycle. They are the most documented barriers in the articles studied here. Table 6 outlines the barriers found in the organizational category.

a. Working methods and a new approach

We have found approximately 50 statements from different authors that deal with issues associated with the current linear approach (see Appendix 3) that cannot be expatiated here due to the limitation of words. Those barriers are due to the fragmentation of the sector and its inappropriate organisation. The factors cited are lack of a holistic approach, safety in the deconstruction process, innovation, effective methods, and lifecycle performance focus.

Dealing with RL, some authors have noticed the lack of support from the management, immaturity and low investment in knowledge management, information systems, and for continuous planning owing to changes in the materials' source location (Chileshe et al. 2015a, Hosseini et al. 2015).

A lack of specific budgetary allocations for CDW Management was noticed by (Río Merino et al. 2010).

More than sixty barriers are related to adopting new approaches, new methods with more collaboration and communication, more holistic and effective, implying new processes. Those barriers are classified into seven subcategories dealing with different issues. First, issues specific to the novelty or complexity of a new approach. Second, difficulties linked with the implementation of a given approach, for example, implementation of RL is a challenge for designers according to (Chileshe et al. 2015b). Third, the lack of flexibility of mainly the designers is outlined by some authors. Fourth, the planning and scheduling issues. The last three subsections deal with issues related to the effectiveness, contract and requirement of different methods.

b. Teamwork multidisciplinary management.

Some authors have highlighted the need of changes especially the use of new methods to improve the teamwork and to address the whole lifecycle of the building (Häkkinen and Belloni 2011, Kifokeris and Xenidis 2017, Inglis 2007, Sassi 2008, Gorgolewski 2008, Jaillon and Poon 2014, Zaman, A. et al. 2018, Hosseini et al. 2015, Nisbet et al. 2012) . Those concerns are related to Cy, De, CL, RL, SB, 3Rs, and CDW minimization. For example, some authors require a change in the approach and the processes for the reuse of building components (Gorgolewski 2008).

Multidisciplinary approach is also an organizational barrier identified in the literature review. There is only one paper where the need for systematic cooperation and a multidisciplinary approach is discussed in the case of IFD (Jaillon and Poon 2014) .

c. Communication issues

Some authors have found a lack of communication between the members of the project team for RL, SB, Disa, and PFA, (Chileshe et al. 2015b, Häkkinen and Belloni 2011, Jaillon and Poon 2010, Knecht 2004, Hosseini et al. 2015). Specifically, the issues related to the late communication between designer-contractor are spotted for RL, SB, and PFA, where early collaboration between architects, contractors and manufacturers is required (Jaillon and Poon 2010, Hosseini et al. 2015).

d. Key players

Barriers related to a large number of stakeholders are outlined for Cy, De, CL, RL, SB, CE, and 3Rs by (Häkkinen and Belloni 2011, Chileshe et al. 2015a, Sanchez and Haas 2018, Kifokeris and Xenidis 2017, Chileshe et al. 2016, Jaillon and Poon 2014, Couto, J. and Couto, A. 2010). The barriers found are mainly specific to Architects (but also impacting other stakeholders as contractors), where the reuse of materials in buildings is requiring acceptance and change in the design and construction processes (Gorgolewski 2008).

Other authors have listed a number of barriers that are coming from the implementation of Cy by.contractors. Most of them are linked to communication issues and lack of skills/knowledge (Kifokeris and Xenidis 2017). The manufacturers' lack of involvement and responsibility to minimize waste is cited by (Cruz Rios et al. 2015). The complexity of the supply chain, in the case of SB, is also cited by (Häkkinen and Belloni 2011) as a barrier. Lastly the lack of suppliers for Prefa is also a barrier raised by (Jaillon and Poon 2010). Kifokeris and Xenidis (2017) have listed a number of barriers specific to the Owners in the case of Cy, amongst others. In the case of 3Rs,

Table 6: Outline of the organisational barriers found in the literature (Source: Author)

Organisational Barriers	**CE-DfCE**	**Cy**	**CL-CLSC**	**RL-DfRL**	**MA-DfMA**	**PFA-DfPFA**	**TB-DfTB**	**IFD-DfIFD**	**Disa-DfDisa**	**Dis-DfDis**	**SD**	**De-DfD**	**3Rs-Df3Rs**	**AR-DfAR**	**CDW Mini**	**CDW Mana**	**LCA**	**SB-DfSB**
A-Working methods and approach	x		x	x		x		x	x	x		x	x	x	x	x	x	x
a-Issues associated with the current approach	x		x	x		x			x	x		x	x	x	x	x	x	x
1-Fragmented nature of the sector				x									x					x
2-Inapropriate organisation/method of the sector	x		x	x		x			x			x		x	x		x	x
3-Lack of holistic approach				x												x		x
4-Health and safety										x		x	x					
b-Lack of support from the top management team				x												x		
c-New approach issues			x	x		x		x				x	x			x		x
1-Complexity to implement new approaches			x	x														x
2-Implementation				x								x						x
3-Flexibility						x							x					
4-Planning				x								x	x					x
5-Methods effectiveness								x				x				x		
6-Methods contract				x														x
7-Methods requirement				x								x	x					x
B-Team work multidisciplinary management		x	x	x				x				x	x		x			x
a-Changes needed		x	x	x								x	x		x			x
b-Multidisciplinary team								x										x
C-Communication issues				x		x			x									x
a-Lack of communication				x					x									x
b-Late communication between designer-contractor						x												
c-Lack of common classification																		x
D-Key players	x	x	x	x		x						x	x					x
a-Multiple stakeholders	x	x	x	x								x						x
b-Architects													x					
c-Contractor		x																
d-Manufacturer						x							x					x
e-Owner		x											x					
E-Training-skills-education-support skilled force	x	x		x		x		x	x			x	x	x	x	x		x
a-Lack of skills																		
1-Building industry incompetence				x		x												
2-Architects incompetence		x		x		x							x	x		x		x
3-Blue and white collars		x		x		x			x			x	x	x	x			x
b-Competence improvement needed	x	x		x				x	x			x			x			x

the unwillingness of the client to spend money upfront purchasing materials at a stage where the contractor is often not appointed yet, (Kifokeris and Xenidis 2017, Gorgolewski 2008).

e. Training-skills-education-support skilled force

The Lack of skills**,** from the organisational point of view, is different from skills related to social background already cited in the related section (46 barriers related in Appendix 2.3). Logically, obstacles related to the competence improvement were also cited with the lack of lessons learned on the:

- Comprehension of SB (Häkkinen and Belloni 2011)
- Application of DfDisa that is restrained by uncertainties regarding its global benefits and financial viability (Brancart et al. 2017)
- RL that remains unexploited or limited in the construction industry (Chileshe et al. 2016, Hosseini et al. 2015).

In complement, some authors have spotted the lack of documentation to help competence improvement:

- Lack of lessons learned documentation for Cy (Kifokeris and Xenidis 2017),
- Lack of empirical evidence to support the widespread use of RL (Chileshe et al. 2016),
- Need for identification of demonstration projects to illustrate the potential of the different methods (Sanchez and Haas 2018, Couto, J. and Couto, A. 2010),
- Lack of IFD studies for high-rise buildings (Jaillon and Poon 2014),
- Lack of studies providing clear instructions on how BIM could be used for CDW Management (Akinade et al. 2018, Jaillon and Poon 2014),
- Lack of studies that quantitatively demonstrate the effectiveness of the pre-project definition for buildings in the CE context (Sanchez and Haas 2018).

E. Technical barriers

The technical barriers are split into different scales, from the building scale to the material scale and from the data management to the technologies. Table 7 outlines the barriers found in the technical category.

a. Building-related barriers

1. Building lifespan, type and size

The long life cycle of buildings exceeds the lifespan of industrials products and also results in multiple changes of ownership (Chileshe et al. 2015a, Jaillon and Poon 2014, Hosseini et al. 2014, 2015). Additionally, the unicity of each building generates a complexity that is difficult to overcome in the modern context (Carvalho Machado et al. 2018, Gorgolewski 2008, Chileshe et al. 2016, Hosseini et al. 2014, 2015, Couto, J. and Couto, A. 2010).

Table 7: Outline of the technical barriers found in the literature (Source: author)

Technical Barriers	CE-DfCE	Cy	CL-CLSC	RL-DfRL	MA-DfMA	PFA-DfPFA	TB-DfTB	IFD-DfIFD	Disa-DfDisa	Dis-DfDis	SD	De-DfD	3Rs-Df3Rs	AR-DfAR	CDW Mini	CDW Mana	LCA	SB-DfSB
A-Building related barriers	x		x	x		x	x	x	x			x	x					
a-Building lifespan-duration-composition-update			x	x														
1-Building lifespan			x	x									x					
2-Building composition - several layers- finishes	x												x					
b-Building type and size as a barrier				x								x	x					
c-Project phases adaptation			x	x		x	x	x	x			x	x					
1-Design phase adaptation			x	x			x		x			x	x					
1-Unsuitable foundation			x															
2-Unsuitable design for current assets			x	x			x		x			x	x					
2-Construction methods adaptation						x							x					
3-In use			x	x								x						
4-Deconstruction processes implemetation (storage facilities)				x		x		x				x	x					
B-Material related barriers	x			x								x	x	x	x	x		
a-Material composition-knowledge & reliability				x								x	x	x	x	x		
1-Product quality				x								x	x		x	x		
2-Uncertain product composition				x									x					
3-Location of collection points				x									x		x			
4-Material availability													x	x				
b-Material recoverability	x			x								x	x					
1-Difficulty to recover materials				x								x	x					
2-Damage during deconstruction				x								x	x					
3-Hazardous components				x								x	x					
4-Building component lifespan												x	x					
C-Data related barriers	x			x								x	x		x		x	x
a-Data management															x			
b-Data availability-accessibility				x								x	x				x	x
D-Technology related barriers	x			x	x							x	x	x	x	x		x
a-Barriers linked to the use of BIM (as a new technology)					x													
b-Lack of technologies and technologies evolution	x			x								x	x	x	x	x		x
1-Lack of technology for deconstruction												x	x					
2-Lack of R&D	x											x	x	x				x
3-Lack of tools technology for recovered materials				x								x	x					x
4-Lack of tools to manage CDW												x	x					
1-Lack of prediction tools															x	x		x
2-Lack of alternative technologies-downcycling													x					x

2. Project phases adaptation

Firstly in the design phase**,** fifteen statements (Appendix 3) emphasise for the barriers related to the designs of buildings that were not made with the SEOL in mind (Carvalho Machado et al. 2018, Chileshe et al. 2015a, Crowther 2002, Gorgolewski 2008, Jaillon and Poon 2014, Hosseini et al. 2015, Xanthopoulos et al. 2009, Couto, J. and Couto, A. 2010, Huuhka and Hakanen 2015).

This includes all the components, even the foundations that are most of the time in concrete (Xanthopoulos et al. 2009).

The necessity to adapt the construction methods is emphasized by Gorgolewski (2008) for using reclaimed materials because it adds a whole new level of complexity to the project (Gorgolewski 2008). One example is given with the use of the in-situ connection between precast concrete elements (Jaillon and Poon 2014).

In the in-use phase, building systems are updated or replaced at different intervals during the building's lifetime (e.g., finishes at 5-year intervals; lighting at 10-year intervals; HVAC systems at 20-year intervals) adding complexity in the update of the data related to the building (Zaman, A. et al. 2018, Hosseini et al. 2014).

Deconstruction processes encounter limitations due to the space available to manage the process and especially store the materials (see also the section on environmental and economic barriers on this point). The lack of recovery facilities and infrastructure is cited by (Chileshe et al. 2015a, Xanthopoulos et al. 2009). The deconstruction is more complex than demolition, especially in the case of non-prefabricated components (Carvalho Machado et al. 2018) and sometimes, materials reuse is impossible (Knecht 2004).

Moreover, demountable connections do not always ensure the possibility of deconstruction, and in general, the poor connection of the elements is an issue (Carvalho Machado et al. 2018, Jaillon and Poon 2010, 2014, Crowther 2005). All these issues are increasing the deconstruction process risks (Chileshe et al. 2015a, Gorgolewski 2008, Crowther 2005). Lastly, there is a lack of identification of demonstration projects to illustrate the potential of the different methods (Chileshe et al. 2015a, Gorgolewski 2008, Hosseini et al. 2015, Huuhka and Hakanen 2015).

b. Material related barriers

1. Material composition, knowledge and reliability

The barriers are related to the low quality of materials, the poor reliability on the characteristics of recovered materials (Chileshe et al. 2015a, Diyamandoglu and Fortuna 2015, Kibert 2003a, Sassi 2008, Zaman, A. et al. 2018, Hosseini et al. 2014, Río Merino et al. 2010, Nisbet et al. 2012, Huuhka and Hakanen 2015). Then we have the barriers with the limited locations of collection points of recovered materials (Carvalho Machado et al. 2018, Jaillon and Poon 2010, 2014, Crowther 2005) that generate limitations to material availability (Gorgolewski 2008). The main source of those issues is the materials recoverability detailed in the following.

2. Material recoverability

The recoverability of construction materials is limited by a number of factors:

- The uses of finishes on building materials that reduce the possibility of reusing such materials (Akanbi et al. 2018).
- The use of concrete (Jaillon and Poon 2014, Couto, J. and Couto, A. 2010).
- The deconstruction process damages the materials because it is difficult to separate the composites (Densley Tingley and Davison 2012, Knecht 2004, Jaillon and Poon 2014, Nisbet et al. 2012, Forsythe 2011).
- Contamination with hazardous materials (Chileshe et al. 2015a, Knecht 2004, Hosseini et al. 2014, Crowther 2005, Forsythe 2011).
- The deterioration rates are unknown (Carvalho Machado et al. 2018, Chileshe et al. 2015a, Couto, J. and Couto, A. 2010).
- The under-estimation of the embedded resources in the building (Sanchez and Haas 2018).

c. Data related barriers

The poor data management is cited by Zaman et al. (2018) in the case of the National data collection and reporting on CDW (Zaman, A. et al. 2018). The other barriers are limited to availability and accessibility (Häkkinen and Belloni 2011). We have noticed the lack of data in:

- design stage to carry an LCA towards the EOL (Akinade et al. 2015)
- deconstruction projects and process (Carvalho Machado et al. 2018)
- Lack of national data on C&D waste (Diyamandoglu and Fortuna 2015)
- the behaviour of recycled concrete durability (Nisbet et al. 2012)
- The composition of buildings at the end of their life (Hosseini et al. 2015).

d. Technology-related barriers

Most barriers are related to the lack of appropriate tools and procedures. There is one lack in prefabricated building design with BIM tools cited by (Yuan et al. 2018); however, the other issues are not related to BIM but to the lack of:

- Common framework and automatic calculation procedures for SB (Häkkinen and Belloni 2011), simple process to reuse of a building project (Sanchez and Haas 2018),
- Science-based user-friendly tools for De, SB, CE (Häkkinen and Belloni 2011, Sanchez and Haas 2018, Couto, J. and Couto, A. 2010), proven alternative technologies (Häkkinen and Belloni 2011),
- Tools for designers enabling: efficient deconstruction (Chileshe et al. 2015a, Jaillon and Poon 2014, Hosseini et al. 2014, Couto, J. and Couto, A. 2010, Nisbet et al. 2012), assessing DW generation (Kim, Y. C. et al. 2017, Akinade et al. 2018, Zaman, A. et al. 2018, Ajayi et al. 2015), inclusion of new techniques for construction (Häkkinen and Belloni 2011, Sanchez and Haas 2018, Gorgolewski 2008), assessing the costs for IFD buildings (Hosseini et al. 2014).

- Techniques for reusing reclaimed materials elements (Chileshe et al. 2015a, Hosseini et al. 2015, Couto, J. and Couto, A. 2010, Forsythe 2011); meanwhile, down-cycling cannot be regarded as a closed loop (CL) principle because of the excessive loss of material value (Sassi 2008).

F. Environmental barriers

Table 8 outlines the barriers found in the environmental category. The first row deals with the cases of De, RL, and AR, where the issue of space for storage is cited by (Chileshe et al. 2015a, Jaillon and Poon 2010, 2014, Zaman, A. et al. 2018, Hosseini et al. 2014, 2015, Xanthopoulos et al. 2009). The site access limitation is also cited by (Jaillon and Poon 2010).

a. Quantity of polluted waste

In that case, many authors have noticed the existence of lead and asbestos in old buildings when dealing with RL, 3Rs, and CDW management (Knecht 2004, Hosseini et al. 2015, Río Merino et al. 2010, Nisbet et al. 2012). Those authors are not linking the high pollutant materials to environmental issues but to additional cost to process. However, we know that the process leads to environmental issues because the wastes must end in landfills. The fact that some authors and stakeholders do not directly link the pollution to environmental issues but to cost may be related to the lack of awareness of impacts on the environment. This is coherent with the previous barriers of cost and market cited in section 2.3.4.A.

Table 8: Outline of the environmental barriers found in the literature (Source: Author)

Environmental Barriers	CE-DfCE	Cy	CL-CLSC	RL-DfRL	MA-DfMA	PFA-DfPFA	TB-DfTB	IFD-DfIFD	Disa-DfDisa	Dis-DfDis	SD	De-DfD	3Rs-Df3Rs	AR-DfAR	CDW Mini	CDW Mana	LCA	SB-DfSB
A-Site constraints for SEOL implementation				x		x												
B-The use of non recoverable materials				x		x			x			x	x	x		x		x
a-Quantity of polluted waste				x									x			x		
b-Awareness of impacts on the environment												x	x	x				x
C-Pollution				x		x			x				x					

b. Awareness of impacts on the environment.

Many studies have identified the lack of strong environmental and sustainability evidence of the benefits of using well-designed principles as De, SB, 3Rs, AR and CDW minimization (Häkkinen and Belloni 2011, Sanchez and Haas 2018, Jaillon and Poon 2014, Zaman, A. et al. 2018, Huuhka and Hakanen 2015). Other authors raised the exposure to health and safety risks with encountering contaminated materials as an important barrier (Chileshe et al. 2015b, Hosseini et al. 2015, Crowther 2005).

Direct specific impacts are noticed by Sassi (2008) in the recycling process where the loss of material mass required additional virgin feedstock to be added. Other authors have identified the emissions from transport and reconditioning for 3Rs and Prefa approaches (Jaillon and Poon 2010, Cruz Rios et al. 2015, Huuhka and Hakanen 2015).

G. **Summary**

Hundreds of barriers hindering the shift to the “design for construction” to a design that would improve the sustainability of the asset EOL management were fund. Those designs are those taking into account directly the EOL (design for deconstruction, for recycling, out waste, for reuse, for Reverse logistics…), and those that take into account only the manufacture of assembly, but they may ease the deconstruction process. Some of those designs are not new but they struggle to be adopted for a number of barriers that were classified into six categories corresponding to six main disciplines (Economy, Sociology, Policy, Organisation, Technology, and Environment), the interrelation between the barriers from different disciplines is very common due to the holistic nature of the construction life cycle. The barriers are also related to the diversity of stakeholders and to the phases of the building process. The author will rely on those secondary data to discuss the data in the next chapters.

2.4 Literature supporting the design of the methods to collect primary data

2.4.1 Design of the theoretical framework

A. Why a framework?

In 1974 Minsky wrote a report entitled “A framework for representing knowledge” where he expatiated that “A frame is a data-structure for representing a stereotyped situation”, (Minsky 1974). The work of M. Minsky was also used by Gao (2011), who is defining a framework as a network of nodes and relations between those nodes that can structure a domain-related knowledge (Gao 2011).

In the field of risk management, Shortreed et al. (2003:4) have defined a framework as an “organizational specific set of functional activities and associated definitions that specify the processes that will be used to manage risks. A good risk management framework should enhance and improve risk management by (i) making it more transparent and understandable to stakeholders (ii) making its processes more efficient and (iii) allowing for sharing of best practice in the implementation of risk identification, risk assessment and risk treatment” (Shortreed et al. 2003).

The framework for integrating the SEOL phase into the asset lifecycle in BIM environment is compliant with the above definitions and is prescriptive if we follow the definition given by Holsapple and Joshi 1999, who have studied frameworks for knowledge management (Holsapple and Joshi 1999). The framework developed in this thesis is prescriptive because it aims at prescribing methodologies to follow in implementing the SEOL into the life cycle of the asset conformably with the aims and objectives of this thesis. Contrarily, a descriptive framework would only attempt to characterize the nature of this integration.

The framework objective is commonly to structure related but disjointed information into something useful and accurate, as defined in the field of knowledge management (Malafsky 2003). The framework developed in this thesis also intends to classify and organise information related to the sustainable management of the asset end of life.

As BIM can be seen as a tool managing information and according to the above definitions unsurprisingly, different frameworks centred to BIM can be found in the literature (76 journal papers found in Scopus with ‘BIM and Framework’ as keywords search in papers’ title, within all disciplines). None of them is dealing with the asset end of life. They address different needs, for example, to foster the implementation of BIM (Gao 2011), to manage energy in buildings, (Cheng and Das 2014) or for the management of construction risk, (Malvar and Likhitruangsilp 2015). Some other frameworks are dealing with a holistic BIM framework to manage waste but only in the construction phase (Liu, S. et al. 2015, Bilal et al. 2016).

In the next subsection, we will give the documents that were used to design the conceptual framework of this study.

B. **Support from the literature to design the theoretical framework**

The basis to draw the theoretical framework was taken from two key documents found in the literature. First, the "Penn State" document (CIC 2011) has defined the BIM Uses and their related processes. Figure 8 is an example of the seventeen processes developed in the Penn State document. Each process has the purpose of explaining and visualizing a BIM use. The theoretical Framework drawn for this research was inspired by these processes. However, none of the Penn State processes is addressing the asset EOL management. As discussed in Chapter 7, there is no BIM uses identified in the Penn State related to the EOL activities.

Secondly, the work conducted by (Won and Cheng 2017) consisting of developing design decision-making BIM-based framework for the improvement of the construction waste minimisation. Figure 9 is the general process summarizing the 8 BIM uses considered by the authors as having a potential for C&D waste management and minimization. For instance, the advantages to developing a model for managing the asset EOL mentioned in the Theoretical BIM-Based Framework (in pink in Figure 10) come from Won and Cheng (2017) process.

The researcher has used those processes (illustrated in Figures 8 and 9) as guidance to design the first draft of the theoretical framework, enriched by the literature review summarised in Table 9. The theoretical framework obtained is presented in Figure 10.

Figure 8: The Design Authoring process from the BIM Execution Planning Procedure used as a basis for the theoretical BIM-based framework (Source: the Penn State CIC Research Team (2011))

Some materials have been removed due to 3rd party copyright. The unabridged version can be viewed in Lancester Library - Coventry University.

Figure 9: An Integrated process map for BIM-based approaches to C7D waste management and minimization used as a basis for the theoretical BIM-based framework (Source: Won and Cheng (2017))

Table 9: Support from the literature to design the theoretical Framework to integrate the SEOL in the asset lifecycle (Source: Author)

References	**Categories**
	Framework structure
CIOB (2014) ; RIBA (2013) ; Messner et al., (2012)	Structure of the framework
	Approach / changes
Crowther (2002) ; Sebastian (2010)	Hollistic view / Multidisciplinary approach
ISO 690 (2002) ; Sebastian (2010)	Contracts / Procurements changes
Sebastian (2010)	Things that should be done to begin a project in BIM
	Client
Liu et al., (2015)	Client change & Poor communication
Bilal et al., (2016)	Clients requirements
	Communication/ Coordination
Akbarnezhad et al., (2014) ; Schultmann F (2008)	Collaboration & Integrated approach
Xanthopoulos et al., (2012)	
Bossink and Brouwers (1996) ; Osmani (2013)	Coordination & Communication
Osmani et al., (2008)	
Kifokeris and Xenidis (2017) ; Sebastian (2010)	Communication between stakeholders
	Phases
Nawi et al. (2009) ; Saghatforoush et al. (2009)	Project All phases
Sanchez & Haas (2018)	Pre-project planning phase
Inglis (2007) ; Bogenstätter (2000)	Design phase
Kovacic & Zoller (2015)	
Couto & Couto (2010)	WMP incorporated during design stage
Knecht (2004)	Planning phase
Van Reedt Dortland (2009)	In use phase changes
Knecht (2004)	EOL phase
Albaloushi & Skitmore (2008)	Supply chain management (phases)
Kibert (2003) ; Akinade et al., (2017)	Link between phases
	Stakeholders importance
Inglis (2007)	Importance of Architects/Engineers
Gorgolewski (2008) ; Srour et al., (2010) ; EPA (2008)	Designer role = essential
Pulaski et al., (2004) ; Knecht (2004) ; Srour et al., (2010)	
Chong & Hermreck (2009) ; Jaillon et al., (2009)	
Srour et al., (2012) ; EPA (2008)	
Couto & Couto (2010) ; Bilal et al., (2016)	Stakeholders involvement
Bossink and Brouwers (1996) ; Osmani (2013)	
Osmani et al., (2008) ; Kifokeris and Xenidis (2017)	
Sebastian (2010)	
Sebastian (2010) ; Kifokeris and Xenidis (2017)	Stakeholders involvement design
Sassi (2008) ; Pulaski et al., (2004) ; Gorgolewski (2008)	
Liu (2009) ; Dolan et al., (1999) ; EPA (2008)	stakeholders challenges
Rios et al., (2015)	
	Data
Sebastian (2010) ; Akinade et al., (2016)	BIM model / Data
Häkkinen & Belloni (2011)	
Chen et al., (2015) ; Lu et al. (2017) ; Niu et al., (2016)	Information management
Akbarnezhad et al., (2012)	Deconstruction stratgies to adopt
	Material
Chini (2005) ; Srour et al., (2010)	Lack of information for material recycling
Sassi (2008) ; Gorgolewski (2008) ; Knecht (2004)	Reclaimed materials/ Inventory
Knecht (2004)	Market development
Kreider and Messner (2013)	**Framework**
Won & Cheng (2017) ; Liu et al. (2015)	

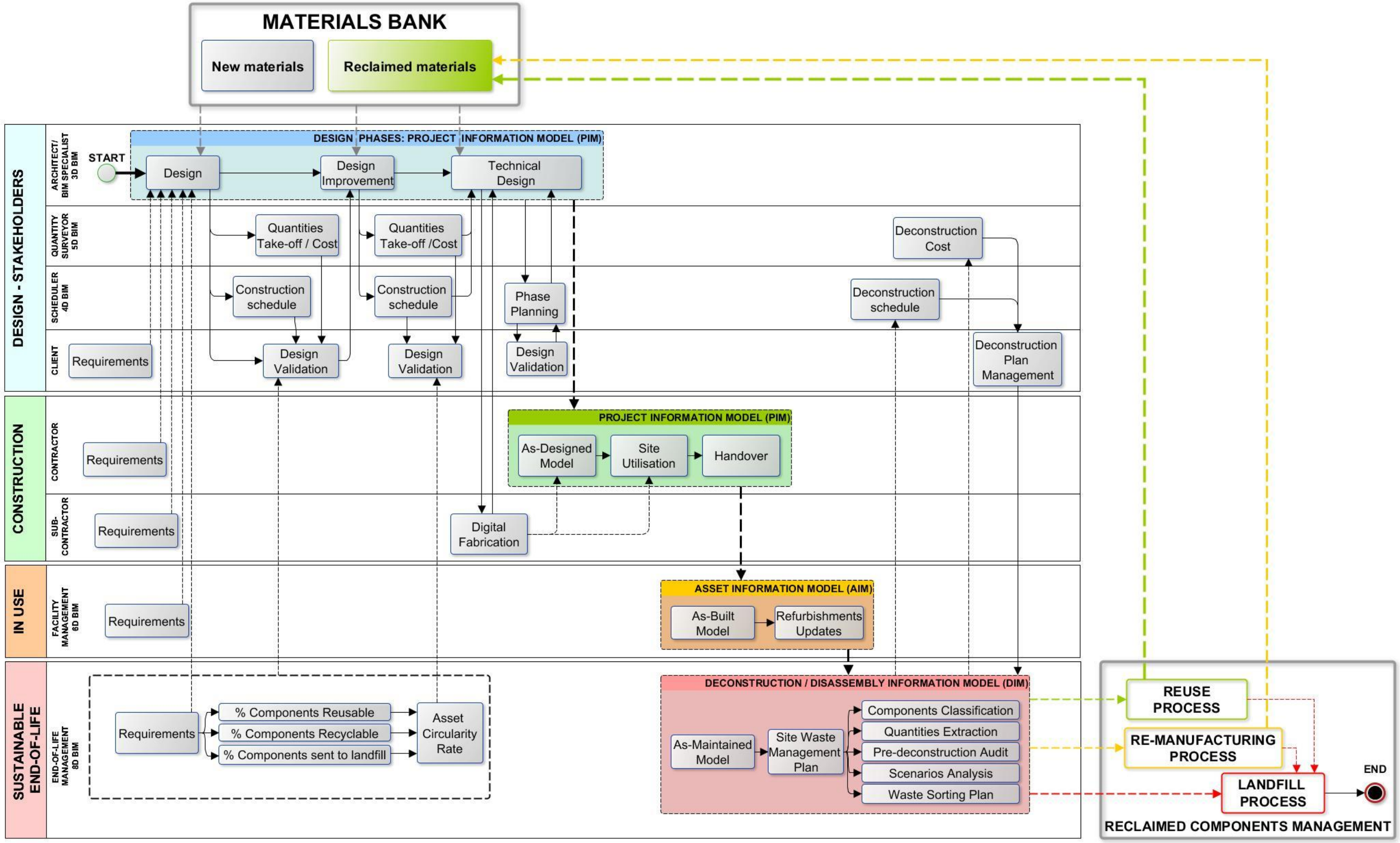


Figure 10: Theoretical framework for integrating the SEOL in the asset lifecycle, designed from the literature review (Source: Author)

2.4.2 Support for the design of the questions of the semi-structured interviews

A literature review was performed to design the theoretical framework but also to design the thirteen questions for the semi-structured interviews. Table 10 summarises the references supporting the questions.

Table 10: Journal papers that support the questions designed for the 20 semi-structured interviews (Source: Author)

References		Questions
Linder, Sarasini, and van Loon (2017)	**1**	Asset circularity measurement: Can BIM help?
Ali Akbarnezhad et al. (2012a)		
Won and Cheng (2017)	**2**	Asset lifecycle Phases: What are the issues for each stakeholder, each phase?
Akinade, Oyedele, Omoteso, et al. (2017)		How Design phase affect the Asset lifecycle EOL?
Akinade, Oyedele, Ajayi, et al.(2017)		
S. O. Ajayi et al. (2015)		
Jaillon, Poon, and Chiang (2009)		
Won and Cheng (2017) ; S. O. Ajayi et al. (2015)		Who should be involved during the design?
Kifokeris and Xenidis (2017)		
Pulaski et al. (2004)	**3**	What are the various Design principles?
Gorgolewski (2008)	**4**	What are the Deconstruction advantages and disadvantages?
Dantata, Touran, and Wang (2005) ; Greer (2004)		Comparison deconstruction/demolition
Couto and Couto (2010) ; Gorgolewski (2008)		
Ali Akbarnezhad et al. (2012b)		
Bradley and Guy (2006) ; Pun et al. (2006)		
Kibert (2003)	**5**	What are the Design for Deconstruction advantages and disadvantages?
Akinade, Oyedele, Ajayi, et al. (2017)		What is the purpose of DfD?
Akinade, Oyedele, Omoteso, et al. (2017)		BIM potential for Deconstruction and Design for Deconstruction?
S. O. Ajayi et al. (2015) ; Volk et al. (2018)		
WRAP (2009)		
Akinade, Oyedele, Omoteso, et al. (2017)	**6**	What are the barriers for DfD (Deconstruction & disassembly) and Designing for
Akinade, Oyedele, Ajayi, et al. (2017)		reverse logistics (DfRL)
Won and Cheng (2017) ; Bradley and Guy (2006)		
Chini and Bruening (2003) ; Pulaski et al. (2004)		
Volk et al. (2018) ; Sassi (2008)		
Leigh and Patterson (2006) ; Chileshe et al. (2016)		
Cruz Rios, Chong, and Grau (2015)		
Bradley and Guy (2006) ; Chini and Bruening		
(2003)Bradley and Scott (2002)		
Kibert 2003)(Bradley and Scott (2002)		What are the Design-construction methods
Akinade, Oyedele, Ajayi, et al. (2017)		
Cruz Rios, Chong, and Grau (2015)		
Chileshe et al. (2016) ; Leigh and Patterson (2006)		
Akbarnezhad et al. (2012b)		
(W. Lu et al. 2017)(Won and Cheng 2017)	**7**	What are the Data required/issues?
(Ali Akbarnezhad et al. 2012a)		
Akinade, Oyedele, Ajayi, et al. (2017)	**8**	Component selection
Bradley and Guy (2006)		
Akinade, Oyedele, Ajayi, et al. (2017)	**10**	What are the factors affecting the reuse/recycling of reclaimed materials?
Gorgolewski (2008) ; Sassi (2008)		
Bradley and Guy (2006) ; Won and Cheng (2017)		
Da Rocha and Sattler (2009)		
Akinade, Oyedele, Ajayi, et al. (2017) ; Ajayi et al.	**11**	Could BIM assist demolition contractors in identifying building components ?
Akinade, Oyedele, Ajayi, et al. (2017)		What are the changes that should be made?
Kibert 2003)(Bradley and Guy (2006)	**12**	What are factors increasing the difficulty to close materials loops?
S. O. Ajayi et al. (2015)	**13**	What are the strategies to put in place for Diversion of C&D waste from landfill?

3 CHAPTER 3: Methodology

3.1 Overview of the Chapter

The purpose of this study is to create a BIM-based framework for incorporating a SEOL phase into the asset lifecycle in the context of Circular Economy. This chapter will present the research strategy and the various sequences used for this research. Several strategies and methods are explained, and appropriate approaches for the study were identified. Three major elements are addressed: theoretical assumptions underpinning the study, strategy of enquiry and the research design.

Section 3.2 focuses on the research paradigm and philosophy, followed by the explanation of the data approaches (section 3.3). Section 3.4 explains data gathering. Then, an explanation is given on the reliability and validity of qualitative research (section 3.5). Lastly, the ethics of the research are discussed in section 3.6.

Figure 11 gives a summary of the choices based on the methodology that the author has made in this chapter.

3.2 Research paradigm and philosophy

Research paradigm has several definitions. According to Kuhn (1962), a research paradigm is "the set of common beliefs and agreements shared between scientists about how problems should be understood and addressed" (Kuhn 1962). For Guba (1990), research paradigms can be characterised through their ontology (what is reality?), their epistemology (How do you know something) and methodology (How do you go about finding it out?) (Guba 1990).

Johnson and Christensen (2005), reported that the research paradigm could be described as how the researcher considers the development of knowledge. The research paradigm refers to two beliefs, one is linked with the nature of the world, and the second is related to the researcher (Johnson, R. B. and Christensen 2010). Figure 11 depicts the complex process of conducting research. The author has highlighted in colours the processes used specifically to drive this research. This can be divided into three main parts: research philosophy, Data approaches and Data Gathering. The Figure was drawn based on the Research Onion (Saunders et al. 2016) and Methods Map developed by (Paterson et al. 2016).

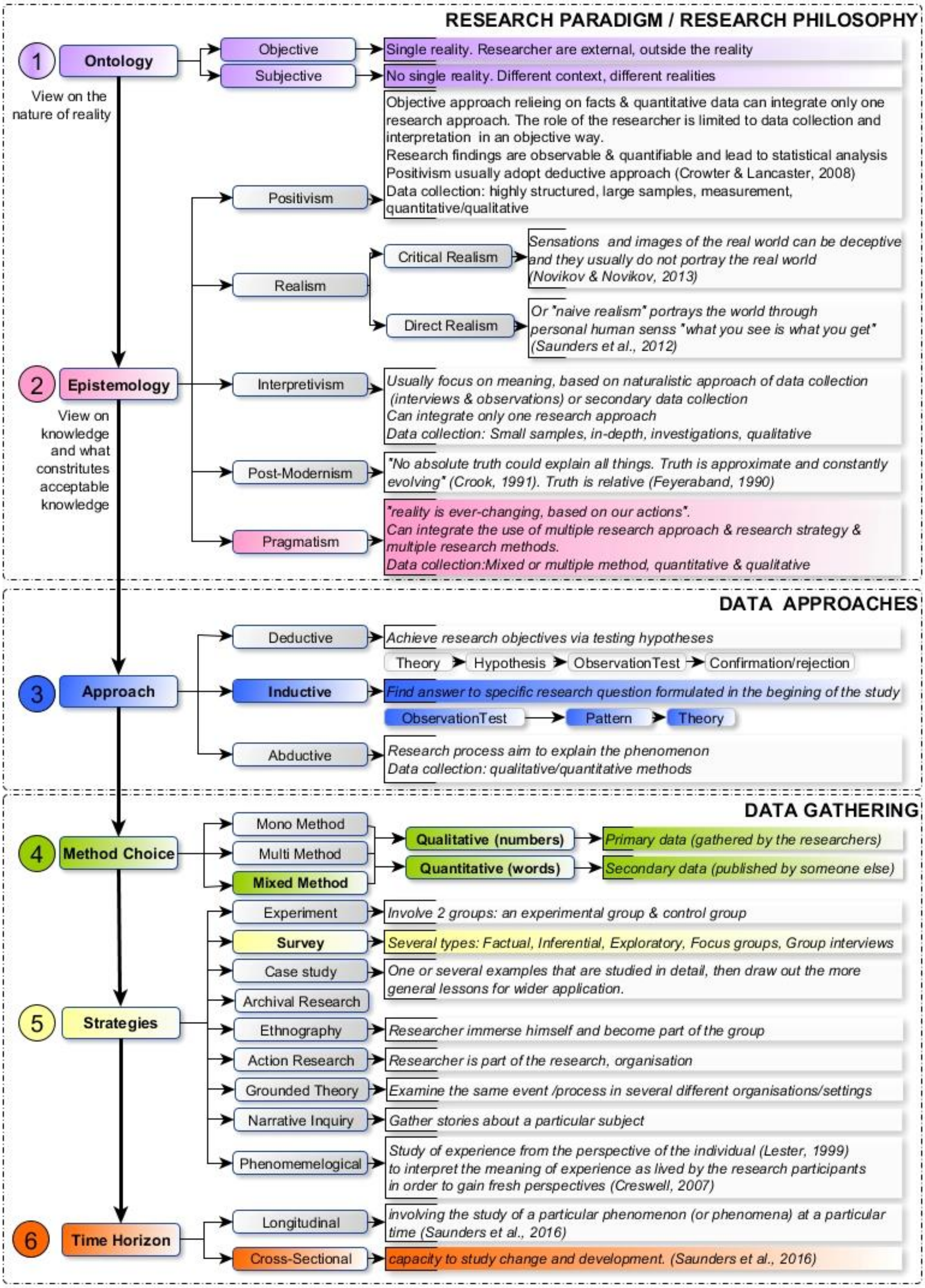


Figure 11 Research philosophies where the processes used specifically to drive our research are highlighted in colours (Source: based on the research Onion Figure 4.1 Saunders et al. (2016))

Kuhn (1962) considered the research paradigm as "single characterizing normal science"(Kuhn 1962). He defined a paradigm as "a general concept and that it included a group of researchers having a common education and an agreement on "exemplars" of high-quality research or thinking (Kuhn 1977). However, Guba (1990) stated that the research paradigm could be characterized through their ontology, epistemology and methodology (Guba 1990). The research philosophy can be viewed in two different ways, ontology and epistemology.

3.2.1 Ontology

Two important aspects of ontology are objectivism and subjectivism. According to Crotty (1998), "the study of being" (Crotty 1998). For objectivists (also known as positivists), there is a single reality. They are external, outside the reality, and they will look at how people think in this single reality. On the other hand, subjectivists consider that there is no single reality. For them, the reality is constructed in the context. Thus there are different contexts and different realities.

3.2.2 Epistemology

They are four key epistemological choices; Positivism, interpretivism, realism and pragmatism (Bryman 1988). Epistemology can be defined as a way of acquiring knowledge. According to Crotty (1998), epistemology is "a way of understanding and explaining how we know what we know" (Crotty 1998). The four main epistemology are positivism, interpretivism, realism and pragmatism.

A. Positivism

Positivists acquire knowledge by developing a hypothesis and testing them, in an objective way, statistically. The positivist scientific model of research is usually associated with quantitative methods (Doyle et al. 2009). Positivism is an objective approach relying on factual knowledge and quantitative data. Findings of positivist research are usually observable and quantifiable. At the opposite, the interpretative model associated with qualitative ones (Howe, 1985).

B. Interpretivism

Interpretivists, also known as constructivists or subjectivists, consider that social phenomena are results of human perceptions in a specific context. They acquire knowledge by asking people and try to understand what they want and report. Myers (2013:39) reported that "reality is seen within its context and is accessed through social construction such as language, consciousness, shared meanings, and instruments" (Myers 2013).

C. Realism

The realism research philosophy can be divided into two groups: direct and critical. Direct realism or naïve realism philosophy considers that "what we see is what we get". The world is portrayed through our senses. While critical realism considers that "sensations and images of the real world can be deceptive, and they usually do not portray the real world" (Novikov, A. M. and Novikov, D. A. 2013). Critical realism is less extreme and focuses on "explaining what we see and experience, in terms of the underlying structures of reality that shape the observable events"(Saunders et al. 2016:151). Critical realists see reality as external and independent. The access to reality is not made through our observation and knowledge of it. According to realists, the access to the understanding of the world can be done by two steps, firstly through sensations and secondly through the mental processing (Reed 2005).

D. **Pragmatism**

Pragmatism is the fifth type of research epistemology in Figure 11. According to Saunders et al. (2016), pragmatism "accepts concepts to be relevant only if they support action". For pragmatics, "there are many different ways of interpreting the world and undertaking research, that no single point of view can ever give the entire picture and that there may be multiple realities" (Saunders et al. 2016:144). For pragmatism research philosophy, the research question is the most important determinant of the research philosophy. According to the type of research question, pragmatism can combine both positivism and interpretivism.

3.2.3 The research philosophy Used for the research

For the research, the epistemological choice is pragmatism allowing the researcher to have multiple research questions and combine both positivism and interpretivism. Indeed, pragmatism research paradigm allows researchers to find out the facts and outcomes of their investigations.

To be able to achieve the research aim, several sub-questions must be answered (Figure 12). For that reason, the author has adopted a pragmatism philosophy to integrate the use of multiple research approach, research strategy & multiple research methods.

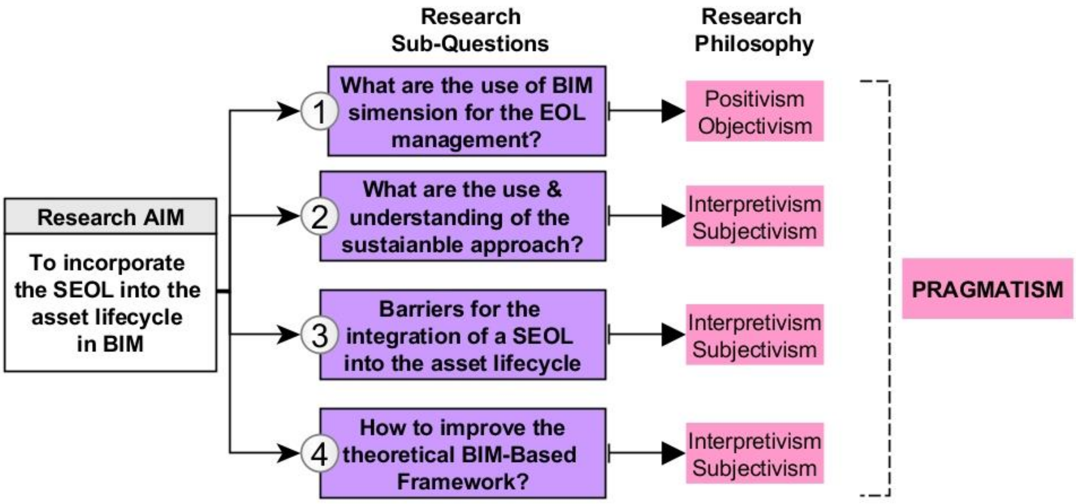


Figure 12: The research philosophy and research sub-questions (Source: Author)

3.3 Data approaches

Regarding the research approach to collect data, there are three ways to do it: inductive, deductive and abductive (Dubois and Gibbert 2010). Figure 13 shows the three approaches and their steps. The figure is adapted from Fisher (2001) and Eco (1992) (Fisher 2001, Eco 1992).

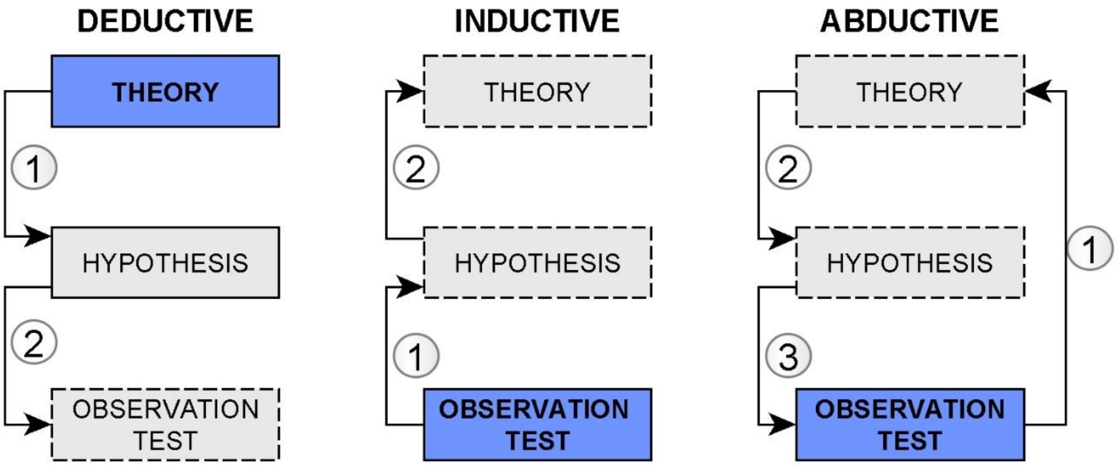


Figure 13: The three types of data approaches (Source: Author)

3.3.1 Deductive, inductive and abductive

Inductive and deductive approaches are usually used to build new theories. Empiricists have a deductive approach to fill a knowledge gap by testing theories. They have a theory, set up a hypothesis, and then they test the hypothesis. Objectively based on statistic findings, they confirm or reject the theory. The lack of clarity for hypothesis selection and the challenge to select a proper theory, are the reasons why deductive reasoning is criticized.

On the over hand, Interpretivism is an inductive approach that aims to generate new theories based on the collected data. For solving a problem, interpretivists also face critics due to their ability to construct a valid theory based on empirical data. Indeed, in an inductive approach, researchers collect data by asking people about the problem. They then, describe and analyse the answers they got. Interpretivism is descriptive research based on the fact that there is no single reality.

The last type of approach, the abductive is set to address the weaknesses of the two precedents approaches by combining them (Suddaby 2006). The interest of the abductive approach is when the researcher wants to develop a credible theory. It starts with the observation of an unexpected fact used by the research as a conclusion rather than a piece of evidence. Based on that fact, explanation and data are provided.

3.3.2 Used for the research

For the research, the inductive approach was chosen. After secondary data collection, the gap in knowledge was identified, and the aim and objectives of the research were set up. Fieldwork was done by conducting interviews to explore and study a specific phenomenon: the barriers of the SEOL incorporation as a phase into the asset lifecycle. Then, the research builds a conceptual framework.

The rationale of adopting the inductive approach is due to the emerging topic of the circular economy in a BIM environment and the use of BIM. The barriers for adding a sustainable End-of-life approach into the asset lifecycle were explored. The observations were incorporated into a conceptual framework and guidelines destined to support the stakeholders to move towards a SEOL approach were proposed.

3.4 Data gathering

3.4.1 Method choice used for the research

A. Benefits and challenges of using mixed methods

As noted by Sechrest and Sidani (1995) and reported by Onwuegbuzie and Leech (2005), mixed methods approach aim to use methods enabling the researcher to find a solution for his research problem. It also reduces issues that could emerge from the use of singular methods. Pragmatic research can benefit from the strength of both approaches (Onwuegbuzie and Leech 2005, Sechrest and Sidani 1995). To support previous authors and the benefits of using mixed methods, Morgan added that researchers could use pluralistic approaches to sort out the research problem (Morgan 2007). Therefore, the researcher is not constrained by a single system of reality. To form a continuum and get an in-depth understanding of the conducted research, he can combine both methods (Creswell, J. W. and Creswell, J. D. 2017).

Hanson et al.(2005) reported that Mixed Methods research is guided by philosophical assumptions enabling the “mixing phase” to occur throughout the research process (Hanson et al. 2005). One of the several strengths of Mixed Methods, particularly the embedded design, is the focus on different questions. Indeed, results can be published together or separately (Creswell, J. W. and Plano Clark 2011).

Several authors have reported the benefits of using Mixed Methods (Creswell, J. W. and Clark 2007, Abowitz and Toole 2010). In this research, the choice of a mixed method was driven by the need to benefit from the strength of both methods. The usefulness of using several methods to “enrich the results in a way that one form of data does not allow” is stated by (Tashakkori and Teddlie 1998, Brewer and Hunter 1989). Using mixed methods, takes advantage of both types of findings: quantitative findings are associated with generalizability and representativeness, and qualitative findings are more in-depth and contextual nature (Greene et al. 1989).

Authors stressed the massive benefits of Mixed Methods, but they also specify their limitations and challenges. In effect, Creswell (2014) reported that Mixed Methods lead researchers to collect extensive data and to spend a lot of time for the analysis of both types of data. This also gives rise to a good understanding of both forms of research. The complex Mixed Methods design was also pointed out as a challenge that should be overcome with a clear visual model, (Creswell, J. W. 2014). Several types of Mixed Methods exist and were discussed in the previous sub-section (3.4.1) (Appendix 6).

B. The rationale for choosing Mixed Methods

The researcher estimates that the used of Mixed Methods for this research is appropriate due to the necessity to answer two types of question. Indeed, to address the aim that is "how to integrate a SEOL into the asset lifecycle in BIM environment, towards the Circular Economy", the researcher has used a Mixed Method in which qualitative and quantitative data are collected. In order to be able to achieve the PhD aim, a detailed understanding of the BIM dimensions actually in use in the industry has to be studied as well as if the EOL activities are linked with a BIM dimension.

The quantitative data should be collected to identify what are the various current BIM dimension and explore if a dimension is already linked with the asset EOL activities. That has required to have a quantification of the consensus on the BIM dimensions by using quantitative data gathered by a questionnaire. The quantitative assessment was possible because the author was able to circumscribe the research questions thanks to enough data on the level of development of BIM in the literature. The exploration of the current use of BIM was first performed by using a systematic review. The results obtained have led the researcher to assess the professionals' views' on what dimension the main construction activities are allocated. Due to the different level of adoption across the world, the European level was selected for quantitative research.

Qualitative data will be collected to achieve the second strand of the research that is to develop a framework for the integration of the SEOL in the lifecycle of the asset as well as the barriers against its implementation. To achieve those objectives, we had to rely on detailed data to enable a proper investigation of those objectives because the analysed data would be used to develop a theory (here a framework). For that reason, Snape and Spencer (2003) have advised using a qualitative method (Snape and Spencer 2003). One of the characteristics of qualitative research stressed by authors is its use for exploring emergent issues. In fact, qualitative data collection usually involves close contact between the researcher and the research participants. Moreover, as mentioned by Chileshe et al. (2016), the semi-structured interview is a technique used to explore a new area and enabling the participant to stay focus on the area investigated (Chileshe et al. 2016). Indeed, to create the framework on a completely new idea, that required to speak to the best experts in the field of sustainable building in the context of a circular economy. That is why the qualitative approach through interviews was also developed. Indeed, the qualitative data will look at the barriers against a BIM-Based Framework for incorporating a SEOL phase into the asset lifecycle in the context of Circular Economy (thesis aim) from the stakeholders' perspective.

C. Adopted research method

The aim of the research was broken in five objectives that enable to answer to the research questions. It was estimated that to be able to achieve the research aim; a pragmatism philosophy should be adopted. A massive literature review was conducted, and then, strategies for data gathering were selected. (Figure 14) summarized the research paradigms, approaches and methods.

For the study, the procedure for the data collection was sequential (Figure 15).

- Step 1: Quantitative data collection was performed and analysed. Priority between the two types of data was unequal. Indeed, priority was given to the qualitative data.
- Step 2: The second step was the collection of qualitative data. Two techniques were used, a structure pre-interview questionnaire and then semi-structured interviews. The results of the Pre Interview Questionnaire were utilised for the analysis of the data collected through interviews.
- Step 3: The data from step 1 and 2 were analysed separately and integrated during the discussion stage. All the data was connected during the interpretation and discussion stage.

Regarding the procedural notations used in Figure 15, Sample (1) and Sample (2) refer to the samples of the first and second steps. Sample (1) and Sample (2) are different. Sample (1) is the sample for the qualitative study where stakeholders (from the UK or France) are using BIM or dealing with Sustainable Building approach were the target. However, the Sample (2) is the sample for the quantitative data: BIM experts from Europe were invited to respond to the online questionnaire.

3.4.2 Strategies for data gathering

In the following subsection, the strategies for collecting the data for the study is explained. This covers the description of sampling techniques used. The type, medium and process of data collection is also described.

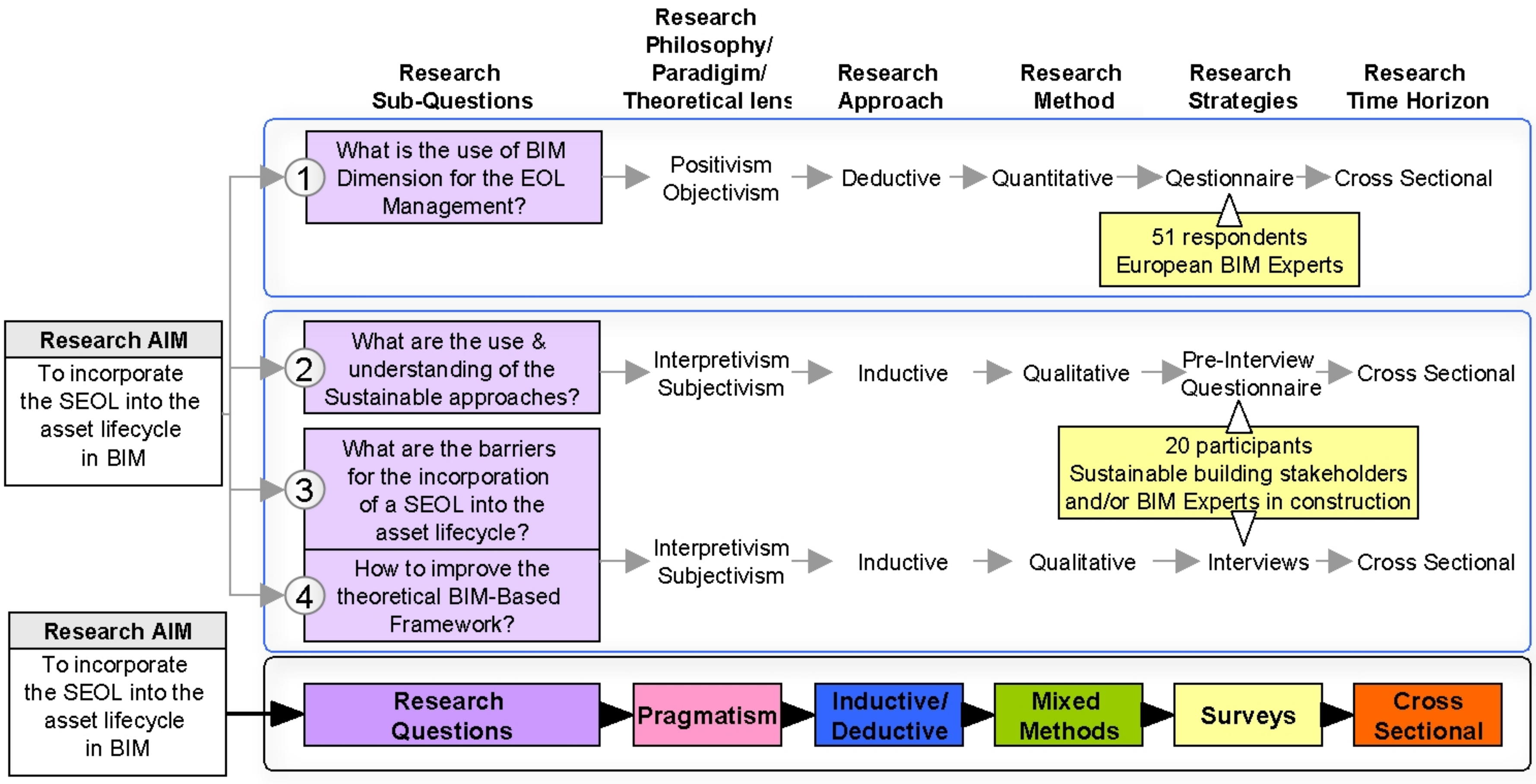


Figure 14: Research paradigm, aim and research sub-questions (Source: Author)

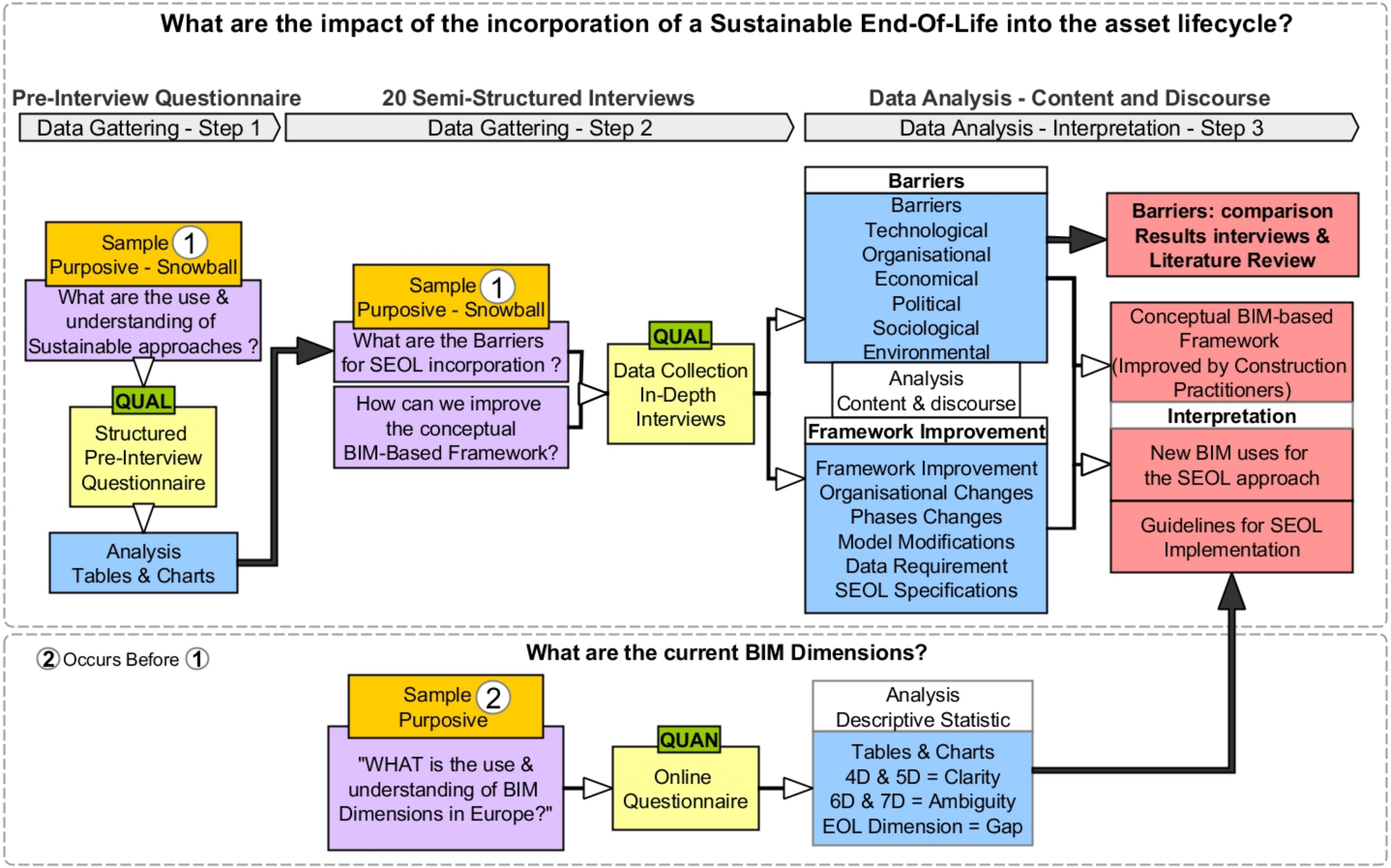


Figure 15: Embedded Mixed Methods Design of the study (Source: Author)

A. Data collection: secondary data

a. BIM dimension for EOL

The literature review is discussed broadly in Chapter 2. To be able to answer to the five research objectives, the literature review covers several topics: A systematic literature reviews were conducted to look for the use and understanding in Europe of BIM dimensions. Does a dimension for EOL activities exist? The systematic literature review enables to the identification of a gap of knowledge for the use of BIM for managing the asset EOL sustainably. The literature suggested also a lack of clarity between the current BIM dimensions. The systematic review was conducted to collect the academics state of the art, and an online survey enabled the identification of practitioners' points of view.

b. Barriers for sustainable EOL

Then the EOL approaches were searched, such as Deconstruction, Dismantling, Disassembly, Demountable. The barriers for concepts, such as Reverse Logistic, Circular Economy, Close Loop Cycle and Sustainable Building, were also searched. When available, Review papers were targeted to have a better overview of principles/concepts. The relevant literature, available in English and French, was carried out by using a variety of database information (Coventry University Library, Scopus and Google Scholar). This literature review enabled the clarification of the various concepts and to highlight their similarities. The author grouped them in categories according to their similarities. It also provided a solid foundation for the study by identifying the barriers for each concept.

c. BIM-based framework for the EOL integration

The third part of the literature review was related to the BIM-based Framework targeted to integrate the SEOL into the asset lifecycle. The literature review investigated whether that kind of framework already existing. A theoretical BIM-framework was drawn based on the data found in the literature review. Table 9 in chapter 2, has summarized the references used for it and for identifying the asset lifecycle phases and the main stakeholders involved in a construction project.

The main objective of the framework is to provide for the stakeholders involved in the asset lifecycle, a systematic view for the implementation of a Sustainable EOL of the building. The framework is proposed in a BIM environment because it takes advantage of the collaborative approach and the data generated by the use of BIM (Akbarnezhad et al. 2012).

B. Primary Data Collection: a Questionnaire survey

The systematic review, focussed on journal papers, peered reviewed. The findings revealed the existence of several BIM dimensions: the 3D, 4D, 5D, 6D and 7D. Fifty-five papers were identified detailing the different BIM dimensions. They were classified according to a matrix developed for the study (Chapter 2). The matrix was used for setting up questions of the survey designed for collecting primary data and addressing the first objective of this study.

The first objective of the research was to assess the level of clarity or confusion on what the numbers of dimension refer to after the 3rd dimension. The questionnaire technique for collecting the data was selected to answer the first objective. The systematic literature review conducted was to investigate what activities are most commonly referred to, like the 4th, 5th and above dimensions in BIM according to academics. Professional practitioners' opinion was also unravelled because they are key actors in the implementation of BIM in the construction industry. Then academics and practitioners' views were compared to highlight where consensuses are, and if confusions exist.

The online questionnaire method was used due to the geographical spread (EU countries) of the study to avoid the cost (Oppenheim 2000). The use of the survey technique for research is relevant because of the low requirement for its organization, its financial cost and timeliness (De Leeuw et al. 2008). The technique is also well known for its flexibility and provision of quality quantitative data (Walliman 2017).

a. Survey procedure

The survey was designed distributed and collected through the Bristol Online Survey (BOS). The analysis was done with BOS and Excel. BOS is an online survey tool which allows design, distribution, collection and analysis of questionnaire data, run by the University of Bristol. The survey took place between the 3rd March 2017 and the 30th May 2017. The questionnaire was reachable via a link emailed to potential respondents.

b. Questionnaire structure

The questionnaire was structured in four sections (Table 11): (i) First, the respect for persons was tackled by including the informed consent section to address the ethical requirement for questionnaires and explaining the terms and conditions of the survey (De Leeuw et al. 2008). We mentioned the objectives of the research project and specified why the participant was chosen and that they incur no risk by being involved in the survey. The respondents were also assured of the confidentiality of their identity.

This section must be read and agreed to be able to pursue the survey. (ii) Secondly, the next section developed a set of 4 questions on the respondent identification Table 11. This part of the survey was structured to identify who are the respondents and their role in the company. (iii) Thirdly, the company description section contained two questions aiming to identify the type and size of the company where the respondents were working in. (iv) Lastly, a set of three questions regarding BIM dimensions was set up, with the aim to determine the awareness, understanding and utilisation of BIM dimensions by the practitioners, across Europe. The three closed questions were designed according to the matrix obtained from the systematic review (Table 11).

Table 11: Questionnaire structure (Source: Author)

Consent	
Identification	
Free text	Company name?
Free text	Current role?
Free text	City/Country?
Free text	Email Address
Company Description	
Multi-choice	What is the business sector of your company?
Multi-choice	What is the size of your company?
BIM Dimensions	
Likert scale	Are you aware of the various BIM Dimension? (4D, 5D, 6D and 7D)
Likert scale	Which BIM Dimension do you use? (4D, 5D, 6D and 7D)
Likert scale	What does BIM Dimension refer to? (4D, 5D, 6D and 7D)
	Scheduling?
	Estimating?
	Facility Management?
	Sustainability?
	Safety?

c. *Questionnaire sampling*

The purposive sampling method was used to ensure potential respondents from all the 28 EU countries since it is a non-probability sample method that allows respondent selection based on population characteristics and the study's aim (Palinkas et al. 2015, Merriam 1998, Miles and Huberman 1984). To avoid bias, authors have decided to have a representative sample composed of 6 BIM professionals per country to send them a request via LinkedIn. Then the aim was to get at least one response per country and 50 respondents in total. The selected sample was purposely targeting position with a high level of responsibilities in the companies, and knowledge in BIM because these people are believed to be well informed in relation to the questions being asked in the questionnaire. The LinkedIn database was used to search for relevant profiles since it provides readily available contacts of a large pool of professionals, including those that work in construction with expertise in BIM. LinkedIn is not uncommonly used as a database for respondent search (Dusek et al. 2015). The population picked out are, among other architects, engineers, contractors, facility managers, BIM Managers and training providers. A combination of the author's private contacts in the AEC industry and three groups on LinkedIn were used: The international "BIM expert group" (approximately 60,000 members), the International BIM Consultants (approximately 3600 members) and Women in BIM (approximately 500 members) (Rodgers et al. 2015) (Figure 16).

As schemed in Figure 16, for each LinkedIn Group, the author clicked on account of the first 200 members and checked their country of origin. Each relevant profile was subsequently selected based on their BIM expertise according to their profile, and their country of origin. LinkedIn provides this information as part of the profile information of each account that is clicked. We also used the Google search engine by typing "BIM expert AND the name of the country". Then the profiles were checked on LinkedIn to make sure that the professionals were working in BIM area and that they had a key role in the company. Once we had six relevant profiles for a particular country are found, the author stopped picking for that country and so on.

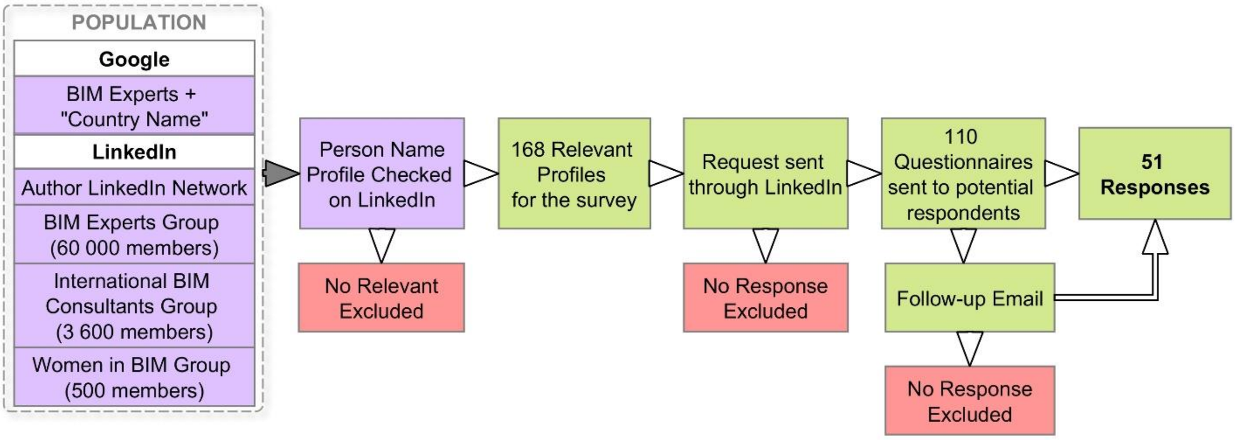


Figure 16: Sampling process for the online Questionnaire (Source: Author)

About 3000 professional's profiles had been reviewed to assess their profile compliance required by the questionnaire sample, and among them, 168 were selected (Appendix 2). The identified relevant profiles were contacted through email to seek their participation consent. Among them, 110 potential respondents gave a positive response. An email with the questionnaire's link was sent to them. After ten days, follow-up emails were sent to those that had not filled the questionnaire yet in order to increase the response rate (Kittleson 1997). According to Frazer and Lawley (2000), there are several ways to increase the response rate for questionnaires (Frazer and Lawley 2000). For instance, conducting pilot study upstream, sending self-addressed and stamped envelope or selecting the more relevant participant (Fowler 2013). For the study effort was made to select the potential participant by reading their LinkedIn profile and sending them a personalized email invitation to participate in the survey. The Table reporting the details of the 168 BIM professionals found with a relevant profile: their current position, their country of origin, and whether they completed the questionnaire or not, can be found in Appendix 2.

A total of 51 respondents filled the questionnaire. The goal was to have at least 50 completed questionnaires and achieve a response rate close to similar studies (e.g. Davies, 2010; Gustavsson, Samuelson and Wikforss, 2012), hence the target was achieved. The response rate corresponds to the number of completed questionnaire divided by the number of the potential respondents (Kviz 1977). A high response rate is usually viewed as desirable and an important criterion to judge the survey quality (Cook, Heath and Thompson, 2000; Shih and Xitao, 2008). It is also admitted that web survey response rates are considerably lower (11%) than other survey modes (Manfreda et al. 2008). The response rate of this study was about 46%, based on the number of completed questionnaires divided by the number sent out. According to various publications, in construction management research, a response rate of approximately 35% was considered as acceptable (Dulaimi et al. 2003, Hadzaman et al. 2015, Yu et al. 2013).

d. Pilot studies for questionnaires

As pointed out by Oppenheim (2000), questionnaire design must follow a lengthy process to make sure that they will "work" for the research and yield the data required (Oppenheim 2000). To be successful, they should be tried several times with several people. By doing that, they are improved and optimised to do the job expected for the research. This inevitable process is usually named "pilot work". The importance of the pilot study was also highlighted by Fellows and Liu (2015), who reported that before launching a questionnaire, the test should be done (Fellows and Liu 2015). For Sapsford and Jupp (1996), piloting is testing in a small-scale the questionnaire with the aim to eliminate potential problems (Sapsford and Jupp 1996). In total, four pilot studies, with construction practitioners using BIM, was carried out before emailing the questionnaire to the targeted population. The purpose of the pilot study was to test the clarity of the questions, the questionnaire length and the questions' order. Some questions were mandatory to be able to pursuit the questionnaire. So, it was also asked if it is acceptable. It is useful in refining the questionnaire, eliminating problems in answering and recording data, and enables the researcher to obtain the assessment on the validity of questions and reliability of data (Saunders et al. 2007). The feedback received enabled the improvement of the questionnaire. In our piloting process, we found that one question was not working properly and had to be redesigned. The wording of questions, in general, was reshaped to make each question easily understandable. The questionnaire length was considered as correct by the fourth respondents.

e. Data Analysis

The aim of analysing the data is to summarize it. The findings are then interpreted with the purpose to try to find answers to the research question. A descriptive statistical analysis and means comparison was performed. BOS, Excel and SPSS were used for the analysis. The responses of the questionnaire enable to identify the understanding and use of the various BIM dimensions. For the statistical analysis, tables and charts (bar and pie charts) are used.

C. Pre-Interview Questionnaire (PIQ)

a. PIQ rationale:

Some Authors, in different fields, have used the Pre-Interview Questionnaire and added the data as factual information (Galea et al. 2012). A pre-interview questionnaire can be use with the aim "to give time to the respondent to source the information required" and increase the reliability of data (Mccarron et al. 2013). The PIQ responses can also help the interviewer in focussing the interview questions (Amundsen and Mcalpine 2009).

For the research, the PIQ was designed to concentrate the interview on the topic, and a link was sent to the interviewees, where they were asked to fill the online questionnaire one week before the interview. The PIQ aims to complete the interview. It assisted in exploring the use of BIM and their awareness of European target related to C&D waste. It also helps to have an overview of the respondent awareness, knowledge and use of the design principles and their potential to reduce the impact of the buildings on the environment. The purpose of the PIQ should be clearly explained to the participant and is to obtain information on the interviewee before the interview.

b. The PIQ structure

The PIQ, split into four parts (Table 12), was designed in a way to add data to the interviews. After the consent form explaining the research briefly, explanation on why they have been selected and what they have to do were mentioned. The voluntary, withdrawal possibility and confidentiality were also addressed. A section explained the absence of risk by taking part in the study. A paragraph was also written explaining who has reviewed the study and to who complain if necessary. Respondents must agree on the terms and conditions before starting to fill the PIQ.

The link to access to the questionnaire was sent with the email containing the interview process; questions planned to be asked during the interview and the conceptual framework in PDF. It was requested to the participant to become acquainted with the framework and to add or remove what they wanted. The questionnaire was reachable over the same period than the interviews, from May 2018 to April 2019. Seventeen participants over twenty have respected the deal. The three missing was re-launch by email and during the interview. The questionnaire was designed, distributed and analysed with Bristol Online Survey (BOS).

The PIQ contains 18 questions Table 12. The first set of questions is the personal detail and their role in the company, years of experience and the asset phases that they are involved in. The company background is also questioned (size, what field the company is focused on, type of project the company work on). Their use of BIM and deconstruction were also assessed. Regarding BIM, questions were also targeting to assess their level of use (BIM level, data exchange and with which stakeholder). We also asked them if they were aware of the European Construction & Demolition Waste policies and if they have already implemented a Site Waste Management Plan. The last set of questions looked for their understanding and use of a list of design principles.

D. **Primary data: collection through Interviews**

As discussed in section 3.2, the research philosophy, the ontology and the epistemological position embraced for the study is pragmatism. Indeed, due to the study paradigm, subjectivist and objectivist views are used. The data were collected longitudinally, by using two techniques: online questionnaire and in-depth semi-structured interviews. The qualitative data have been collected through interviews was preceded by an online PIQ sent to the survey participants a few days before the interview. Both the PIQ and interviews comprised the dataset.

Table 12: Type of questions of the pre-interview questionnaire

Interviewee background	
Free text	Company name?
Free text	Current role?
Free text	Years of experience?
Multi-choice	Asset phase involved in?
Multi-choice	BIM experience?
Company background	
Multi-choice	Field focus on?
Multi-choice	Project type?
Multi-choice	Company sixe
Multi-choice	Company & BIM?
Multi-choice	Data embedded into the BIM Model?
Multi-choice	BIM Data excahnge?
Free text	With who?
Free text	Whcich format?
Construction and demolition waste strategies	
Multi-choice	European C&D waste policies awareness?
Multi-choice	Has the company already implemented SWMP?
Likert scale	The frequency of adoption of strategies?
Design principles	
Likert scale	How frequently do you use the following principles design?
Likert scale	Which principle is the most appropriate for deconstruction?

a. *Semi-structured Interview: the rationale*

A descriptive, interpretive study was undertaken to identify barriers for the integration of the SEOL into the asset lifecycle. There is no right or wrong methods choice, but the method selected must answer the research question. According to Rowley (2012:261), “interviews are generally used in conducting qualitative research, in which the researcher is interested in collecting “facts”, or gaining insights into or understanding of opinions, attitudes, experiences, processes, behaviours, or predictions”(Rowley 2012). Similarly, Gill et al. (2008:292) reported that “the purpose of research interview is to explore the views, experiences, beliefs and/or motivations of individuals on specific matters” (Gill et al. 2008). Interviews provide a deeper understanding of the phenomena (Silverman 2000). For this study, interviews are selected to collect data because the explored area is new. The researcher is looking for "facts", what are the barriers for the SEOL incorporation into the asset lifecycle?

Qualitative methods, such as interviews, are believed to provide a ‘deeper’ understanding of social phenomena than would be obtained from purely quantitative methods, such as questionnaires.

According to Moustakas (1994), descriptive, interpretive research uses dominantly two types of methods: in-depth interviews or Focus Group (Moustakas 1994). Descriptive, interpretive methodologies, based on the experiences of several people, aim to highlight the common ideas emerging. Individuals’ experiences about a phenomenon are thus better understood (Creswell, J. W. and Poth 2007). Holloway and Wheeler (1996) believe that interactions between researchers and the participants are crucial when a phenomenon is unwell conceptualized (Holloway and Wheeler 1996). Because the interviewees were very experienced and had huge responsibilities in their companies, it was difficult to group them and conduct Focus Group interviews, particularly for fifteen of them. Moreover, they were geographically in different countries and different towns sometimes separated by more than 1000km. Therefore, the use of individual interviews technique was selected.

By using interviews, this research aims to explore the experience of the interviewees that are, for the majority, national leaders in terms of sustainable buildings. The findings of the literature review were used to set up questions for the Pre-interview Questionnaire and the interviews. Interviews techniques were selected to investigate the impact of the incorporation of a SEOL into the asset lifecycle. Face-to-Face interviews and telephone interviews were conducted, with a total of 20 respondents. The level of structure of the interviews was “semi-structured”, and the type of interview was Guided open interviews.

The laddering technique was used by asking “Why?” to get more information from the participants. The laddering down or up techniques can be differentiated. The laddering up is used to expand out into new areas. Instead, the laddering down was used to focus down onto definite parts of the new areas. During the interviews, the researcher was brought to use both, particularly with respondent that were not very talkative.

b. Sampling: Convenient and snowballing

The sample was designed with the aim to have at least one of the main stakeholders involved during the asset lifecycle. Due to the background of the researcher (designer with 14 years in the industry) and the risk of bias, the designers are more numerous. This kind of bias associated with the researcher knowledge and understanding of the research areas was addressed by (Johnson, R. B. 1997). To remedy this, in addition to having chosen the technique of semi-structured interviews, the researcher has increased the number of designers in his sampling. The reason is also related to the importance of the role of the designer raised by several researchers (Chong and Hermreck 2010, Gorgolewski 2008, Sanchez and Haas 2018, Pomponi and Moncaster 2017).

The process of the interview participant selection is described in Figure 17. Two methods were used convenient and snowballing methods. The researcher and supervisor network was the main pool of selection. The interviewees were selected from France and the UK. A convenient sampling approach was used to identify participants, enabling the researcher to select individuals who met the specific criteria of the research. As stressed by Merriam (1998), convenient sampling allows researchers to select participants purposefully because they are considered information-rich for the research (Merriam 1998). Convenience sampling is a technique usually used in construction research (Oyedele 2013, Hodgson et al. 2011, Zahrizan et al. 2013, Akinade et al. 2018). Complementary to the researcher and supervisor network, sources such as LinkedIn or conference helped to find interviewees. As recommended by Burns et al. (2008), the snowballing method was also used to find interviewees. This technique enables the author to explore the existing links between the initial sample and other potential candidates, which are not easily approachable (Burns et al. 2008).

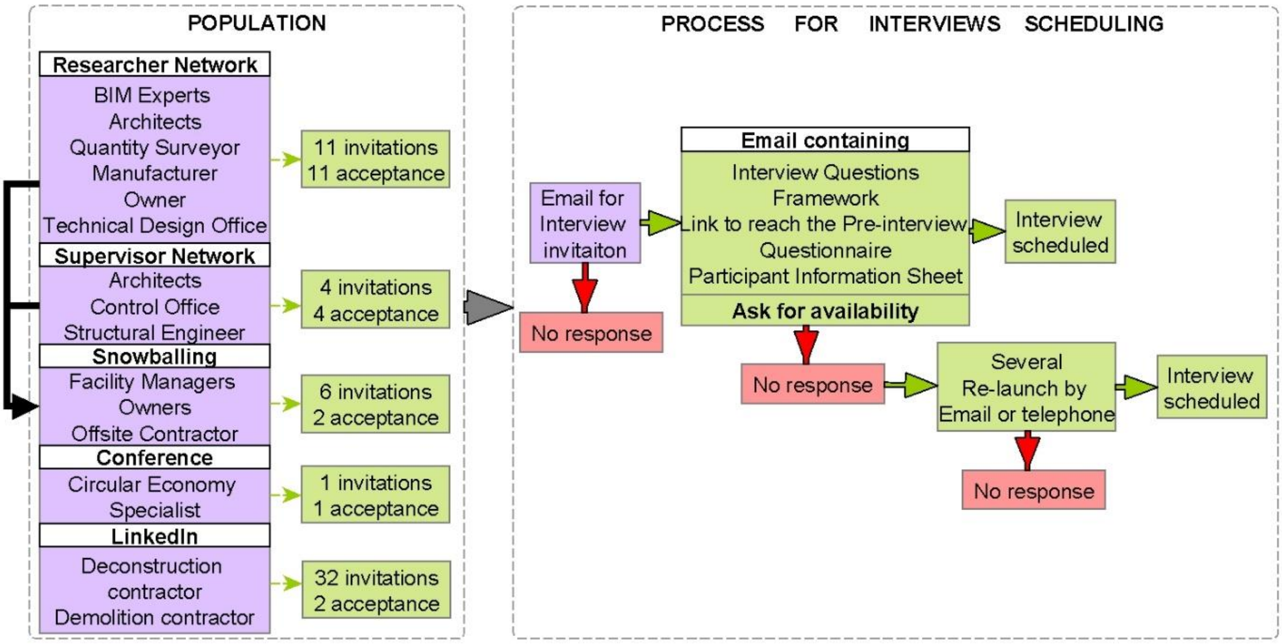


Figure 17: The sampling process of the interviews (Source: Author)

The stakeholders selected for the semi-structured interviews are those involved throughout the asset lifecycle, from programming phase to End-of-Life phase. In order to ensure a deeper understanding of the research topic, the participants were chosen based on their experience in sustainable approaches or in BIM. Indeed, sixteen interviewees over twenty have more than 10 years of experience (Chapter 4). Convenient sampling enables researchers to drive an effective understanding of the subject explored. It enables to highlight the participants' common meanings, based on their personal experiences. A wide range of perspective can be in-depth explored during a short period of time (Gray 2004). The researcher aim was also to get interviewees involved in several phases with at least one for each phase of the life cycle. Table 13 reports the stakeholders' role and companies' size, years of experience, the type of projects and phases involved in.

The researcher also targeted to seek people having worldwide experiences. Eight interviewees have worked in more than one country. Figure 18 shows the amplitude of the worldwide experience of the interviewees.

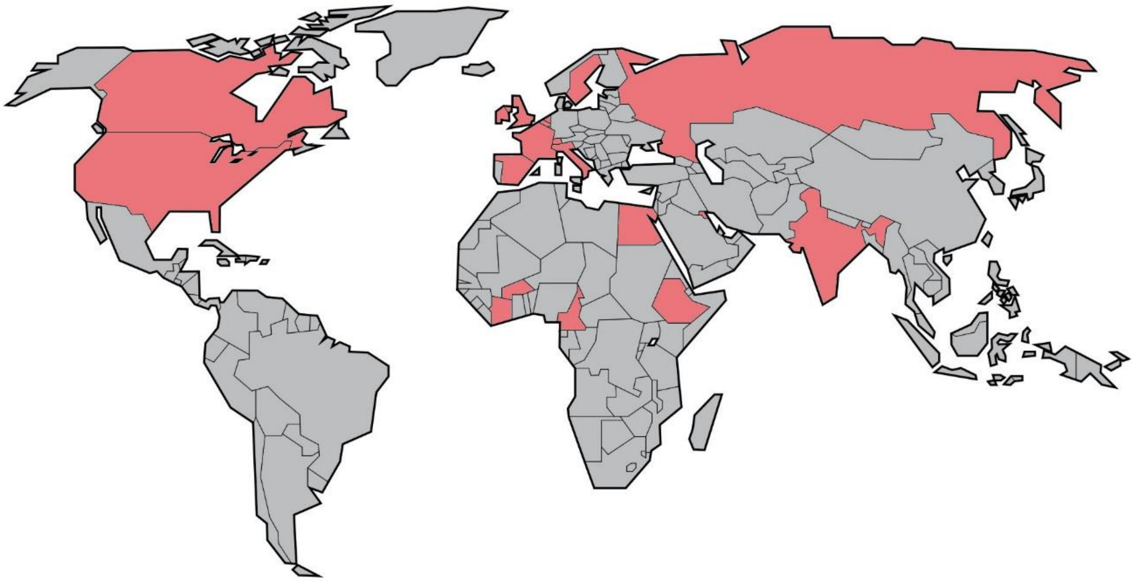


Figure 18: Interviewees worldwide experience (Source: Author)

a. Interviews schedules

The researcher faced issues to schedule interviews due to limited availability of the interviewees. To overcome this obstacle, the researcher decided to extend the time allocated to the data collection and to schedule some of them after office hours. It took ten months for the researcher to achieve twenty interviews.

b. Interview process

Seventeen interviewees have filled the pre-interview questionnaire before the interview. Two of them had filled when the interview was already completed. The last remaining did not fill it at all, despite several re-launch during the interview and after the interview, by e-mail. The collection of the data was done by conducting Face-to-Face interviews, in person or via Skype. Three interviews were performed by phone.

The dissemination of the interviews and their follow-up was done through two main documents. A first email, briefly explaining the research topic, and the duration of the interview was sent to potential participants. After their agreement, a second email containing the participation sheet, the questions, as well as the conceptual framework, were sent to the participants. The participants, in return, had to send a slot to schedule the interview. Due to the sampling and scope of the study, some interviews were performed in English and others in French. Some transcripts were made manually and some with the help of “trint”, an automated transcription tool that provides a collaborative platform for editing the audio contents. It converts the audio files into text automatically. It uses an automated speech-to-text algorithm to generate the transcripts. Despite their undeniable support, Automated Speech Recognition (ASR) transcripts contain a lot of errors. Therefore, the researcher must simultaneously listen and read them to improve the transcripts (Pan et al. 2017). Eighteen French transcripts were translated by the researcher in English. The process began with familiarization with the data by reading the transcripts several times in search of reoccurring patterns and issues. Despite the time-consuming aspect of transcription and translation, it helped the researcher to familiarize with the data. As highlighted by Bilal et al.(2016) familiarization of the researcher with the data is part of the process of searching for patterns and similarities (Bilal et al. 2016).

Table 13: Interviews Sample (Source: Author)

INTERVIEWS SAMPLE									
			Phases						
Respondent	Stakeholder	Company Size	Design	Construction	O&M	End-Of-Life	Project types	Exp.
R20	Project Manager (Engineer)/Owner	+100	x	x	x	x	R	18
R04	Engineering Office/Owner	0-5	x	x		x	R	20
R06	Architect	0-5	x	x		x	R – O	30
R07	Architect	21-50	x	x		x	R -H&L-O	15
R09	Architect	0-5	x	x			All types	30
R12	Architect	0-5	x	x	x		R-O-E	30
R16	Architect/BIM Manager	10-15	x	x	x	x	R-O	15
R18	Architect/Circular Economy specialist	0-5	x			x	All types	35
R03	Engineering Office	20	x	x			C - I	20
R08	Control Officer	+100	x	x		x	All types	30
R05	Research & Development	0-5	x	x			R	10
R11	BIM Manager/Quantity Surveyor	0-5	x	x			All types	8
R19	Structural Engineer	21-50	x	x			All types	7
R10	Digital Project Manager (Environmental Engineer)	+100	x	x	x	x	All types	15
R01	BIM Manager	21-50	x	x	x	x	H-E-R	10
R14	BIM Manager/Facility Manager	5-10	x	x	x	x	All types	10
R13	BIM Manager/Manufacturer	+100	x	x	x		All types	31
R02	BIM Manager/Facility Manager	21-50	x	x	x		C - I	37
R15	BIM Manager /Facility Manager	+100	x	x	x	x	All types	8
R17	Deconstruction Engineer	51-100				x	All types	8

Project type: *(R) Residential Buildings, (C) Commercial Buildings, (I) Industrial Buildings, (O) Office Buildings, (H) Health Buildings, (E) Education Buildings, (H&L) Hospitality and Leisure*
Company size *: (0-5) Employees, (6-20) Employees, (21-50) Employees, (51-100) Employees, (+100) Employees*
(Exp.): *Experience in years*

Before each interview, it was explained that the session would be recorded.Interviews' transcripts were recorded with two devices, by security. Then, the recordings were transcripted words-by-words and sent to the interviewees for validation.

c. Duration of the interview

It was established that the duration of each interview would be at least 1 hour. To focus during the interview to the core of the research, a pre-interview questionnaire was set up to gather the information about the company, role of the participant and their use and understanding of the design approaches for environmental impact minimization. Only one interview was less than one hour. In total, the researcher gathered more than 22 hours of interviews (Table 14).

Table 14: Semi-Structured Interviews: Location, Technique and Duration

SN	Location of the Interviewee	Date	Technique	Duration
R01	France	25/06/2018	Skype	1 hour 18 minutes
R02	France	28/06/2018	In Person	1 hour 16 minutes
R03	France	28/06/2018	In Person	1 hour 16 minutes
R04	France	02/07/2018	In Person	1 hour 00 minutes
R05	France	02/07/2018	In Person	1 hour 15 minutes
R06	France	04/07/2018	In Person	0hour 53 minutes
R07	France	09/07/2018	In Person	1hour 19 minutes
R08	France	10/07/2018	In Person	1 hour 30 minutes
R09	United Kingdom	31/08/2018	In Person	1 hour 20 minutes
R10	France	04/09/2018	Skype	1 hour 25 minutes
R11	France	14/09/2018	Skype	0 hour 55 minutes
R12	France	17/09/2018	Skype	1 hour 29 minutes
R13	France	30/11/2018	Skype	1 hour 35 minutes
R15	United Kingdom	05/12/2018	In Person	0 hour 52 minutes
R14	Spain	12/12/2018	Skype	1 hour 00 minutes
R17	France	13/02/2019	Telephone	0 hour 37 minutes
R16	France	04/02/2019	Telephone	0 hour 45 minutes
R18	Belgium	15/02/2019	Skype	1 hour 00 minutes
R19	France	07/03/2019	Skype	1 hour 20 minutes
R20	France	05/04/2019	Telephone	1 hour 37 minutes

d. Questions for Interviews

The interviews questions were structured in four parts, starting with general questions, as detailed in Table 15. In total, twenty-two questions were asked for a duration ranging from 37 minutes to one hour and 37 minutes.

Based on Hannabuss, (1996), probed questions could be used to obtain in-depth information or when the responses were not fully understood during the interview. When seeking more details, probes questions technique was used. It can be used for clarification, specify the purpose of the statement, for seeking completeness and accuracy, asking for examples to illustrate the interviewee's statement or seeking to extend the response. Probes questions were also used to get the evaluation of the interviewees about a statement, situation or project. Permissions to record the interviewee was asked twice, by email and before starting the interview. The interviews were recorded to assist the researcher for the analysis and to ensure accuracy and objectivity (Fellows and Liu 2015). The interviews were conducted from June 2018 to April 2019.

Regarding the questions listed in Table 15, they were asked to each interviewee. But due to the variety of stakeholders, the questions were used as a basis and were adapted to the role of the respondent. The questions listed in Table 15 were designed for the stakeholders having a design background. However, for the manufacturer, the owners, the deconstruction engineer and the Circular Economy specialist, the researcher has adapted the questions. The question modification was raised by King (2004) , (Miles and Huberman 1994) who said that in semi-structured interviews, the researcher uses the questions that may vary from interview to interview. For this research, the sample was designed progressively as the data collection progressed.

Therefore that means that the first round of interviews was performed, analysed, and another round of field data collection started. These enabled the researcher to adapt a bit the questions to cover some grey area that appeared after the coding of the first round transcripts. “There will be instances of missing or unclear data, and of unanswered research questions: these provide the targets for the next round of data collection” (Miles and Huberman 1994) p.84. Figure 19 describes the process of data collection.

e. Pilot studies for Pre-interview Questionnaire and interviews

Regarding the interviews, among the three types of piloting described by Forza (2002), the researcher opted to conduct peer review technique (Forza 2002). Indeed, in-house peer reviews were easier to set up rather than focus group discussion or cognitive interview, the two other piloting techniques.

For the interview questions and pre-interview questions, several pilot interviews were conducted with researchers at the Centre for Research in the Built and Natural Environment at Coventry University. The aim was to test the audio recording devices, the length of the interview and its understanding by the interviewees. In the meantime, the PIQ understanding and length was also tested. Clarity of the questions and length were the main considerations to take into account to improve the questions. Some questions were removed, and the ambiguity of others was eliminated (Kvale and Brinkmann 2009).

Table 15: Questions for the semi-structured interviews (Source: Author)

		Questions
General	**1**	What does **Deconstruction and Design for Deconstruction (DfD) or Design for Disassembly** mean to you?
	2	Have you already used or **worked with a client using** the "Deconstruction" or "Design for Deconstruction" or "Design for Disassembly" principles?
	3	What do you think about **replacing Demolition by a sustainable End-of-Life**?
	4	What **main changes** should be made to **improve the asset's deconstructability**?
A new Asset lifecycle: From design to a Sustainable EOL	**5a**	What are the **main impacts of adding a sustainable EOL (such as Deconstruction)** phase into the asset lifecycle on the following stages: programming, design, construction, in use?
	5b	Which **phases are mostly affected** by adding a sustainable EOL phase into the asset Lifecycle? Why?
	6	What are the **main impacts of adding a sustainable EOL (such as Deconstruction)** phase into the asset lifecycle on the relationships between the stakeholders involved in a project with a sustainable EOL?
	7	What are the **mains changes in roles and responsibilities** of the stakeholders involved in a project based on the sustainable asset EOL concept?
	8	Does it affect the **designer's creativity**?
	9	Does it affect the **project duration and cost**?
	10a	What are the **barriers for incorporating a sustainable EOL phase** into the asset lifecycle?
	10b	How can these **barriers be overcome**?
Use of BIM for the new Asset	**11**	How the **use of BIM can help** for the integration of a sustainable EOL phase into the asset lifecycle?
	12	What would be the **main barriers for using BIM** throughout the new asset lifecycle (from design to EOL management)?
	13	How can these **barriers be overcome**?
	14	What **data should be embedded into the Model** for an effective sustainable EOL management to avoid landfilling?
	15	Does it impact the **duration and cost of the project**? Why?
	16	How can we **improve the Framework? (Boxes and links between them)**?
Reclaimed materials	**17**	Does your company already deal with **salvaged material**? If yes, how?
	18	What are the **barriers to the use** of reclaimed components?
	19	What would be the main **barriers and barriers for the market for reclaimed components**?
	20	Hou can these **barriers be overcome**?
	21	Who are the **key players** for the use of reclaimed components?
	22	What **kind of data is needed** for using reclaimed materials?

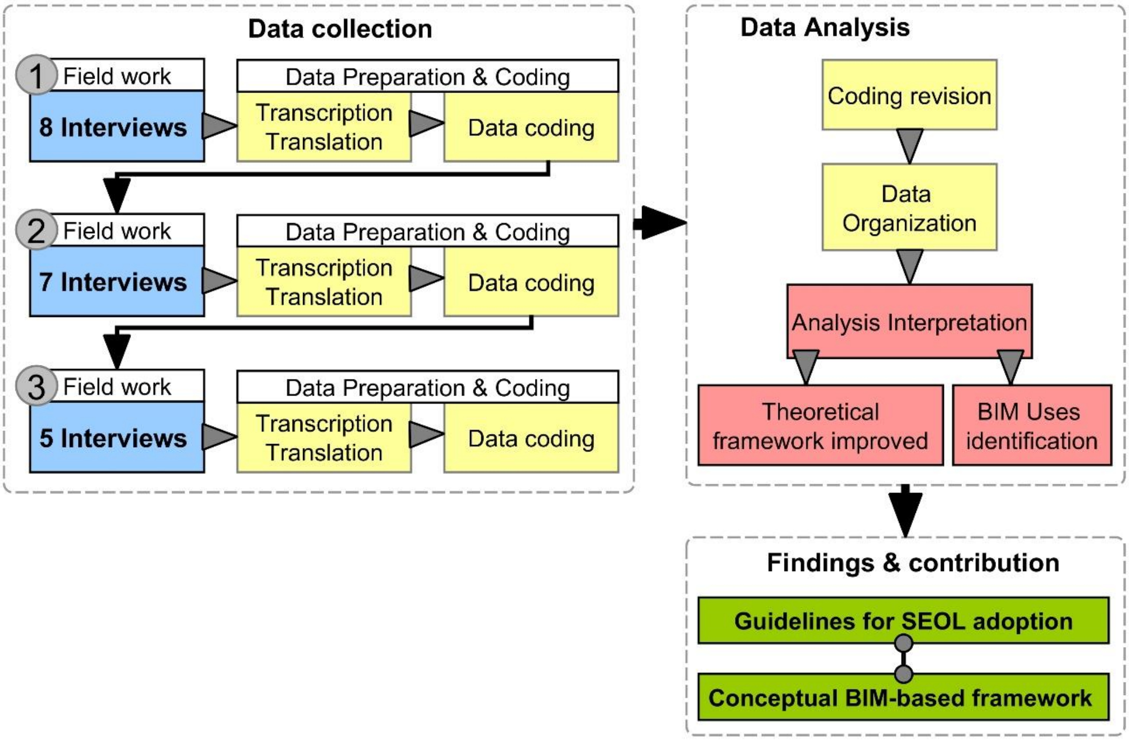


Figure 19: Data collection process (Source: Author)

f. Data analysis method

According to Easterby-Smith et al. (2012), the language-based data analysis can be classified into six main systems (Easterby-Smith et al. 2012). In Table 16 are listed the various types of analysis of the data, including the Computer Aided Qualitative Data Analysis (CAQDAS). For the research, the data was collected through recording. So the first step was to “digitize” the data. It was made in a naturalistic fashion instead of de-naturalistic to stick perfectly with the respondent thought by including every utterance and slightest details.

For the study, the researcher has used the content analysis and discourse analysis techniques supported by the use of NVivo. The software package was selected based on the researcher aim that was looking for themes that will emerge from the data. The researcher's will was to conceptualize and order the data based on themes. Interviews’ transcripts were coded, starting with ideas got from the literature review. Following the coding, themes and sub-themes emerged. So finally, it was decided to use NVivo, a "code-based" software. The types of language-based analysis used for the research are in grey in Table 16.

Figure 20 explains the cyclical process of coding and qualitative analysis of the data. The initial codes were set up manually. First, the author spent time on the data by starting to read the first transcript freely before starting to code. The idea was to read the data without any biasing or assumptions. During the first reading process, important ideas were highlighted.

Table 16 Types of language-based data analysis (Source: from Easterby-Smith et al., 2012), in grey the types used in this research

	Type of language-based data analysis
Content Analysis	Coding technique: Start with ideas about themes and look for them in the collected data.
Grounded Analysis	Similar technique for coding as "content Analysis". The difference is that there is no start with a defined point. The data can 'speak for itself': Themes emerge from the discussion. Themes can also be updated in the course of the research.
Social network analysis	To understand what motivates human's behaviour, links between individuals are examined.
Discourse analysis	Conversations are analysed by taking into account the social context in which the interview is undertaken. It can include analysis of written sources (emails, letters) and body language. Complete the words said with their surrounding data.
Narrative analysis	To understand the way individuals think, we look at the way stories are told. Four types of narrative: · Bureaucratic: highly structured and logical · Quest: the ambition is to have the most compelling story · Chaos: when the story is lived and not told. · Postmodern: the narrator is aware of the story
Conversation analysis	Used in ethnographic research. Conversations are governed by rules and patterns, regardless of who is speaking.
Computer Aided Qualitative Data Analysis (CAQDAS)	A software package that can be used for data analysis: NVivo, ATLAS. Ti, HyperRESEARCH, WordSmith. They help to structure and manage a large amount of data.

Then, a table was created, integrating all the important ideas collected from the three transcripts. Ideas were grouped and classified into (themes also called categories) codes and sub-codes, based on the themes found in the literature review. This classification are used for a cluster of two transcripts. Then these initial codes were revised to accommodate various perspectives in the analysis. The aim was to revise these initials codes constantly. After, finals codes structure was set up. Ultimately, the final codes were applied to all the transcripts by using NVivo. In the end, a comprehensive, fully coded set of narrative data is obtained.

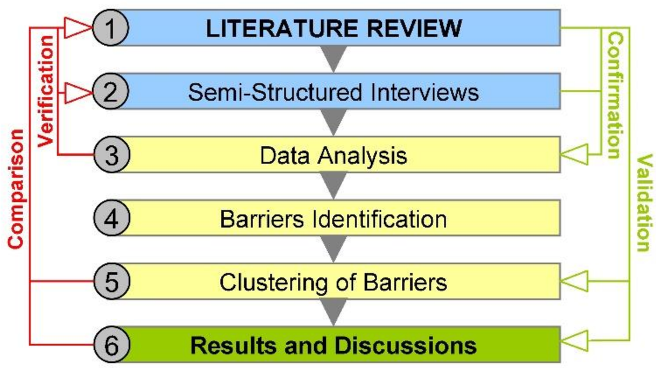


Figure 20: The cyclical Research process for qualitative data collected (Source: Author)

Then, the data can be analysed at some more complex levels. As recommended in the literature, the aim was to target a maximum of 8-10 codes containing themselves sub-codes and sub-sub-codes (Elliott 2018). Even if a lot of authors alert researchers on the risk to have too many codes (Creswell, J. W. 2015, Richards 2014), Saldaña (2013:24) reported that "the final number of major themes or concepts should be held to a minimum… but there is no standardized or magic number to achieve" (Saldaña 2013).

After the creation of the codes, NVivo software was used to support the analytic process of transcripts coding. The coding process was done with this question in mind and by focussing on the analysis. We allowed us to be flexible in refining the code structure. A constant comparative method was used, consisting of applying a working process "back and forth" between the emerging data and the code structure set up. This is to make sure that all the data is accommodated within the codes.

As reported by several authors, the use of software, such as NVivo enhances the rigour of qualitative data analysis (Bazeley and Jackson, K. 2013, Lewins and Silver 2007). The analysis also followed the two steps process approach used by (Dransfield et al. 2004): Firstly, interviews transcript are coded and categorised into parents codes. Secondly, the researcher runs for each parent codes, a word frequency analysis enabling to unearth the underlying contexts. This approach is also supported by (Ryan and Russell Bernard 2003) qualifying the word frequency analysis as the most efficient method for texts' embedded themes discovery.

The clustering step compares the results got from the qualitative data with the results get from the literature review. Gibbs (2002) termed this step "pattern matching" and stated that "(…)strong support is given to the validity of results when two patterns coincide" (Gibbs 2002) P.158. A few years later, this statement was supported by Uprichard (2009), saying that the cluster analysis can provide "cross-validation" to researchers (Uprichard 2009). According to Bazeley and Richards (2000), the ideas generated from the interviews' transcripts could be classified in tree organized in three levels: Coat hanger, parent node and child node (Figure 21) (Bazeley and Richarfs 2000).

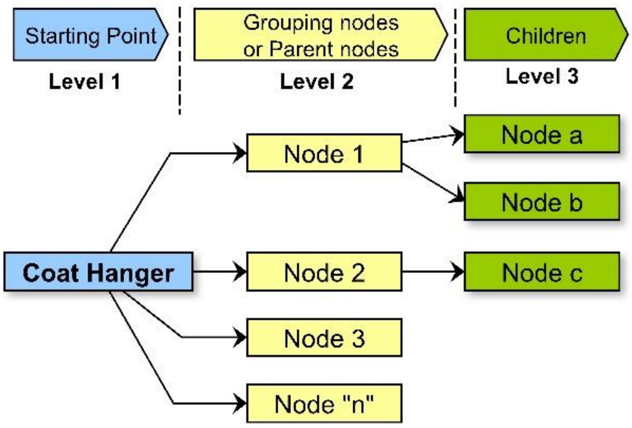


Figure 21: Logical tree organization of nodes from qualitative data (Source: Author)

3.4.3 Time horizon

During the research design, a time horizon should be chosen according to the aim and objectives of the research. There are two types, cross-sectional and longitudinal research. The cross-sectional research also refers to “snapshot” time horizon study, a particular phenomenon that is taking place in a particular time and often employ the survey strategy. Oppositely, longitudinal researches refer to “diary” perspective and study change and development (Saunders et al. 2016). In this study, a cross-sectional time horizon was selected.

3.4.4 Unit of analysis and unit of observation

According to Trochim and Donnelly (2008), “the unit of analysis is the major entity that is analysed in a study”. The unit of analysis is the “who” or “what” that has to be analysed for the study. Defining the unit of analysis and unit of observation are crucial because they put boundaries for the research and the data analysis. The definition of the unit of analysis is required before starting to analyse the data (Trochim and Donnelly 2008).

Various categories of a unit of analysis were reported by (Bless et al. 2006). For Hopkins (1982), the unit of the study refers “to the major entity that would be explored or analysed in a study”(Hopkins 1982). To avoid ecological and exception fallacies, the unit of analysis must be appropriate to the study. The unit of analysis could also be a focus on one characteristic of the population involved in the survey.

For the research, the data is taken on the barriers for the integration of the SEOL into the asset lifecycle. The unit of analysis of the research is a social artefact: the incorporation of the SEOL into the asset lifecycle. And the unit of observation is the AEC stakeholders involved in eco-friendly construction projects. In this study, the unit of analysis and unit of observation are different because the target of the investigation is to cover the stakeholders involved in all the asset lifecycle and not only the stakeholders involved in the EOL phase.

3.5 Validation and data quality

Several authors have attempted to give clarity for all the criterion that revolve around the quality of the data. According to Lincoln and Guba (1985), there are several criteria that are specifically used for quantitative research, such as "internal validity," "external validity," "generalizability," and "objectivity”. Instead, for qualitative research, different terms are used such as, "credibility," "transferability," "dependability," and "confirmability" (Lincoln and Guba 1985) or "validation" (Angen 2000).

3.5.1 Trust, credibility and cultural reflexivity:

To set up trust and credibility**,** the researcher designs the cover letter presenting the survey and the sponsorship (Saunders et al. 2016). In this research, there was no trust and confidence concern with participants. Indeed, the purposive snowball sampling technique was used. Due to the relationships with the interviewees, they were comfortable to exchange freely. Despite this and to address the Ethical requirement, a "Participant Information Sheet", detailed in section 3.6, explaining the research was sent to the participants.

The cultural reflexivity is also a parameter pointed out by Court and Abbas (2013) that should be taken into account by the researcher (Court and Abbas 2013). For the study, the interviewee's cultural background is French or British. The researcher was familiar with both, and there were none acceptance issues. The interviewer has used her personal network and the supervisor personal network for the sampling. Therefore, he already knew most of the interviewees. There were some cultural differences that affected the topic discussed with the interviewees. In effect, the construction process in France and in the UK has some differences, discussed in Chapter 4, section 4.2.

3.5.2 Reliability and validity for qualitative research

A. **Reliability**

One of the criteria to measure the quality of research is its reliability, referring to its consistency and its capacity to be replicable. Research is considered reliable if the process could be replicable, and the finding would be the same. Other authors claim that reliability refers to the degree of consistency (Hammersley 2013), or the instrument dependability to measure adequately (Long and Johnson, M. 2000). For instance, trustworthiness and authenticity criteria were developed by Guba and Lincoln (Lincoln and Guba 1985, Guba and Lincoln 1989). For the authenticity criteria, participants are considered as "co-constructors of learning moves toward transformation and change". Erlandson et al. (1993) stressed that both, the trustworthiness and authenticity criteria should be used in the same study (Erlandson et al. 1993). Reliability is a very important parameter for judging the quality of the research, but it is not sufficient.

B. **Validity**

The other criteria to measure the quality of the research is the validity criterion aiming to ensure the reliability of the findings. For Punch (2013), the assessment of validity refers to the ability to research tools to well measure the phenomenon under investigation (Punch 2013). According to Patton (2003), validity *"enhances the research understanding by strengthening confidence in the research findings"* (Patton 2003). Indeed, validity refers to the accuracy of the results' analysis and the suitability of the measurements used. The generalization of the findings is also a parameter important for assessing the validity of the research (Saunders et al. 2016).

C. How to measure validity and reliability?

Onwuegbuzie and Leech (2005) reported several techniques stressed by Creswell (1998) for assessing the auditability or credibility of qualitative research, such as “triangulation, prolonged engagement, persistent observation, leaving an audit trail**,** member checking, weighting the evidence, checking for representativeness of sources of data, checking for researcher effects, making contrasts/comparisons, checking the meaning of outliers, using extreme cases, ruling out spurious relations, replicating a finding, assessing rival explanations, looking for negative evidence, obtaining feedback from informants, peer debriefing, clarifying researcher bias and thick description”(Creswell, J. W. 1998, Onwuegbuzie and Leech 2005). According to Guest et al. (2012), to ensure the adequate exploration of a phenomenon, internal and external validity should be combined (Guest et al. 2012). The data from the semi-structured interviews were combined with results from an extensive literature review to enhance the overall credibility of this study.

Three parameters should be considered to assess the validity of the research. First, the measurement validity linked with several types of validity (construct validity, content validity and predictive validity) was considered. The second and third aspects are internal and external validity. According to Saunders et al. (2016), “Measurement validity” is another term for “internal validity” (Saunders et al. 2016). They consider reliability as validity, is also declined in two types: internal and external reliability. Validation of the research means that the researcher undertakes a process to verify the data, analysis and interpretation. There are two ways for the validation of the data: triangulation and participant validation**.** Another parameter, the transferability and generalizability can also be used for assessing the quality of research (Onwuegbuzie et al. 2012, Lincoln and Guba 1985).

On the other hand, Long and Johnson (2000) advised interpretive researchers to avoid hiding behind quantities of synonyms. He suggested accepting the fact that reliability cannot be demonstrated for qualitative data (Long and Johnson, M. 2000). In fact, according to several authors, validity measurements are seen as inappropriate for qualitative research for which the research philosophy is subjective (Saunders et al. 2016). Thereof, researchers will face problems to give evidence for the quality and credibility of their research. The intention of using in-depth interviews is not necessarily replicability. Indeed, they are conducted at a specific time and in a situation that might change. So, they reflect a relative reality at the time where the interviews were conducted.

To overcome the inherent lack of validity highlighted by to the previous authors, Saunders et al.(2016:399), suggested showing that the findings are dependable and obtained after a rigorous design**.** Detailed explanations of the data collection process would also help to overcome the lack of reliability and dependability derived from the use of in-depth or semi-structured interviews. “Therefore, an attempt to ensure that qualitative, non-standardised research could be replicated by other researchers would not be realistic or feasible without undermining the strength of this type of research” (Saunders et al. 2016).

According to Lincoln & Guba (1985), the terms Validity and Reliability are an essential criterion for quantitative research but are not adapted for qualitative research. For assessing the quality, they prefer to use the terms Credibility, Neutrality or Confirmability, Consistency or Dependability and Applicability or Transferability (Lincoln and Guba 1985). For Seale (1999), instead of discussing validity and reliability, the author reported that examination of trustworthiness is essential to qualitative research. According to Creswell & Miller (2000) “the validity is affected by the researcher’s perception of validity in the study and his/her choice of paradigm assumption. As a result, many researchers have developed their own concepts of validity and have often generated or adopted what they consider to be more appropriate terms, such as, quality, rigour and trustworthiness (Lincoln and Guba 1985, Davies, D. and Dodd 2002, Mishler 2000, Seale 1999, Stenbacka 2001). Stenbacka (2001) argues that the concept of validity is not adapted to qualitative research and should be redefined (Stenbacka 2001).

From the foregoing discussion, the validity and reliability of qualitative research is still a hot topic where researchers disagree. Golafshani (2003) reported that "reliability and validity are conceptualized as trustworthiness, rigour and quality in qualitative paradigm" (Golafshani 2003). For this research, the terms rigour, quality, transparency are considered the keywords to enable the reader to trace the research process (Roberts et al. 2006).

D. Rigour for the research design

a. Interviewees selection: worldwide experience

For the sampling, as stressed by Merriam (1998), convenient sampling allows researchers to select participants purposefully because they are considered information–rich for the research (Merriam 1998). Convenience sampling is a technique usually used in construction research (Oyedele 2013, Hodgson et al. 2011, Zahrizan et al. 2013, Akinade et al. 2018). The researcher targeted to seek very experienced participants and considered as experts in their area. The researcher also targeted to seek people having worldwide experiences. Eight interviewees have worked in more than one country. Figure 18 shows the amplitude of the worldwide experience of the interviewees. This is an important point for the transferability and generalizability of the findings. And, as reported by several authors, the transferability and generalizability can also be used for assessing the quality of research (Onwuegbuzie et al. 2012) (Lincoln and Guba 1985). The transferability was also sought by selecting the main stakeholders involved during the asset lifecycle.

b. Selection of appropriate space for the interviews

Saunders et al. (2016), listed several traits to increase the validity of qualitative research. Participants and researcher errors / bias were avoided as maximum by selecting appropriate space for the interviews. Indeed, for the face to face interviews, they were all conducted in a closed office (Saunders et al. 2016) p.203. For the interviews done by phone, the interviews were conducted without any disturbance. For each interview, whether by Skype or phone, a meeting room was booked at the University, and the interviews were conducted rigorously. However, for three interviews, the location was less appropriate, but it did not affect the flow of the interview. One interview was very challenging because the interviewee, after many relaunches (over more than 3 months), had accepted to be interviewed, but he was a car passenger.

c. Record and transcription

Reliability can be achieved by using tools for recording and transcribing and ensuring accuracy during both processes (Roberts et al. 2006). As recommended by Roberts et al. (2006), each interview was recorded with two devices checked before the interview. Then, each interview was rigorously transcripted word-for-word. During the data analysis process, several steps were followed: reading the transcript, coding, themes and sub-themes identification. Reading the findings and then back the transcripts to make sure that no unintentional distortion appeared. Some transcripts were made manually and some with the help of “trint”, an automated transcription tool that provides a collaborative platform for editing the audio contents. Despite their undeniable support, the transcripts contained some errors. Therefore, the researcher simultaneously listened and read them to improve their quality (Pan et al. 2017). Despite the time-consuming aspect of transcription and translation, it helped the researcher to familiarize with the data. As highlighted by Bilal et al. (2016) familiarization of the researcher with the data is part of the process of searching for patterns and similarities (Bilal et al. 2016).

d. Support for interviews

For this research, it was not possible to be supported by another interviewer as suggested by (Saunders et al. 2016) for all the interviews. The researcher was able to be supported by another interviewer for only three interviews. Furthermore, the researcher made sure to develop a research design following the eight steps recommended by Creswell (2014) for the coding process (Creswell, J. W. 2014).

e. Validation process

For this study, the researcher followed six steps for the qualitative data collection, analysis and interpretation. The validation process was split into 8 steps, reported in Figure 22. The importance of checking the data was also pointed out by Miles and Huberman (1984); the validity of the data collected must be checked (Miles. and Huberman 1984). The keyword for qualitative research is “transparency” to enable the reader to trace the research process, whether the context, methodology and analysis (Roberts et al. 2006). To be in line with this recommendation, Figure 22 explains the coding process and data validation and verification (in green).

f. Researcher bias

One difficulty expressed by (Johnson, R. B. 1997) is associated with the researcher bias, especially during the analysis and interpretation process. Indeed he believes that researchers that are familiar with the field may fail to identify certain subtleties, such as nuances and ambiguities, due to his well understanding of the research topic. He added that being familiar with the research topic could be both advantageous and unfavourable. This was mitigated by other authors who claimed the impossibility to have complete objectivity in the research process (Guba and Lincoln 1981). Despite this, to avoid this situation, the researcher used semi-structured interview techniques to frame the interview. She also, due to his design background has decided to increase the number of interviewees having a designer background. Although bracketing is often difficult, if not impossible, to achieve, the credibility of findings is increased if researchers make explicit their presuppositions and acknowledge their subjective judgement (Ashworth 1997).

E. **Internal validity**

According to Saunders et al.(2016), internal reliability refers to ensuring consistency during a research project (Saunders et al. 2016). Based on Long and Johnson (2000) recommendations, the researcher has used several techniques to ensure the internal validity of the research.

a. Pilot studies

Pilot studies are also recommended by several authors to increase the validity of qualitative data (van Teijlingen and Hundley 2002, Bartlett 2014, Steiner et al. 2016). For instance, the consistency of the research design is to conduct pilot studies before data collection. According to Sapsford and Jupp (1996), piloting is a small trial before the real investigation aiming to assess the adequacy of the research design (Sapsford and Jupp 1996). A few years later, Saunders et al.(2007), stated that piloting enables the researcher to check the quality of the questionnaire understanding and design. This gave researchers the assessment on the validity of questions and reliability of data (Saunders et al. 2007).

For the research, four pilot studies were conducted. Indeed, the pilots' studies ensure the questions' understanding and are manners to assure the validity and relevance of the interviews' answers. At the end of the piloting, the two questionnaires were drastically improved and more understandable.

Qualitative data analysis is also a stage where the research reliability could be increased. Indeed, some authors believe that the reliability of the data could be gravely weakened during the transcription, coding and sorting phase (Silverman 2013, Bryman 2004, Marshall and Rossman 2016) . In response to this weakness, the research has recorded the interviews and has used an automated transcription tool, "trint", that provides a collaborative platform for editing the audio contents.

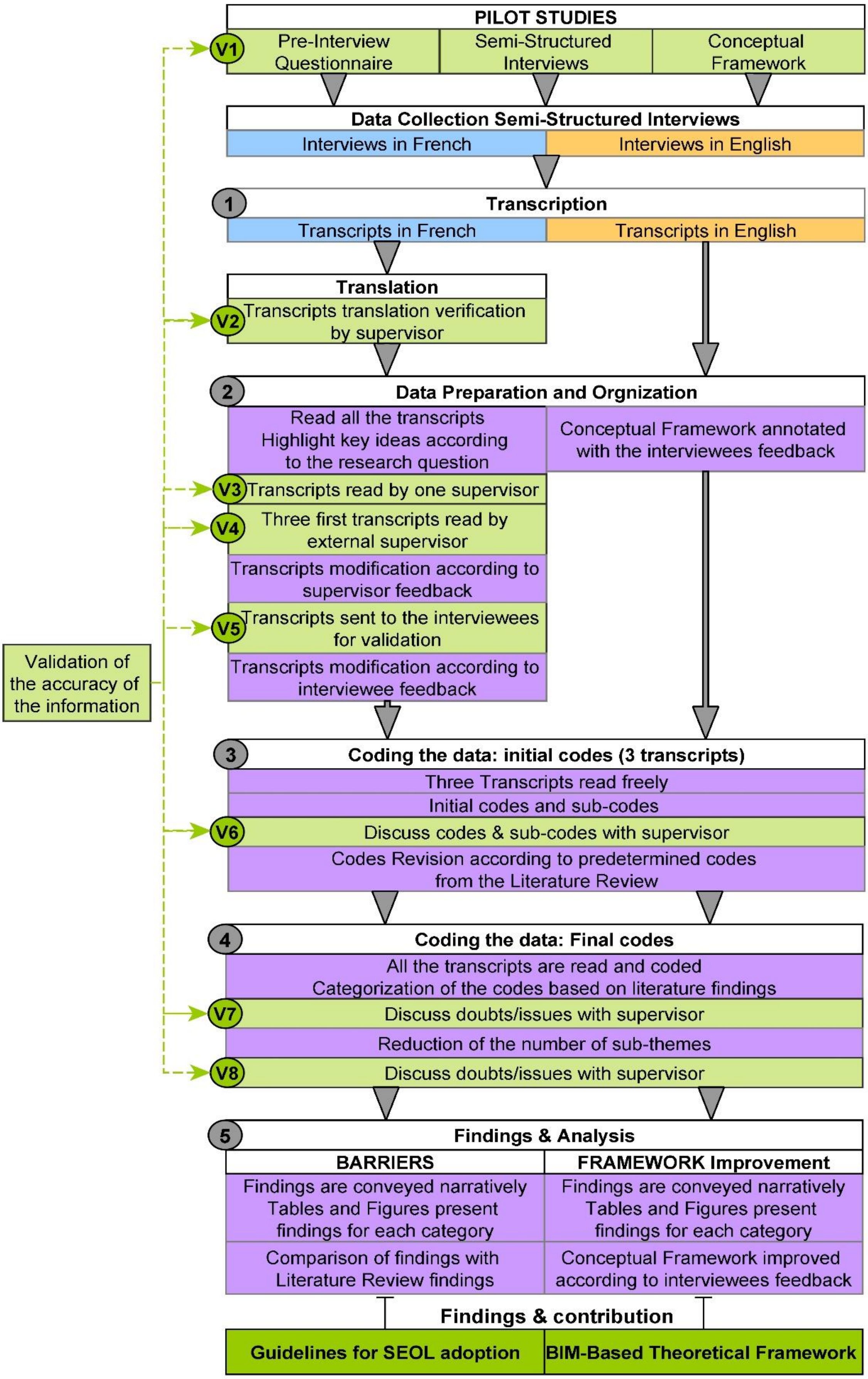


Figure 22: Data process: collection, treatment and validation (Source: Author)

The codes used were defined based on the literature review. Boyatzis (1998) warns about the risk of biases to use prior data and research for the development of codes (Boyatzis 1998) p. 37. The data which the researcher was looking for was barriers for the incorporation of a SEOL into the asset lifecycle and the improvement of the BIM-Based Framework. The six categories of barriers found in the literature review were used as a basis to structure the codes emerging from the interviews data. Several round-trips were done.

b. Peer debriefing

As recommended by Lincoln and Guba (2009), peer review was undertaken to search evidence of inconsistency (Lincoln and Guba 2009). The relevancy of the codes was checked by discussing each difficulty with supervisors or colleagues, as suggested by Miles and Huberman (1984). They said: "clear operational definitions are indispensable", whether or not you are thinking of using them as a way of testing reliability (Miles and Huberman 1984) p.63. According to these authors, codes definition might be another way to either increase reliability or to improve the validity and credibility of the research as a whole.

According to Harding (2018), the accuracy of findings could be checked by following several measures. A colleague, familiar with the subject, could also read the transcripts and the findings. In this study, the supervisor read the transcripts and the findings. During the coding process and the themes identifications, all doubts from the researcher about codes or themes were discussed with the supervisor (Harding 2018).

c. Participants' data collected validation

As recommended by Long and Johnson (2000), the validation technique selected for the study was validation performed by the interviewees (Long and Johnson, M. 2000). At the end of each interview, the interviewer told the respondent on the process of transcription and agreed that the transcript must be validated by them. They would have, at that time, the opportunity to add or remove whatever they want and confirm the accuracy (Cayla and Arnould 2013). As recommended by Miles and Huberman (1994), all the transcripts were validated by the interviewees by email or verbally by phone (Miles and Huberman 1994) .The researcher gets three validation with a comment, some grammatical corrections. The others have sent back an e-mail for approval without mentioning any comment or agreed by phone for the content. Despite several attempts, the researcher struggles to get a response from two respondents. According to Glesne (2016), to increase the validity of finding is to involve the participants for giving feedback on the data collected (Glesne 2006).

d. Data analysis

Another way to increase the reliability of qualitative data is the way used to analyse the content of the data. Indeed having a qualitative content analysis is a reliable approach to handling data. The creation of codes aims to describe the data. Reliability can also be improved by moving backwards and forwards between the data and the researcher interpretation (Roberts et al. 2006). According to Roberts and Woods (2000), the use of computerised data analysis packages such as Nvivo can enhance reliability by applying the rules built into the programme (Robson 1994, Roberts and Woods 2000). Table 17 is a summary of the validation process used.

Table 17: Reliability and Validity of the study (Source: Author)

Criterion		Techniques used to achieve each criterion
	INTERNAL Validity	
	Research Design	Questions adaptations/stakeholders
	Research Design	Pilot studies
Trust & Confidence	Research Design	Participant Information Sheet sent to the interviewees
	Research Design	Rigorous design and detailed explainations of data collection process
Credibility	Research Design	Research design: 8 steps recommended by Creswell
Reliability	Detailed Data Collection	Consistency during the data collection and the analysis was very important for the researcher (Figure 22)
Dependability	Detailed Data	Rigorous design and detailed explainations of data collection process
Cultural reflexibility	Sampling	Participant from UK & France
	Data validity	Interview recording
	Data validity	Accurate transcription
	Data validity	Supervisor validation
	Data checking	Use of reflection: The transcripts were read and discussed with one of the supervisors
	Data checking	Checking the data with participants
Adequately	Data checking	Data quality was checked by peer debriefing
	Data Analysis	Data Analysis: code based on the Literature Review
Credibility	Multi-Data Source	Data from interviews combined with Literature Review findings
Credibility	Multi-Data Source	Triangulation
	EXTERNAL Validity	
	Research Design	Full rigorous description of the research question, sub-questions, the description of
Generalization, Transferability	Sampling	Authentic sampling strategy: Purposive snowball sample
Generalization, Transferability	Sampling	Participant have worked in different countries
Generalization, Transferability	Sampling	Several stakeholders
Generalization, Transferability	Sampling	Stakeholders have worked on different types of project
Generalization, Transferability	Sampling	Existing buildings and new buildings
Generalization, Transferability	Sampling	Well experienced participants
Dependability	Data validity	Checking the data with participants
Validity	Data validity	Appropriate space for conductiong the interviews
	CONSTRUCT Validity	
	Data checking	Data collected from several sources: Triangulation
Objectivity	Ojectivity	Researcher familiar with the research topic: bias avoided by having several designers

3.6 Ethical issues

The research philosophy is pragmatism using Mixed Methods employing qualitative and quantitative data collection strategies. Both involve human participants leading to consider the ethical aspects. Indeed, as reported by Saunders (2016:220), “ethics are critical aspects for the success of any research project” (Saunders et al. 2016). Before starting to collect the data, researchers must get approval from the administration dealing with ethical aspects. After an examination of questions and interview process, the research is approved as adhering to ethical guidelines. For this research, several steps were followed. First, the researcher has set the questionnaires and questions for the interviews. Then he filled the University Ethical form.

At the end of the ethical process, a certificate of Ethical approval is obtained. The project was approved as Medium Risk. Secondly, a “Participant Information Sheet” was set up and sent to the interviewees attached to the email containing the interview questions, the theoretical framework and a link for the Pre-Interview Questionnaire. The Participant Information Sheet gives information about the research and the purpose and several other information reported in Table 18. The anonymity of the interviewees was completely respected. Each respondent is identified via a number. During the analysis, the name of the project was replaced by a letter. The Participant Information Sheet and the certificate of Ethical approval can be found in Appendix 4 and 5). The various ethical activities are reported in Table 19.

Table 18: The participant information sheet

Participant Information Sheet
1. Information about the project/Purpose of the project
2. Why have I been chosen?
3. Do I have to take part?
4. What do I have to do?
5. What are the risks associated with this project?
6. What are the benefits of taking part?
7. Withdrawal options
8. Data protection & confidentiality
9. What if things go wrong? Who to complain to
10. What will happen with the results of the study?
11. Who has reviewed this study? Supervisory team contacts
12. Further information: Research contact

Table 19: The ethical activities for the research

Ethical Activities	**Questionnaire and Pre-Interview Questionnaire**	**Semi-structred Interviews**
Consent obtained from the participants	Consent before starting to fill the online questionnaire	Participant Information Sheet sent to interviewees by email and returned signed by email or given to the research before the interview.
Contacts detail (researcher and Supervisory team)	Yes	Yes
Anonymity guaranteed	Yes	Yes

3.7 Summary

This chapter has presented the research strategy used for this thesis. The chapter has exposed the various sequences that compose the research strategy of the study. Several strategies and methods were explicated, and the appropriate approaches for the study were identified. The author will use pragmatism as the research philosophy (section 3.2). The data approach will be inductive due to the novelty of the topic (section 3.3). The data gathering will be made by a mixed method using surveys to get quantitative (through a questionnaire) and qualitative (through semi-structured interviews) data (section 3.4). A detailed explanation is given on the reliability and validity of the qualitative data gathering (section 3.5). Lastly, the ethics of the research are discussed in section 3.6.

4 CHAPTER 4: BIM research bases of this study

Chapter 4 aims at giving background information on the study that is necessary to understand the data and their analysis. It is also useful to give some insights into the processes used in both countries (France and UK) in order to ground the data. Therefore, the chapter will focus on the practical BIM implementation specifically to France and UK because the qualitative data from the interviews are mainly coming from people with working experience in the UK and France (although some of them have also worked internationally). However, the UK environment will be more developed in section 4.3 because the UK standards are the bases of the new ISO 19650 (British Standards Institution 2019). Then we will expatiate on the specific interviewee's work environment.

4.1 A brief overview of what is BIM

The traditional workflow in construction progress at the end of the 20th century was a paper-based design method. At this time, the 3D visualisation of the design was usually done with hand-built real mock-up. The apparition of CAD technology changed first the design method that was based on hand drawings. This mutation of one habit to another one introduced a big change in the design process of the construction Industry. The period with hand drawing was more social than the “CAD period” leading to work collaboratively. CAD has allowed designing more quickly and deleted a number of hand re-drawings. It was a real leap forward, but “CAD Technology” did not encourage working collaboratively. It was more something like “everybody behind his own computer screen”. The high speed of working of “CAD Technology” meant that a single person could handle an entire building and work completely alone, without any communication. Dialogue was cut out. The leap to BIM processing will be difficult if people don’t change the way that they are now used to working.

Definitions of BIM follow

“BIM is a digital representation of physical and functional characteristics of a facility. A building information Model is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition” (buildingSMART, 2015). BIM is “a systems approach to the design, construction, ownership, management, operation, maintenance, use, and demolition or reuse of buildings” (Smith and Tardif 2009) p.216.

BIM is a process and a fundamentally different way to work, think and exchange information. BIM gives a massive opportunity to completely revolutionize the AEC Industry. BIM is not just about a building and not about design construction either. All stakeholders need to be engaged with the technology in an intelligent way. They need to be involved, in the beginning, and to know what the purpose of the project exactly is. The apparition of the BIM process in the AEC Industry brings changes in the way the stakeholders have to work. They have to work more collaboratively. The major difference with BIM is that each discipline needs to produce a single discipline-rich Model that will be shared with other partners. A coordinator Manager, for each discipline, has the responsibility to check the Model and the BIM process to ensure that the Model is progressing satisfactorily. In the collaborative work brought with BIM, there are a lot of rich Models containing accurate data that will be exchanged between different disciplines. This collaborative environment raises some issues like interoperability between models, quality of information, roles and responsibilities of all the actors involved in the project, and so on.

The 3D Model can be designed directly and can be viewed at any stage of the process, and it helps the design team in the design thinking and facilitates understanding. The 3D Model permits an accurate visualization of the design anytime. When changes or corrections appear in the design process whatever or whoever a requests them, it is easier to implement them. And this permits the avoidance of a number of errors linked with omission when making modifications in one view, for example. It is easier to verify the design intent in the technical building and to check the qualitative requirements rapidly (e.g. this room needs to be near this other one).

The benefits of adopting a BIM strategy are plentiful. The difference between the traditional plans is that the 3D Model can provide both traditional documentation and non-graphical data. For example, the 3D model enables the extraction of accurate and consistent 2D drawings at any time in the process. This operation in 2D software (like Autocad 2D) was very time consuming, and any change necessitated a lot of re-work. The reduction of the time for this task is enormous and avoids paper exchanges between the stakeholders.

The following subsection gives an overview of the projects' organisation in France and the UK.

4.2 British and French digital plan for the building process

The Royal Institute of British Architects (RIBA) is in charge of the regulation of the British Architects activities, and has set up a number of documents to help professionals. In particular, the Digital Plan of Work is a document that sets the scene without being a contractual document by guiding the design process for any project types and sizes. This guidance could help all stakeholders involved in a project.

In the RIBA approach, the linear and fragmented system is composed of eight phases, starting with "Strategic Definition" and ending with the "In Use" phase (phase 0 to7 in Table 20). Both the RIBA plan of work and Green overlay do not take into consideration the End-of-Life. Even if the document mentioned “buildings are refurbished and reused or demolished and recycled in a continuous cycle”, the EOL, as a stage in the “continuous cycle” is not integrated. In this thesis, and by the anticipation of the developments of the following chapters, the author has added one stage after stage seven, the eighth stage that refers to the deconstruction stage (Table 20, on the bottom). This is the stage to close the loop of the life cycle of the asset, and its fate is linked with the design and construction processes. The construction system tends then towards the circular economy concept.

Table 20 and Table 21 are comparing the phase already described in the RIBA guidance with the French phases. The French phases are established according to the experience of the researcher who has been working in the French AEC industry.

4.3 The asset lifecycle in BIM environment based on the RIBA

This subsection will expatiate on the British standard “PAS 1192-2,” that describes the asset lifecycle (British Standards Institution 2013). The author has reworked the figure from the PAS 1192-2 and included the End-of-life of the asset (Figure 23). In this figure, several possibilities are indicated. Before each deconstruction, an investigation will be made to assess the possibilities of materials’ recovery from the deconstruction.

Figure 23 highlights that the Design and Build are quite small compared to the next phases, which are management, maintenance and operation. The architects and the other stakeholders that are involved in a construction project usually consider only the phases Design & Build of the asset, which typically takes 5 years, on average. With the BIM process, the entire construction team needs to consider the whole requirements of the asset. Moreover, with the consideration of the Sustainable End-Of-Life, deconstruction contractors are included in the parties which need to be involved in the project as soon as possible.

The analytical vision is replaced by a holistic view where all the phases are linked and interconnected. The SEOL is completely integrated into the building lifecycle. Consequently, the Asset Lifecycle is composed of three main stages: “Design & Build”, “Operation & Maintenance” and “End-of-Life.” In this study, the Sustainable End-of-Life of the asset is deemed as a significant matter in the construction process. Designers and builders have to bear in mind what will happen after their tasks are completed and also should take into account requirements associated with the asset and the SEOL management (Figure 23).

Table 20: The Digital Plan of Work stages is adapted. The deconstruction stage – phase 8 is added for the purpose of this thesis (Source: the RIBA Plan of Work 2013 and BIM certificate training – RICS.

STAGES	DOCUMENTS REQUIRED	DIGITAL PLAN OF WORK - TASKS
Stage 0 	**Asset Information Requirements (AIR)**	• Development of the AIR sets out what are the requirements for the asset management (in use phase) • The AIR and the EIR may be updated • An Information Manager may be appointed by the client • Develop the DIR to sets out what are the requirements for the asset EOL
Stage 1 	**Employers Information Requirements (EIR)**	• Development of EIR: Issue EIR & Capability Assessment • The CDE should be procured • Selection of the design Team • Information exchange from the suppliers • Employers Decision Point
Stage 2 	**Post-Contract BEP (Design Team)**	• Populate post-contract Award BEP by the Design team (including the design Team Pre-Contract BEP and the EIR should be issued to bidding contractors) • Suppliers Information Exchange • Employers Decision Point
Stage 3 	**Post-Contract BEP (Design Team)**	• Appoint Main Contractor • Validation and assurance checks • Expect the update of the Post Contract-Award BEP by the Design Team • Suppliers Information Exchange • Employers Decision Point
Stage 3.5 	**Post-Contract BEP (DFMA Team)**	• Design modularization phase • Check compliance of design modularized with the clients requirements • Suppliers Information Exchange • Employers Decision Point
Stage 4 	**Post-Contract BEP (Main Contractor) MIDP**	• Expect the production of the Post Contract-Award BEP • Implement Post Contract-Award BEP and deliver the Master Information Delivery Plan (MIDP) by the main contractor/client representative • The design would be tested against the client requirements • Validation and Assurance checks • Suppliers Information Exchange • Employers Decision Point
Stage 5 	**Post-Contract BEP (Main Contractor)**	• Expect the production of the Post Contract-Award BEP • The design would be tested against the PLQ set out by the client • Validation and Assurance checks • Appoint soft Landing Champion • Suppliers Information Exchange
Stage 6 	**Post-Contract BEP & Soft Landings**	• Expect the production of the final Post Contract-Award BEP • Expect Soft Landings documentation • The design would be tested against the PLQs set out by the client • Validation and Assurance checks are carried out • Suppliers Information Exchange • Employers Decision Point
Stage 7 	**Asset Information Requirements (AIM)**	• Asset Information Model (AIM) updated and inform the AIR • The design would be tested against the PLQs set out by the client • Validation and Assurance checks are carried out • Suppliers Information Exchange • Employers decision Point
Stage 8 	**Deconstructio n Information Model (DIM)**	• Asset Information Model (AIM) updated is used for the DIM • Deconstruction contractors Information Exchange • The Deconstruction strategy would be checked and tested according the Employers requirements • Employers decision Point

Table 21: Asset Life Cycle including the Deconstruction stage (Source: based on the PAS 1192-2)

Acronym FR	FRANCE	RIBA 2013		
		Stages	**NAME OF STAGE**	**DOCUMENTS REQUIRED IN BIM**
PROG	Design Brief			
OAD	Prepare Administration File	**Stage 0**	Strategic definition	AIR
PRE	Preliminary outline Design	**Stage 1**	Preparation & Brief	Employers Information Requirements (EIR)
APS	Scheme Design	**Stage 2**	Concept Design	Post-Contract BEP (Design Team)
APD	Detailed Design	**Stage 3**	Developed Design	Post-Contract BEP (Design Team)
DPC	Building Permit Application	**Stage 4**	Technical Design	Post-Contract BEP (Main Contractor)
PRO	Technical Design			
DCE	Tender File			
ACT	Procurement Process Assistance			
VISA	VISA Execution Studies			
DET	Construction Phase	**Stage 5**	Construction	Post-Contract BEP (Main Contractor)
AOR	Handover	**Stage 6**	Handover & Close-out	Post-Contract BEP & Soft Landings
DOE	As-Built	**Stage 7**	In Use	Asset Information Requirements (AIR)
	As-Deconstructed/Dismantled	**Stage 8**	Sustainable EOL	D – Information Model (DIM)

4.3.1 Incorporation of the Deconstruction phase in the BIM process

Figure 21 depicts the proposed information delivery cycle during the entire Asset Lifecycle. The original figure, given in the PAS 1192/ISO 19650, did not include the End-of-Life of the asset. The author propose to incorporate the SEO phase and explore the requirements needed for its management. The supplier's information exchange points and Employers decision points associated with the SEOL/Demolition phase are also added (to the right in Figure 21).

Figure 21 summarises the process and highlights the documents that need to be set out (the Employer Information Requirements (EIR), the BIM Execution Plan (BEP) and the Master Information Delivery Plan (MID)) and the different data drops (red bullet points in the bottom of Figure 21). These documents are discussed in the subsection 4.3.3. After having set up all these documents, in accordance with them, the design team can start to develop the Model.

The Information Delivery Cycle (Figure 24), is read anti-clockwise, starting with "Phase 0 Strategy" (top right). The "As-Maintained" step was added (after the black dotted line) to mark the transition between the O&M phase to the EOL phase. Operation Expenditure (Opex) will end when the asset becomes unusable, and its deconstruction starts. Opex is the expenditure incurred because of the day-to-day operation of a business. The Capex is expenditure incurred in the acquisition, construction or enhancement of the asset, including land. Then, the End-of-Life Expenditure Endex was also added (red circle after the black dotted line), encompassing the entire deconstruction management. After the deconstruction phase, the client will recover a Model "As-Deconstructed".

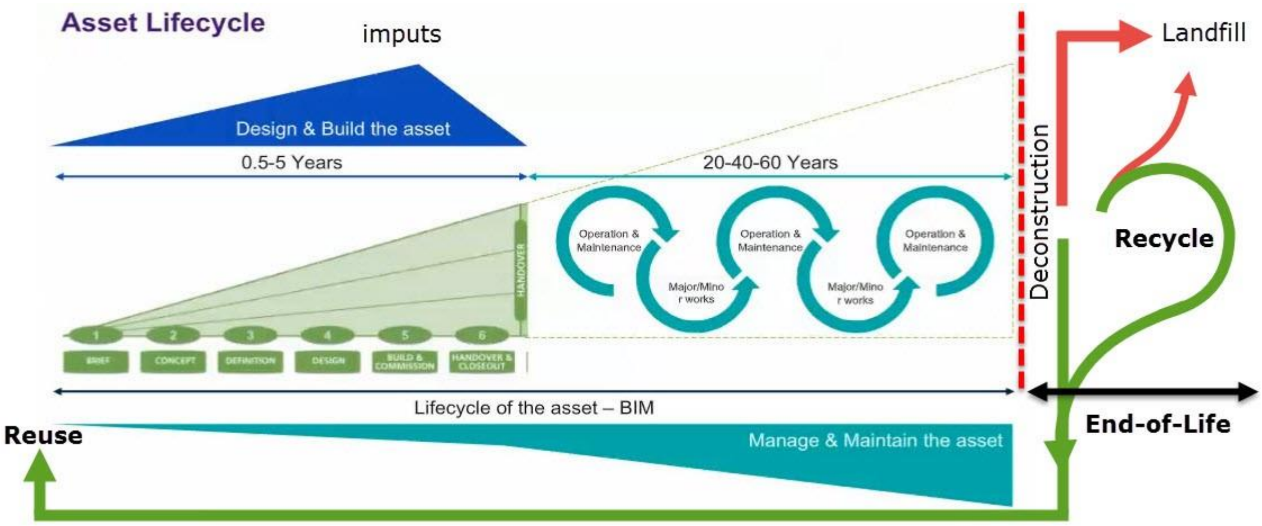


Figure 23: Asset life cycle including the EOL stage (Source: based on the PAS 1192-2)

4.3.2 The Common Data Exchange (CDE)

The BIM Model will contain vast amounts of information, cost, programme, design, physical performance and other information about its entire lifecycle. The information is collected throughout the whole lifecycle of the asset; which implies that Facility Managers and Deconstruction/Demolition managers need to be involved as soon as the project starts because they need to recommend appropriate requirements regarding the data required to achieve specific tasks. This also highlights the need to maintain and update the model during the Asset Lifecycles.

During the lifecycle of the asset, the information created is shared and managed in the Common Data Exchange (CDE). The ISO 19650 further supports the information management concept by highlighting the information requirements in the operation phases (British Standards Institution 2019).

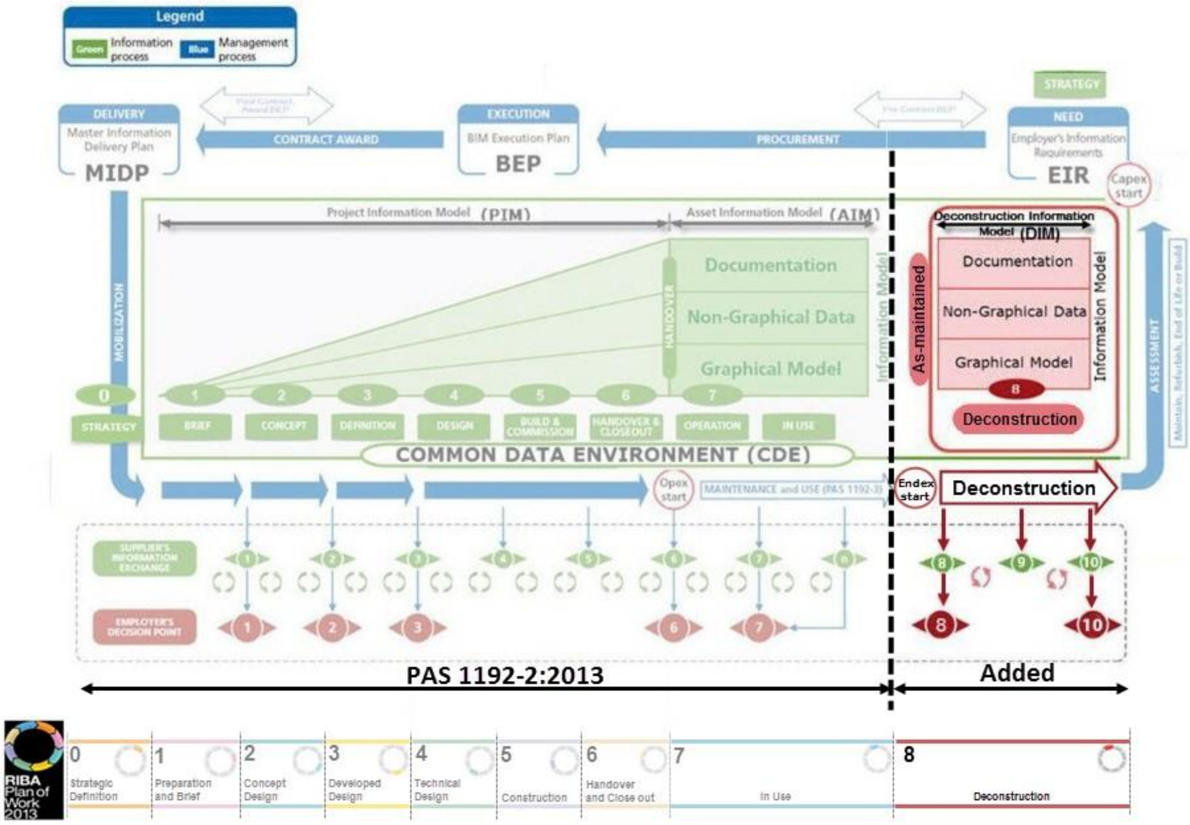


Figure 24: The Information Delivery Cycle integrating the new Asset Lifecycle concept (Source: Adapted from PAS 1192-2:2013 Figure 2)

The CDE, as defined by ISO 19650, is an online platform that can collect, manage and share the data that is created around a project. This common space accessible to all project stakeholders was designed to support the achievement of level 2 BIM adoption along the “Bew/Richards BIM Maturity Model” (Liu et al. 2015).

The CDE facilitates information exchange and thus facilitates collaborative working between all parties. The aim of the CDE is to enable the creation and management of the data flow, which starts by setting up the EIR. It contains the client's requirements, including asset life management expectations and the deconstruction strategy needs. Because the data will be used for several activities, it needs to be structured in a common format, the Industry Foundation Classes (IFC), which was developed and is maintained by buildingSMART International as its "Data standard." Interoperability is a prerequisite for efficient data exchange in the CDE (Palos et al. 2014).

As depicted in Figure 24 there are two types of information exchange; the suppliers and the Employers. The green circles and triangles (on the bottom of Figure 24) refer to the CIC (Construction Industry Council) scope of services stages and mention the different steps taken when information needs to be exchanged between the project team members. This is aligned with the RIBA stages (Table 20). The red balls indicate the information exchanges between the project team and the Employer. Three stages were added to the deconstruction phase; firstly information exchange; which is when the deconstruction contractor receives the Model and explores how deconstruction activities will be managed. Secondly, during the process of deconstruction, it is important to ensure all activities are aligned with the EIR. The last step is ending asset deconstruction.

In parallel, there are also different employer decision points, known as information exchanges between the project team and the employer. During these decision points, the employer checks if the deliverables are achieving as mentioned in the EIR. Two validation points "employer decision" were added (red balls 8 and 10). The red balls correspond to the reception of the "As-maintained" Model (the Asset Information Model updated.). This first exchange is done with the client; this is the step where possible methods and requirements for deconstruction are discussed. The content of the received model (AIM) is checked to verify what information is needed to achieve the deconstruction.

Decision point 10 (in Figure 24) is the receipt of the Deconstruction Information Model (DIM) by the client when deconstruction is reached. The DIM must contain all data relating to the decommissioning process, which was carried out in accordance with the client's requirements. The acronym DIM was previously used by Michael Ulyatt, who says that "the time is right to extend BIM into DIM – Deconstruction Information Modelling" (Ulyatt 2015).

To obtain accurate and secure data, the CDE includes a strict data checking process which needs to be scrupulously respected by all parties. If the CDE is managed properly, it will build an accurate and structured data set known as the Project Information Model (PIM). In the Asset Management phase, the published information used is the Asset Information Model (AIM).

4.3.3 Setting up key documents

The original Information Delivery Cycle (Figure 24) indicates four key documents required before starting to develop the design of a project. By integrating the SEOL in the Asset Lifecycle, the content of these key documents needs to be adapted. This section will explain the four key documents and point out the adaptation in the new lifecycle concept: Employers Information Requirements (EIR), Pre-Contract BIM Execution Plan (BEP), the Post-Contract Award BEP and the Master Information Delivery Plan (MIDP).

First, in the Information Delivery Cycle, the first step is the Capital Expenditure (Capex) phase with the production of the Employer's Information Requirements (EIR) document which sets out the information to be delivered by the supplier. The EIR enables a clear definition and understanding of the projects "Needs". In the case of existing buildings, the EIR must be put in place with the “assessment”, at the start of the project. In the case of new buildings, the “Employer needs” will be set up. The EIR contains information on management, commercial management and competence assessment. Employers need to specify in this document their asset End-of-Life requirements that should be taken into account by the design team. A good EIR establishment and closely-followed industry standards are keys to successful BIM collaboration.

Secondly, the BIM Execution Plan (BEP), produced by the client, sets out processes and protocols based on the EIR. The firstly Pre-Contract is submitted to respond to any issues that have arisen in the EIR. Next, the Post-Contract-Award BEP explains the BIM methodology such as the Project Information Plan (PIP), the project's objectives and goals, the Collaborative working methodology and the Project information Model deliverable strategy. The Post-Contract-Award BEP contains the information requested in the EIR. The main lines of EOL management need to be clearly mentioned in the BEP.

Thirdly, the Master Information Delivery Plan (MIDP) is created by the supplier after the contract is awarded and has to be in place before the design phase. It sets out the information required to be prepared, who need to prepare it and the necessary procedures and protocols for the production of the information and its publication. In simple words, it sets out the “Who”, “What” and “When”. By incorporating the SEOL issue in the EIR with the willingness of the client, the other documents (BEP, MIDP) will also refer to it. Once all these documents are in place, the design team can start to develop the Model, in accordance with these documents.

4.3.4 Asset requirements and models generated during its lifecycle

As depicted in Figure 25, the EIR discussed previously is linked with the models generated during the building lifecycle. The End-of-Life of the building and its specific requirements have been added to the original Figure (blue boxes were in the original Figure).

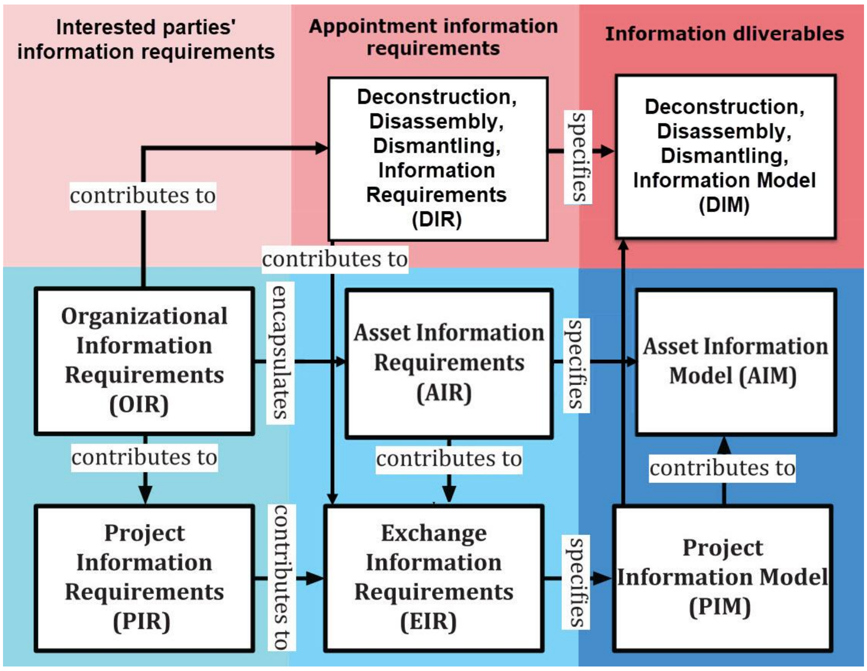


Figure 25: Relation between elements of information management during the Asset Lifecycle (Source: Adapted from ISO 19650)

Foremost, the Organisational Information Requirements (OIR) describes the information required by an organisation for asset management systems and other organisational functions. The OIR includes data and information which are required to achieve the organisation's objectives. It describes the information needed by an organisation to manage a building. The OIR generates the Asset Information Requirements (AIR) (British Standards Institution 2019). The AIR, based on the OIR, forms part of the EIR. The OIR shall specify data and information to be captured and fed into the AIM. As mentioned in Figure 25, the Deconstruction Information Requirements (DIR) was added and will contain all the requirements needed by Deconstruction contractors regarding their specifics tasks. Similar to AIR, the DIR will inform the EIR, which is managed and explained by the PAS1192-2 and ISO 19650 (British Standards Institution 2014, 2019). The DIR will also generate the Deconstruction Information Model (DIM), also added in Figure 25. This model would contain all the information needed for Deconstruction, including information related to materials suitable for proper waste management.

In conclusion, the integration of the Sustainable End-of-Life as a stage in the lifecycle of the building requires modifying the Digital Plan of Work by integrating the Deconstruction stage, as phase 8. It leads to a change in the Information Delivery Cycle by incorporating the SEOL phase and the information exchanges related to it. More developments will be given in the next chapters with the analysis of the data.

4.4 Background information of the interviewees

4.4.1 Company size, field focus, type of projects and phases

The company sizes of the interviewees are given in Figure 26. The 0-5 employee size is typical of the architecture offices in France and the UK (e.g. in the UK over three-quarters of the chartered architects' practices have fewer than 10 staff following the RIBA.

The interviewees' companies are within a large range of activities, covering the life cycle of the building from design to facility management (Figure 27) and deal with all the asset phases, from programming to deconstruction (Figure28). All types of projects are part of the activities of the interviewees' companies (Figure 29).

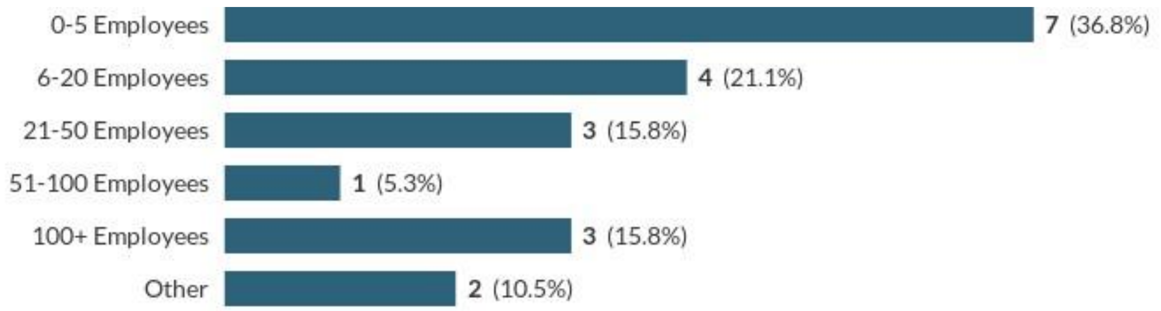


Figure 26: Size of the Interviewees' company (Source: author)

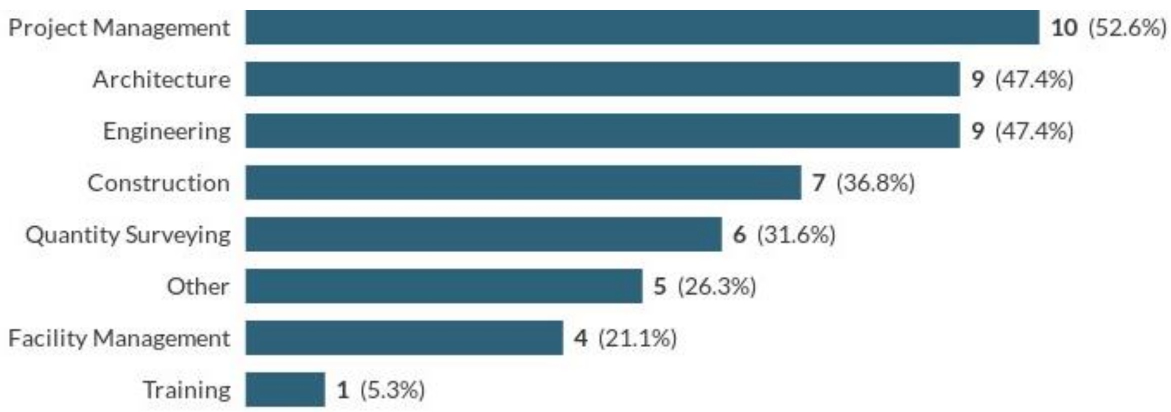


Figure 27: Field of the interviewees' company (Source: Author)

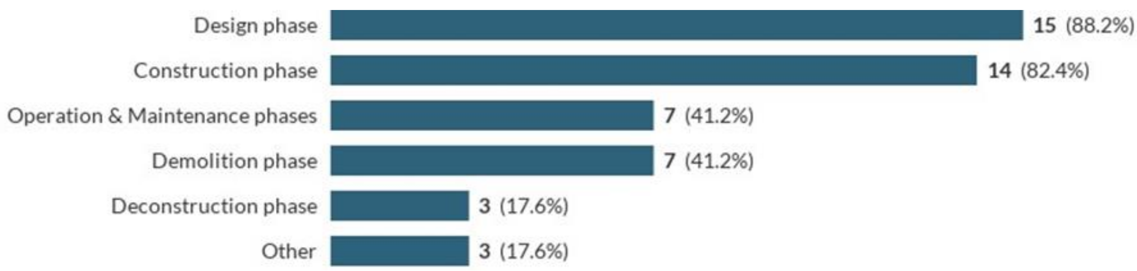


Figure 28: Phase focus on (Source: Author)

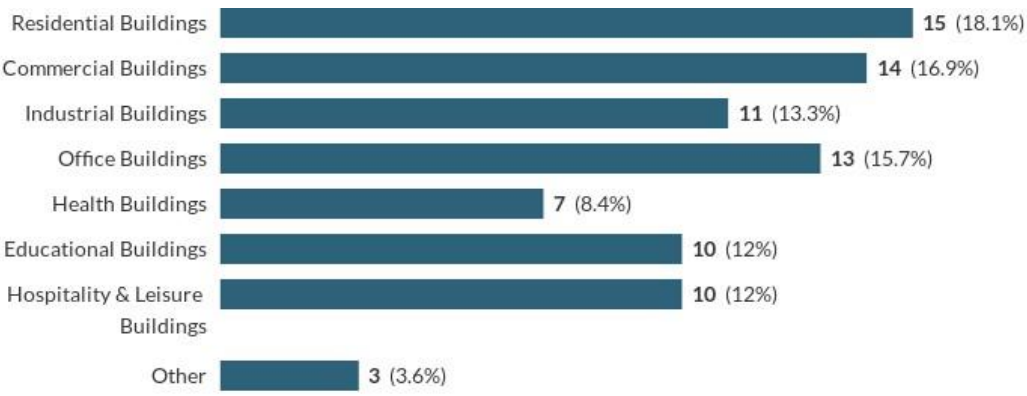


Figure 29: Type of projects dealt by the interviewees' company (Source: Author)

4.4.2 Experience in BIM and data exchange

Twelve interviewees among nineteen are using BIM. Among them, six interviewees are using BIM level 2. The data embedded into the models created by the interviewees are listed in Figure 30.

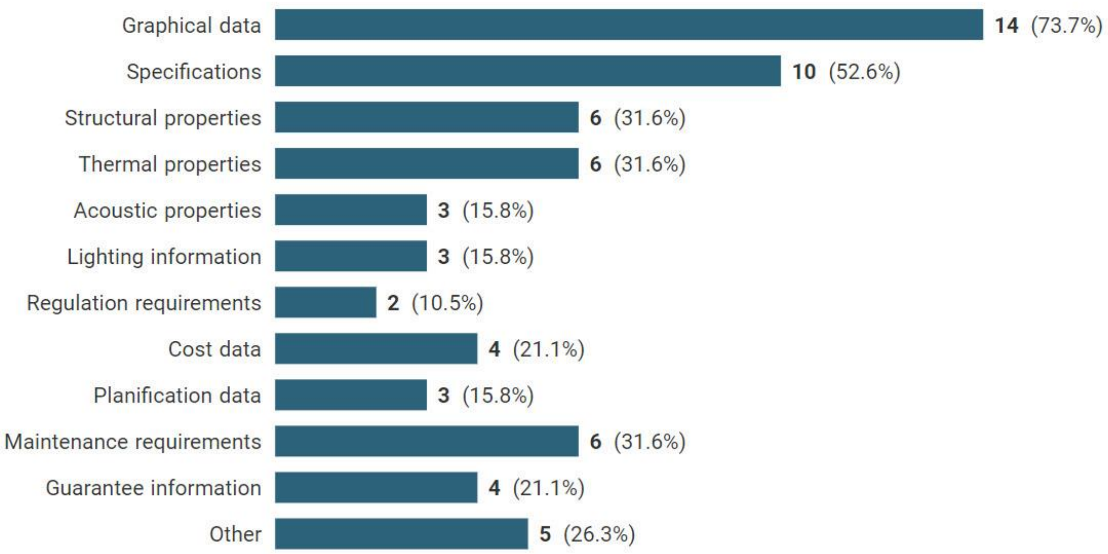


Figure 30: Type of data embedded into the BIM model (Source: Author)

4.5 Strategies for reducing the building's impact on the environment

4.5.1 Company awareness for C&DW

Ten respondents over 19 are aware of the European Construction & Demolition Waste policies. Only six respondents have already implemented a Site Waste Management Plan. Several questions were asked to assess their awareness and current use of the design principles found in the literature review to reduce the environmental impact of buildings.

4.5.2 Design principles understanding

Nineteen respondents have answered the question "In your opinion, which principle (listed in Table 22) is the most appropriate for deconstruction?". It is worth noting that there is a consensus on design for deconstruction and disassembly. Nine respondents think that design for prefabrication or design with reclaimed components are not appropriate.

Table 22: "Design for" principles followed by Interviewees' company (Source: Author)

Design for	Number of the interviewees (over 19) thinking that the design is appropriate or most appropriate
Flexibility & Adaptability	13 (68%)
Building Complexity Reduction	13 (68%)
Disassembly	19 (100%)
Deconstruction	19 (100%)
Reuse	17 (89%)
Pre-fabrication	10 (53%)
Recycling	15 (79%)
)esign with Reclaimed Components	10 (53%)
Design out Waste	14 (74%)

4.5.3 The strategy followed by the company to reduce the impact of buildings

Nineteen respondents have answered the question "How frequently does your company adopt the following strategies (Table 23) for reducing the impact of the buildings on the environment?" It is worth noting that nine respondents are using all of those strategies, and 14 are using both "Design options" along with "Construction Strategies" which makes sense.

Table 23: Design strategies followed by Interviewees' company (Source: Author)

Design strategies	Number of companies (over 19) applying this strategy frequently or mostly
Material selection	13 (68%)
Component selection	10 (53%)
Design options	14 (74%)
Construction strategies	14 (74%)

4.6 Stakeholders involved in this research

4.6.1 Designers: several approaches

Architects often use multiple design approaches to achieve sustainable buildings. However, they are classified in this subsection under a specific approach that seems to be emblematic of their design. Similarly, other respondents have multiple skills and had different work experiences. They are also presented under only one category, although they may have contributed to another category. For example, one respondent is currently a facility manager but has been working previously in DfMA.

A. Circular Economy Approach and flexibility/modularity (Respondent R18)

The architect, CEO with 35-years' experience, has an international background of practice in Europe, including France and the UK, among others. He is a pioneer in involving all the stakeholders in the early stage of the building design process, including manufacturers to secure a high-quality achievement of the construction in the circular economy. He is targeting a high Indoor Air Quality (IAQ) as well as modularity in his designs.

B. Flexibility/modularity (Respondent R16)

The architect, a CEO of an SME, is a BIM manager working mainly with public owners that are more sensitive to a long term approach to reducing costs and the impact on the environment in France. The type of projects designed by R16 team is mainly offices that could be adaptable to different functions. They work essentially on existing buildings and use to have, prior to the rehabilitation, a deconstruction phase. Even if they use BIM Level 2 for their project, they do not use yet BIM for deconstruction.

C. Reuse reclaimed material and finishing works avoidance

a. Respondent R07

The architect, a CEO, with 16-years' experience, has an international background of practice in Asia and Europe, including France. He is a pioneer in involving all the stakeholders in the early stage of the design process, including blue collars (e.g. carpenters and masons) to secure a high-quality achievement of the construction. He uses local materials found on the construction site, (earth from excavation and demolition waste from existing building on the site) to achieve green buildings with a low embodied carbon. The respondent implements a highly collaborative approach in his day to day work, however not in the BIM framework.

b. Respondent R09

The architect, CEO with 48-years' experience, is a pioneer in sustainable building in the UK and uses bio-based construction materials (e.g. hempcrete) and reclaimed materials to achieve green buildings with a good IAQ and a low embodied carbon. He has a background of professor of architecture in a UK university and is working toward the recognition of the blue collars skills, the key factor of quality in the built environment. The respondent implements a highly collaborative approach in his day-to-day work, however not in the BIM framework.

c. Respondent R12

The architect, with 30-years' experience, is a pioneer in sustainable building in France with the use of bio-based materials (straw bales load-bearing walls) and local materials (earth). He has been a researcher in an international context for 15 years on earthen architecture before coming back to practice. By avoiding finishes, he is relying on a very good quality of the structural walls to be apparent. The SME uses BIM level 1.

d. Respondent R06

The architect, with 38-years' experience, designs with reclaimed building components and soils extracted on the construction sites. The high quality of the construction of the building enables him to avoid finishes. He is designing with the end in mind by using waste material and trying to reduce the environmental impact of the building by using materials having a low-impact. He also tries to use local material, use local workers, the use of excavation earth, stone and wood. The respondent implements a highly collaborative approach in his day-to-day work, however not in the BIM framework.

4.6.2 Deconstruction

A. Respondent R10

The environmental engineer, with 18-years' experience, is a BIM manager in the French context with international experience in Europe, Canada and in the USA. She was engaged in deconstruction projects in France using BIM. She also worked on "Haute Qualité Environnementale" (HQE) buildings, a standard for green building in France. For the HQE buildings, they had LEED ambitions with gold and Platinum levels on which they were asked to justify the ability to deconstruct or integrate recycling elements from projects that had been deconstructed nearby. So, it was really reuse of a deconstruction for this project. And, to ensure that the design elements of the building incorporated facilities for the separation and selection of materials so that they could be reused in turn. The project was a tertiary project in Canada. Generally, there were tertiary projects, offices with a mixed, lower part school.

B. Respondent R17

The engineer is in charge of designing deconstruction projects in France without using BIM. During deconstruction, they do what a SOGED, acronym of "The Waste Organisation and Management Scheme". A SOGED is a diagram that allows knowing what can be deconstructed, where the materials will go, and what can be reused and recycled. This makes it possible to sort the materials and try to recover as much as possible, within the framework of a circular economy. The circular economy makes it possible to manage waste better. They also make a waste diagnosis. The company, mainly work in the urban area with the constraints associated with it, such as neighbours' issues, lack of place for storage and material sorting.

4.6.1 Manufacturer (Respondent R13)

The respondent is a BIM project manager working for a leading manufacturer of plasterboard. His 31-years' experience was within Europe, including the UK and France. He has been involved in the company project of setting up a recycling process for the waste from construction sites. The company put on the market products that are 100% recyclable for life. They have a recycling process during the products' manufacture. They also developed a recycling process for their products' waste generated during the construction phase. They are involved in big and complex projects where BIM is used during the design, construction and operation & maintenance phases. For some projects, the digital "As Built" record model will be delivered instead of the traditional paper files.

4.6.2 DFMA (Respondent R15)

The architect, with more than 8-year experience, is currently a facility manager in a UK university but has been working previously for a company using DfMA approach in a BIM environment. The company is currently a leader in the UK in the field of DfMA. They build modules like boxes, put them on Lorries and then, to be assembled on-site. They literally finish everything, even sometimes they attached furniture, bathroom etc. The company work with normal architects who usually just design a building without specifically designing with the modular approach. The modularization of the design usually happens within the design office and the contractor itself. The person used to receive the layout from the architect and modularize everything. On top of that experience, R15 is currently a facility manager involved in many projects, whether refurbishments and new buildings.

4.6.1 Research and Development (Respondent R05)

The engineer, with 10-years' experience, is working in France on developing building components using the soils excavated from the construction sites.

4.6.2 BIM managers

A. Respondent R01

The respondent is an expert strategic deployment in BIM/CIM, in the French context with 10-years' experience. The company is an early BIM adopter. They are involved in big and complex projects where BIM is used during the design, construction and operation & maintenance phases. For some projects, the digital "As Built" record model will be delivered instead of the traditional paper files.

B. Respondent R02

The respondent, with 37-years' experience in the French context, is the CEO of an SME specialised in BIM. The main focus is on existing buildings and the scanning phase to be able to manage the building through BIM.

C. Respondent R03

The respondent, with 20-years' experience in the French context, is the director of the technical office in an SME specialised in BIM. Their main activities are commercial building for which they must get commercial authorisations, linked to the environment. They have an environmental part, notably on the materials that are used. They should know how to deconstruct and be able to reuse the materials resulting from deconstruction. Large commercial buildings are subjected to this regulation. Therefore, the goal is to have projects with high environmental quality necessitating a rigorously materials selection. The regulation, the CDAC (departmental commercial development commission) is mandatory for new buildings and refurbishments with extension. For them, they do not really have demolition because gradually, deconstruction contractors replace the demolishers who know how to recover the waste resulting from the deconstructions. According to R03, they are not landfilling everything anymore.

4.6.3 Control officer (Respondent R08)

The Engineer, CEO with 37-years' experience, is working in France where the control office is a key stakeholder in the project management, especially in the case where innovation is needed. The control officer will take or not the responsibility to validate the new buildings' components. In France, the control officer responsibility is to check the building compliance with regulations. In the UK, this role does not exist that form. Indeed, according to R09, a UK stakeholder, the architect can be responsible for the control. It could be an engineer or whatever but somebody who must be registered with the local authority and be a certified person. Then they are responsible for checking and for the regulations' compliance. They have to pay special insurance to play that role.

4.6.4 Owner

A. Respondent R20

The engineer is working for 18 years for the French leader of social housing. The company uses BIM and manages more than 250 000 social dwellings in France. They build more than 7000 new dwellings every year. The company have largely implemented BIM internally by training their workforce, and they use BIM for mainly all the projects.

They have already worked on projects with existing buildings that should be deconstructed. As the client, they get assistance from CE specialists and start-ups that are specialized in recovering materials. It sometimes happened that the recovered materials are reused for the new building. The start-up that they work with is acting as a material bank because they identify, organise the database and sale the recovered materials.

B. Respondent R04

The client, CEO of an SME, with 30-years' experience, was a pioneer in sustainable building in France with his first project of single-family houses in a village in France. The houses were built with local materials from the site (stone masonry with soil mortar). For this project, they have to manage the storage of the excavation earth onsite, which lead them to multiphase the operation. The respondent implements a highly collaborative approach in his day-to-day work, however not in the BIM environment.

4.6.5 Quantity surveyor (Respondent R11)

The respondent, with 8 years' experience, is working in an SME that pioneered the use of BIM in France for quantity surveying.

4.6.6 Facility manager (Respondent R14)

The respondent, a BIM manager has worked as a facility manager for several years. He usually acts as Assistant to the Contracting Authority for owners, designers or alongside control offices to owners). He worked on several projects across Europe. His BIM knowledge is extended to data management, platforms and IoT.

4.6.7 Structural Engineer (Respondent R19)

The engineer, with 7-years' experience, deals with the structural assessment of structures made with on-site materials (soils for earthen architecture and crushed concrete for new structural walls) using non-conventional materials and methods. He struggles to tackle the lack of standards for un-industrialised materials made on site by contractors. Those projects are in France. The company is just starting to use BIM level 1.

4.7 Chapter summary

The chapter expatiates on the usage of BIM in France and in the UK because it is the main background of the interviewees, although most of them have a wider international experience. A comparison of the French and British approach of construction is given where the different steps of the management of the building project are compared. Then, the UK BIM environment was more detailed because the UK standards are the bases of the new ISO 19650.

The background information of the companies of the 20 interviewees is also developed along with the different interviewee approaches of sustainable building. That information shows that the interviewees' skills and positions in the companies cover the whole lifecycle of the building management. Moreover, most of the interviewees are CEOs or working in companies that are leaders in a field related to the aim of the research (DfMA, construction, low carbon building, BIM) and have substantial experience.

5 CHAPTER 5: Barriers - Findings and Discussions

5.1 Introduction

Chapter 4 presented the interviewees' background and their use and understanding of the design principles used for the reduction of the buildings' impact on the environment. This chapter presents the results of the semi-structured exploratory interviews used to collect the primary data. The aim was to investigate the stakeholder's point of view on the impact of the incorporation of a sustainable End-Of-Life (SEOL) into the asset lifecycle in the circular economy context. A BIM-based theoretical Framework was presented to the interviewees and questions on how we can improve it were asked. Twenty interviews were conducted with interviewees selected on the researcher and supervisor networks and by using a snowballing technique. All the interviewees are stakeholders involved in the asset lifecycle. They have experience in BIM or Sustainable buildings or both.

The result of the analysis pointed out the barriers when the asset lifecycle is reconsidered to move toward the circular economy concept. These results are then discussed with the findings from the literature review. Both results, from the semi-structured interviews and the literature review, will support the creation of a BIM-based conceptual framework that can support the stakeholders for moving from linear to the circular economy.

They are structured into six sections representing the high-level themes, associated with mid-level and low levels themes. The high-level themes were based on the classification of the barriers for sustainable building found in the literature review (i) Economic barriers, (ii) Political barriers, (iii) Sociological barriers, (iv) Technical barriers, (v) Environmental barriers and (vi) Organizational barriers.

5.2 Economic barriers

The discussion of the economic barriers is based on the current perception of the interviewees for moving from conventional demolition to a more sustainable asset EOL management such as a structured deconstruction or dismantling to recover materials. The economic barriers are split into four parts: the economic context, the replacement of demolition by a SEOL, the additional cost for a SEOL approach and reclaimed materials market. The number of respondents and quotations are reported in Table 24.

5.2.1 Economic context - Profit-seeking challenge

First, four respondents highlighted the economic context, as a barrier (R09, R10, R16 and R19). According to them, this is the matter of profit-seeking by clients and the other stakeholders involved in a project. R10 says that the owner of an asset should think about the asset EOL and not only about the price of the rent. They usually have objectives based on a very short-term vision. R10 stated that when the building is still under construction, most of it is already sold. R09 supported this idea by saying that the problem with thinking to a sustainable EOL for the asset is challenged by the fact that the asset is usually considered from its financial aspect. R19 added that financial profitability is the most important for a property developer. If they go for a sustainable approach, it is because they have seen a way to have a display at the marketing level.

> *"…just a financial asset. They are not really worried about the physical asset because that is **financial that's important**. At the end of the day, it's **all about business and people cutting corners and making as much money as they can**."*
>
> Architect, R09

> *"… between **25% and 50% of the building is already sold**. And it is sold in its entirety before the end of its construction".*
>
> Digital Project Manager, R10

Table 24: The number of respondents and quotations for the economic barriers (Source: Author)

52-ECONOMIC Barriers	**Respondents**	**Quotations**
	20	**187**
521-Economic Context -Profit-seeking first	**4**	**7**
A-Financial asset that is important	2	3
B-Interest only the money	1	2
C-Short term vision - Looking for profitability only	2	2
522-Sustainable EOL versus demolition	**13**	**24**
A-Modernization bad sides - less manpower and more mechanization	2	3
B-SEOL approach is more expensive than demolition	7	9
C-EOL duration and labour cost	8	11
D-Estimation challenges	2	2
523-The drawbacks of using new approaches for a SEOL	**18**	**91**
A-Cost of the approach	18	88
B-Quantify and Sale the approach	5	8
C-Client readiness to pay for the new concept	4	5
524-Barriers related to reclaimed materials	**16**	**83**
A-Lack of structured market for reclaimed materials	12	49
B-Lack of facilities for reclaimed materials	7	16
C-Reclaimed materials costs (transport, treatments, recyling and reuse)	11	27

The profit-seeking challenge was not identified in the literature review. However, several authors raised the market issues and the absence of an appropriate marketing plan for reclaimed materials (Jaillon and Poon 2014). The established market dominated by materials is not favourable for deconstruction (Xanthopoulos et al. 2009, Zaman, A. et al. 2018). The highly competitive construction market (Häkkinen and Belloni 2011) and the lack of second-hand materials markets (Chileshe et al. 2015a, Hosseini et al. 2014, Xanthopoulos et al. 2009, Río Merino et al. 2010) are crucial barriers. Moreover, material recovery facilities and infrastructures for recycling must be developed (Río Merino et al. 2010, Nisbet et al. 2012). As for every kind of market, a good balance between supply and demand is vital. Many previous studies have been reported the lack of demand for reclaimed materials (Häkkinen and Belloni 2011, Forsythe 2011, Huuhka and Hakanen 2015) and the importance of coordinating the demand with the supply for reuse, for instance (Gorgolewski 2008).

To be able to balance the supply and demand, the SEOL approach aiming to recover materials when the asset is not useable anymore. Reclaimed materials can be directly reused or reprocessed beforehand to their reinjection into the construction material loop.

5.2.2 Sustainable EOL versus demolition

A. Modernisation bad sides: less workforce and more mechanisation

Secondly, from an economic point of view, it is difficult to do things differently without having to absorb additional costs. Respondent R07 is an architect having a sustainable approach by using materials available on-site, as much as possible. He thinks that the bad side of having the means and the modernisation is that architects are building aberrantly. Respondent R12, who is also a designer supported the previous architect's argument.

> *"…we often build in an* ***aberrant way by going to look for building materials very far away****".*

Architect, R07

> *"…there is much less workforce and more mechanisation. I remember a discussion with a manager of one of the big plasterboard factories in France, who said that they were very proud to sell their plasterboard for 10 or 15 years, at almost the same price because they had "saved on meat"…" "…So* ***there are fewer people, it costs less****. And running a machine 24 hours a day is no problem. Whereas doing human work 24 hours a day is complicated".*

Architect, R12

B. SEOL approach is more expensive than demolition

According to the interviewees, one of the main barriers to move towards a SEOL rather than demolishing buildings is economical. The reasons highlighted by the respondents are multiples. The cost of the deconstruction in comparison to demolition is one of them. The higher cost is due to the process of deconstructing, demounting or dismantling buildings that is very time-consuming and labour intensive (R08). R10 proclaimed that demolition costs less than deconstructing cleanly and recycle reclaimed materials recovered. He added,

> *"…deconstructing cleanly in a structured and ecological way* ***will cost too much****".*
>
> Property Developer, Engineering office, R04

> *"…****even if we must pay for the landfill****". "And it's not the same working time, and it's going to* ***take longer"****.*
>
> Digital Project Manager, R10

C. SEOL duration and labour cost

SEOL will also take longer, as noted by respondents R10 and R17 *"In terms of time, deconstruction is slower than demolition. It's about twice as long".* Furthermore, to be able to recover material and to make them viable for reuse, the SEOL principle used "…*needs to be done thoroughly",* as reported by R06. This was also supported by R13, saying that "…*obviously* ***it is a cost,*** *because it requires equipment and people*". The respondent R10 push the idea by comparing the deconstruction process to construction and proclaimed that

> *"…****Deconstruction would require almost the same resources as the construction phase*** *of buildings. Indeed, in deconstruction, it is necessary to be able to separate each of the materials, take care of the materials, store the materials (with the storage cost to add) and add the cost of logistics for its disposal****".***
>
> Digital Project Manager, R10

This leads to say that SEOL estimation becomes a critical and challenging task deeply linked with the amount and quality of the material that will be reclaimed from the asset. Regarding the deconstruction or dismantling processes cost, R06 stated that the process to make recovered materials reusable is a long and costly process requiring equipment and people to do the work. The SEOL management needed space for process implementation, including storage. The deconstruction engineer supported this argument. The lack of space implicates additional cost due to the distance to find a new place where you can send the reclaimed material. So, the cost of storage and processes to set up a sustainable EOL for an asset is costly

> *"Sometimes you* ***can't send everything to the same place". "…w****e have to try to send our waste as close as possible to the site to limit our carbon impact".*
>
> Deconstruction Engineer, R17

The EOL duration and labour cost are also barriers found in the literature review. Indeed, the labour-intensive effort required for deconstruction activities were raised by several authors for reverse logistics approach (Hosseini et al. 2015), 3Rs approach (Huuhka and Hakanen 2015, Cruz Rios et al. 2015, Nisbet et al. 2012) and deconstruction approach (Jaillon and Poon 2014, Hosseini et al. 2015, Couto, J. and Couto, A. 2010).

D. <u>Estimation challenges and Cost of Deconstruction</u>

R17 revealed that as they are a design office and not a deconstruction company, the estimation of the deconstruction is a bit double-faced. For them, *"…the longer the work takes, the higher the cost, the higher our remuneration"*. He said that the duration of the deconstruction phase is also associated with the storage capacities and the implementation of the deconstruction process. If space is available, the duration will be shorter than if they need to deal with the city council. Indeed obtaining authorisation to use the public domain is a long process, and this will increase the project duration. Respondent R03 stated that in their current activities, the demolition phase used to be very difficult to estimate because the prices fluctuate according to the rate of material recovered by demolishers and say that

> *"… If the deconstruction contractor is interested in certain things that we don't see, everyone wins. He gets back what he wants, and it costs us less money". He assumed that "…the* ***estimation of deconstruction will also be difficult****, and it can vary from simple to 10 times more".*
>
> Design Office, R03

One of the additional barriers found in the literature review is the low cost of landfills. This was raised by several authors for different approaches whether reverse logistic, deconstruction, C&D waste minimisation and 3Rs (Sanchez and Haas 2018, Jaillon and Poon 2014, Zaman, A. et al. 2018, Hosseini et al. 2014, Xanthopoulos et al. 2009, Nisbet et al. 2012). Hosseini et al. (2015) assumed that the viability of Reverse Logistic adoption would depend on landfill levy and landfill costs(Hosseini et al. 2015). One other leverage is the cost of construction materials usually less expensive than recovered materials (Gorgolewski 2008). Nisbet et al. (2012) gave the example of building aluminium scraps that are very difficult to recover economically. They stressed that recycling of building waste must be competitive with natural resources in terms of cost and quality (Nisbet et al. 2012).

5.2.3 The drawbacks of using new approaches for a SEOL

A. <u>Cost of the approach</u>

a. More work in the Design and Construction phases

Globally, respondents that are architects thought that the design phase would be longer. R16 said that, based on their recent move to the use of BIM, their workload was increased. They had to give support for the operation and maintenance phase, whereas before they limited themselves to know how they delivered the building. So, working with the EOL in mind will change the workload significantly. R18 added that adopting a SEOL approach gives more tools, more criteria to deal with. It will increase the amount of work. R06 and R07, also designers, supported the previous statement by saying that the difficulty in implementing a SEOL approach is the increase in the workload.

> *"All these are small accumulated charges. It's a little insidious; it doesn't show. Little by little,* ***we are adding work****".*
>
> Architect – BIM Manager, R16

> *"…more studies must be integrated into the process, and it is* ***more work in terms of time and study costs****."*
>
> Architect, R06

R05 think that there will be more work in the design phase. Another architect R12 supported these thoughts and added that the design phase should be more advanced due to the use of prefabrication. R10, a BIM Manager think that the additional cost will not be for studies cost, *"…but the cost of construction will not be less".* Respondent R20, an engineer who is working for 18 years for the French leader of social housing, reported that it will extend the preparation phase which means for them the start of the construction phase. Regarding the modular approach, it will generate a longer preparation phase. He said

> *"…We imagine that the* ***time to make prototypes or find the manufacturer****, the time to agree on the usefulness of module A, module B of module C, and how we will anticipate the construction? How will we plan production? How will we plan supplies? How will we plan the construction?* ***It's going to take a lot more time to prepare"****.*
>
> Owner – Engineer, R20

b. Cost for the adoption of the new approach

1. *<u>Additional cost on the project</u>*

To move from a linear system towards the circular economy, the overall approach should be changed. When a new approach is adopted, the financial impact on the project could be important. Thirteen respondents thought that the incorporation of a SEOL into the asset lifecycle concept would increase the cost and the duration of the project. Adopting a new approach generates cost related to the time for the new approach uptake and the necessary tools. The move towards a SEOL should be made in a construction context, assumed to put a lot of pressure for getting the projects done on time. R20 reported that as "Owner" and due to the use of BIM, they notice a total increase in the project costs that should generate better projects' quality.

> *"…additional cost of project management should already generate* ***fewer hazards on the sites, less additional work, less construction time, and therefore having***

timely deliveries. *And then, then, (so we don't measure that today), rent entries as it was planned".*

Owner – Engineer, R20

2. *The pressure to get the project done*

R09 pointed out another challenge, observed in the construction industry is the pressure put on the stakeholders involved in a project to get the project done. This should change and cannot work with the next challenge, noted by the same respondent, which is the care needed for deconstruction, dismantling or demounting a building. These concepts are associated with the care needed to be able to deliver a dismantlable or deconstructable buildings.

"…if I had a builder or quantity surveyor; they will say that the project will cost more because ***the builder would have to take much more care****. It's all about being careful. If you're going to make it possible for it to be dismountable, you* ***must be very careful to make sure that's not compromised****".*

Architect, R09

3. *Schedule issues*

Doing things carefully takes more time, but as reported by the deconstruction engineer, R17, they often have a very tight schedule for doing the work because a new project is already scheduled with tight timing. Scheduling for a project with a sustainable EOL is different for a standard construction project. According to R07, there aren't more constraints, but the schedule is more complicated and different. It should be set up rigorously with planners. R05 reported the complicated aspect of the adoption of a SEOL approach.

"…There's extra planning. Need to know the quantities, the place for land storage, and the place for the factory. It's ***more complicated than ordering a cinder block truck****. It disrupts conventional practices and changes processes and adds hazards".*

Research & Development, R05

4. *The time needed for adaptation to new approaches*

R02 explained that for BIM implementation, they noticed that time is needed for the adoption of new processes and new ways of working, especially in the beginning. This will affect the duration of the project and its global cost. This need to be taken into account. The respondent R02 thinks that it will take years. This was also stressed by R07. For him, bringing all the stakeholders involved in a project to understand and believe in the new approach is *"…not easy, takes a lot of energy and time"*. A real philosophical discussion should start with them, explaining that we want to work differently and how the work will be done.

"…this is not going to happen in one generation".

BIM Manager – Facility Management, R02

"…you must put yourself in people's thought patterns…the mental schema of a person doesn't change after one explanation. You need to insist again and again. ***Working under these conditions takes longer****". "…they must be* ***brought into the philosophical discussion*** *on what we want for tomorrow".*

Architect, R07

c. Cost of tools & processes

In addition to cost related to the new approach adoption and implementation, costs associated with new processes and the creation of accurate technical materials' sheets were highlighted by several respondents.

1. <u>Cost for the Material Technical Data Sheet (MTDS) process</u>

R10 pointed out the complexity of the French technical material sheets process, the MTDS (in French FDES). The MTDS contains information about materials provided by laboratory tests. The material federation supports the cost. Once the MTDS form is made, it is validated at the standard level by an accreditation service. After their accreditations, they go to INES (Institute National of Solar Energy). This is a very expensive process that most of the manufacturers don't want to do. It raises the issue that not every material has its MTDS. And for that material, we won't have enough data on it to be able to use it and prove that the material is consistent with the SEOL approach. This also leads to reducing the choice to prescribe materials that have a complete and accurate technical sheet.

2. <u>Less choice - Number of manufacturers & stakeholders working with this approach</u>

The construction industry, already faces this phenomenon with BIM objects. Since all the products aren't available in BIM format, R19 noticed that he would preferably prescribe products that are available in BIM. R16 said that

"…it will reduce the number of manufacturers and stakeholders willing to work in this direction. As a result, we are more inclined to ***work with manufacturers who have developed their objects*** *than with those who have not. This* ***reduces the field of the possibilities****".*

Architect – BIM Manager, R16

3. <u>New processes</u>

When we want to move towards the Circular Economy by incorporating a SEOL into the asset lifecycle, new processes should be put in place, and they are costly for a company. For example, a manufacturer (R13), gave the example of the processes set up for enabling to have plasterboard, which is 100% recycled. R18 reported that to be able to get the right insulation material for Circular Economy project, it was necessary to prepare the market.

"…it has not been without cost. We worked there for many years. We had to set up the supply chain; ***it took time. This is a costly process****".*

Manufacturer – BIM project Manager, R13

"When you want to do circular economy if you don't prepare the market for what you asked for, ***you will never have a solution****". "****The process used was long and unusual****…" "…went to the whole medical profession (all the possible "ologist", oncologist, pulmonologist and so on) to see what was the size of the fibres that could get into the blood, as asbestos does".*

CE Specialist - Architect, R18

Then, it enabled the manufacturers to set a minimum fibre size. Thanks to that, today, most materials and catalogues indicate the minimum fibre size in their products. This was necessary to do that because if they hadn't done that, they wouldn't have had the necessary materials three years later. It also enables manufacturers to prove that they had the right fibre size because they had measured it.

d. Insurance cost

To have a SEOL, materials used are less complex and more natural, commonly named non-conventional materials. This raises the insurance challenge. According to R04, who uses excavation earth as a material for his projects, the insurance issue is crucial because it increases the total project cost by at least 20%. R05 said that the use of non-common techniques doesn't enable you to get insured without a "technical certification". In France, the ATEX procedure is a long and costly process. According to R19, the Commission encourages the applicant to pay for additional missions to hold preparatory meetings to get a robust file. He considered that *"… there's also a certain business behind it".* To remove the additional insurance cost due to the use of natural materials or reclaimed materials, R12 went further and said that we should rethink the French insurance system to have the

"…the same system as in Switzerland, there is no ten-year insurance. There is no insurance. There is a guarantee deduction which is higher than in France, by 10%. Then, there is a direct liability on the company's or architect's property, which will also be ten years…The ***cost of ten-year insurance, for any player in France, is almost a hundred times higher than the cost of insurance in Switzerland****. And the* ***level of claims in Switzerland is not 100 times higher than in France****".*

Architect, R12

e. Research, development & Certification cost

In the context of the circular economy and the reconsideration of the asset lifecycle, new certification should be developed. This requires research efforts and development and inevitably costs. This must be part of the strategy. We should be able to prove the recyclability of products and the level of circularity of the project. Research and development are necessary to set up this new certification program but expensive. This was reported by R13 who worked in a company that has had set up a program to be able to propose a plasterboard 100% recyclable for life. To prove the recyclability, he said that they were obliged to go through an external certification body. R14 added that a fixed cost of certification need to be taken into account and he explained

> *"…what happens at the BIM and HQE level, all the work of upstream* ***research, training, dissemination of good practices*** *or even potentially certification of these buildings,* ***it has a cost that is necessarily higher at the start****…"*

BIM Manager, R14

f. Additional cost for training & new roles-mission-tasks

In addition to research and certification costs, training and equipment acquisition are also important barriers as R11 said. When a new approach is adopted, the first project is all the time investment in time and money. Equipment and training should be taken into account. In a SEOL approach, new roles or missions will appear. R18 explained that he is doing consulting, a new role, in the implementation of a circular economy. He stressed the difficulty to get paid for it.

> "…therefore it is **very difficult to get paid to do it**, because we are under the responsibility of the architect, engineers, etc. and we work alongside the client, alongside the contracting authority".

CE Specialist & Architect, R18

> *"…you cannot bring the deconstruction contractor into the design team to help you with his expertise without being paid for that".*

Property Developer – Engineering Office, R04

g. Additional cost for storage and transportation

The additional cost generated by the needs for space for reclaimed material storage and SEOL activities was pointed out by six respondents. R17, for instance, noticed that sometimes they have to send the reclaimed materials for recycling very far, increasing their carbon footprint and the cost consequently. Furthermore, to be able to reuse some materials from a project to another, storage is a critical barrier and should be planned to avoid storage. For instance, R20 explained that they were able to reuse candelabra from a site to another because they did not have to store them. They were already installed, so they just keep them installed, until their installation in the new project.

B. Quantify and Sale the approach

How to quantify and sale the new approach to the client is a real challenge. R16 said *"to quantify how much more it costs. It has to be quantified, and that's the hard part".* The respondent R18, a circular economy specialist, said that the client needs to understand that by adopting the CE approach, he is investing that if he "…*do not make this investment in the first place, it will cost them a lot later"*. An overall project cost should be take into account the entire lifecycle of the asset. The estimation should be made differently and according to R18,

> *"…it's part of the circular economy and the approach". RD13 added that "…you cannot ignore the overall price of the building".*
>
> CE Specialist - Architect, R18

C. Client readiness to pay for the new concept

The additional cost will also affect other stakeholders and therefore increase the total cost of the project. Each stakeholder will take the new approach as a driver to increase its cost. Based on the interviewee's response, when a SEOL approach is adopted, the total costs of the projects might increase. In that case, the client readiness to pay more for the new approach is an important barrier to consider. This statement was also supported by R19.

> *"If you tell the plumber that he has to stop glueing his PVC but rather find a system like the old one. He will* ***increase his prices for sure****. But we can find clients who are ready to add +10-20% on their project for that.* ***We won't find many****, but they exist. We might find* ***clients that are ready to engage at the beginning of the project*** *but later, when they have to pay;* ***they will change their mind****".*
>
> Design Office, R03

> *"They intend to, they* ***find it good but not necessarily provides financial resources****, energy and analysis. Sometimes these are intentions that remain "dead letters".*
>
> Structural Engineer, R19

Some barriers raised by the respondents are in accordance with the literature review findings, such as the client readiness to pay for a new approach and the additional cost for the new approach. Indeed, for Reverse Logistic (RL), deconstruction and 3Rs approaches, many studies reported the cost for the approach adoption as a barrier (Jaillon and Poon 2010, Gorgolewski 2008, Hosseini et al. 2014). Zaman et al. (2018) reported that clients are not ready to pay for the adoption of Reverse Logistic approach that is not a priority for the organisations' investment (Sanchez and Haas 2018). The initial cost that must be considered for a new approach implementation was reported by several authors for various approaches RL, TB, PFA, deconstruction, disassembly, 3Rs and C&D waste minimization. Indeed, Hosseini et al. (2014) considered that for new buildings, the considerable initial cost must be required for the RL adoption (Hosseini et al. 2014). He added that RL could be costly for poor results by ending up with a few reusable materials (Hosseini et al. 2015). Chileshe et al. (2015) and Ajayi et al. (2015) supported the previous authors by specifying that disassembling existing buildings is costly (Chileshe et al. 2016, Ajayi et al. 2015). Zaman et al. (2018) brought numbers by assuming that deconstruction costs could be 17-25% higher than demolition due to labour, time and disposal costs. They also think that prefabrication and modular approach are more expensive than traditional construction (Zaman, A. et al. 2018). This is in disagreement with Baldwin et al. (2009:2069) who believe that even if the initial set up cost is higher than cast-in-situ construction, precasting can result in significant reductions in production cost (Baldwin et al. 2009).

When RL, deconstruction or disassembly are adopted, additional cost must be considered. Indeed, labour (Hosseini et al. 2014, Gorgolewski 2008, Knecht 2004), transportation and tipping fees (Forsythe 2011), cost for collection and recovery processes for C&D waste processes (Xanthopoulos et al. 2009), multiple handling and refabrication lead to increase the cost of reused components (Gorgolewski 2008). The additional cost can also be the results of specific treatments and processes for hazardous components (Hosseini et al. 2015, Río Merino et al. 2010, Nisbet et al. 2012). The difficulty to separate contaminated components from the others leads to an increase in the cost (Hosseini et al. 2015). Several authors considered that the additional cost is a result of additional time needed during the design phase for designing for prefabrication (Jaillon and Poon 2010), for 3Rs approach (Gorgolewski 2008) or Reverse Logistic (Hosseini et al. 2014). Huuhka and Hakanen (2015) stressed that insurance cost for the use of the 3Rs principle could increase the project cost (Huuhka and Hakanen 2015).

Some barriers were not raised by the respondents. For instance, the lack of ROI (Return on Investment) evidence for the benefits of using prefabrication approach represents a barrier for (Jaillon and Poon 2014) and (Xanthopoulos et al. 2009). In line with the previous studies, Pitt et al. (2009) have identified as a barrier, the lack of a business case for sustainable construction (Pitt et al. 2009). Moreover, the authors reported that for the 3Rs principle, the distribution of the construction budget is completely different and can be seen as a barrier (Sanchez and Haas 2018).

5.2.4 Barriers related to reclaimed materials

Materials related barriers are also a set of barriers raised by the respondents and split into three parts: the lack of structured market for reclaimed materials, the lack of facilities and the cost of reclaimed materials to reintroduce them into the material loop.

A. **Lack of structured market for reclaimed materials**

Many respondents have raised the lack of a structured market for reclaimed materials (R01, R05, R06, R08, R09, R10, R11 and R15). For R08, the construction waste sector must be organised in the same way as the recycling of household waste. For him, to move towards deconstruction instead of demolition, the reuse/recycling sector will be forced to exist. R06, an architect who tries to use reclaimed materials as much as he can, noticed that it started to happen a little, especially for a luxury home, for instance. He strongly believes that if the market exists and it is known where the material is located, it will work. He added that the cost of reclaimed material must be less than new materials. R15 agreed by adding that “the market is already there and they are already using reclaimed materials”. For R07, is an architect for who using reclaimed materials is at the centre of his approach. He is currently working on a project where excavation earth from the site is used as a construction material. They have also deconstructed a building onsite and plan to reintroduce the reclaimed materials into the new construction. If they need more materials, he added:

> *“…we could find out about the various demolition sites in the city, look at what materials they are demolishing and see how we could reuse these materials on the site. This is not our priority, but i**f we lack materials, that is what we would do”**.*

Architect, R07

R09 reported that the sector is not structured yet for reclaimed materia**l,** He added that the start of the market already exists, but it lacks organization. He gave the example of the BRE in the UK that tried to set up a database, but it does not work effectively. The lack of a structured market was also stressed by R10. According to him, in France, the market is more established for “old materials”**.** In France, some "recycling professionals" platform started to appear. The quantities of available materials are accessible on the platform.

> *“But the problem is that a kind of micro-ecosystem, more or less popular, is emerging in several small regions. So, there are initiatives that are being put in place, but they **are not framed and centralized**…” ”… The materials must be made available to **large purchasing centres**. Today it exists but in small pieces”.*

Digital Project Manager, R10

> *“I think there is a market for reclaimed materials, but **it is a question of organising it**. There was some talk a few years back of someone was trying to set up a database. I think the **BRE** (Building Research Establishment) **tried to set up a database** that anybody who had reclaimed materials available could put it into that database. Then, other people could access the database and find somebody who's got windows, for example…”*

Architect, R09

The lack of a structured second-hand materials market (Chileshe et al. 2015a, Nisbet et al. 2012, Forsythe 2011) and facilities (Río Merino et al. 2010, Nisbet et al. 2012) for reprocessing them were also identified by several authors. The lack of recovery facilities is also discussed by many authors in the literature (Häkkinen and Belloni 2011, Kifokeris and Xenidis 2017, Bouzon et al. 2015, Hosseini et al. 2014). Indeed, Nisbet et al. (2012) have identified more specifically, a lack of materials recovery / reprocessing facilities, especially for source-separated materials. Forsythe (2011) added that there is also a low demand for reclaimed materials. It was supported by Gorgolewski (2008) who consider that the principal issue with reuse is to coordinate demand with the supply chain. He has identified a lack of client demand (Gorgolewski 2008), also raised by Hakkinen and Belloni (2011), and Jaillon and Poon (2011) who assumed that there is no appropriate marketing plan for reclaimed materials (Häkkinen and Belloni 2011, Jaillon and Poon 2014).

B. Lack of facilities for reclaimed materials

R10 draw attention to another aspect, which is organising the recovery processes. According to R10, manufacturers are voluntary, and they started to put in place processes to be able to reuse their waste. Indeed, for instance, concrete's companies are well organised. The steel is recyclable by more than 80%.

> *"…a bit like the carpet manufacturer XX. When he started to reuse the fibres from his old carpets, it was necessary to put in* ***place channels to recover*** *his old carpets. Carpets' manufacturers are beginning more and more to have* ***new processes…"***
>
> Digital Project Manager, R10

R13, explained they have set up, in his company, a whole process with partners for recovery and recycling waste. The product produced by his company is 100% recyclable for life. They worked several years to set up a sector with the partnership. All the extra on waste under construction, are recovered and goes back into the production line. For him, they can use the processes already developed to create new processes to recycle their product during the deconstruction phase.

C. Reclaimed materials costs

According to several respondents (R12, R03, R10, R18, and R11), one of the biggest challenges for managing assets' EOL is asbestos removal. The process is costly. According to R10, contaminated materials require expensive specific treatments. R11 reported that the costs of asbestos on a project are high. In line with the previous statement, R17 also raised the cost of removing materials contaminated with hydrocarbons.

> *"The* ***costs of asbestos*** *on a project are* ***very high****, ranging from zero for those who are very lucky to sometimes more than half the cost of a demolition".*
>
> Quantity Surveyor and BIM Manager, R11

> *"…if you have a slab that contains* ***hydrocarbons****, that slab cannot be recovered. This type of waste goes into* ***different channels and is much more expensive****".*
>
> Deconstruction Engineer, R17

For participant R06, some old materials are more expensive than the new because the recovery process is time-consuming. Indeed, "deconstructing requires sorting, cleaning and standardisation". The price of the component can increase if the recovery process is not done on-site. In agreement with the previous statement, R09 reported that sometimes recovered materials cost the same price or more than buying new.

"…if you deconstruct at one place and bring it for processing to one place and bring it to another place for use: you have to ***add up the transport cost each time****. Labour is always very expensive".*

Architect, R06

5.2.5 Summary

In this sub-section, the main economic barriers were discussed. The economic context where profitability is the most important driver, leads actors to have a very short term vision and a lack of overall and holistic view of a building. The higher cost of managing the assets' EOL sustainably, the current waste and business conditions are more favourable to demolition rather than deconstruction. Indeed, the lack of clients' will for using a SEOL approach and the cost of adopting the SEOL approach are significant barriers stressed by the interviewees and many previous studies. As illustrated in Figure 31, the cost appears as the most important barrier. It was stressed by 18 interviewees over 20 (Table 5.3).

The market issue was also reported by both interviewees and literature review findings. Indeed, the lack of a structured second-hand materials market will slow down its emergence. Further, the lack of coordination between demand and supply will hinder the use of reclaimed material. Another obstacle to the development of the reclaimed materials market is the lack of facilities. SEOL management will generate a huge amount of materials that must be absorbed by the development of reuse and recycling facilities. The creation of a centralised database for reclaimed material will help to balance the demand and supply. Another important issue is the lack of facilities for reuse and recycling recovered materials.

Table 25 lists the twelve economic barriers identified by the twenty interviewees but not found in the literature review undertaken for the research. Additional barriers were found in the literature but not identified by the interviews participants. For instance, according to Kifokeris and Xenidis (2017), constructability principles and its implementation have to face a set of barriers, including finding a place in a highly competitive construction market (Kifokeris and Xenidis 2017). Zaman et al. (2018) stressed that the current waste and business conditions are more favourable for demolition rather than deconstruction (Zaman, A. et al. 2018). Authors try to investigate how deconstruction could be a more viable option for materials recovery. For Chikeshe et al. (2018), the main problem is the uncertainty about the results for the use of Reverse Logistic approach (Chileshe et al. 2015a). The difficulty to source and locate reclaimed components is also a barrier identified by a couple of studies (Chileshe et al. 2015a, Gorgolewski 2008, Hosseini et al. 2015).

Table 25 Economic barriers identified by the respondents and not found in the literature (Source: Author).

	ECONOMIC BARRIERS
1	Modernization bad sides: less manpower and more mechanization
2	Using SEOL approach: more work in the design and construction phases
3	The pressure to get the project done
4	Schedule issues
5	Time needed for adaptation to new approaches
6	Cost of tools and processes
7	Cost for the FDES process
8	Less choice - Number of manufacturers & stakeholders working with this approach
9	Research, development & Certification cost
10	Quantify and sale the approach
11	Market preparation
12	Reclaimed materials costs: sometimes more expensive

Figure 31: The word cloud frequency for economic barriers (Source: Author)

Table 26: The summary of the results for the economic barriers (Source: Author)

ECONOMIC BARRIERS																				
BIM Users / BIM Manager																				
Roles	Designers						FM			Owners			TE	E	QS	M	SE	CO	D	R&D
Respondents	R06	R07	R09	R12	R16	R18	R02	R15	R14	R04	R20	R01	R10	R03	R11	R13	R19	R08	R17	R05
521-Economic Context -Profit-seeking first																				
A-Financial asset that is important			x														x			
B-Interest only the money													x							
C-Short term vision - Looking for profitability only					x								x							
522-Sustainable EOL versus demolition																				
A-Modernization bad sides - less manpower and more mechanization		x		x																
B-SEOL approach is more expensive than demolition										x		x	x	x		x	x		x	
C-EOL duration and labour cost	x				x								x			x	x	x	x	x
D-Estimation challenges														x					x	
523-The drawbacks of using new approaches for a SEOL																				
A-Cost of the approach	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x		x	x
B-Quantify and Sale the approach					x	x	x									x	x			
C-Client readiness to pay for the new concept					x	x						x		x						
524-Barriers related to reclaimed materials																				
A-Lack of structured market for reclaimed materials	x	x	x			x		x		x	x	x	x		x			x		x
B-Lack of facilities for reclaimed materials	x					x					x		x		x	x		x		
C-Reclaimed materials costs (transport, treatments, recyling and reuse)	x		x	x						x	x	x	x	x	x	x			x	

(FM) Facility Managers, (TE) Thermal Engineer, (QS) Quantity Surveyor, (CO) Control Officer, (DE) Deconstruction Engineer, (SE) Structural Engineer

5.3 Political barriers

The discussion of the political barriers is based on the current perception of the interviewees for moving from conventional demolition to a more sustainable asset EOL management such as a structured deconstruction or dismantling to recover materials. The political barriers are split into three parts: the weakness of regulations, lack of policies and weaknesses, and the willingness to get around the law. The number of respondents and quotations are reported in Table 27.

Table 27: The number of respondents and quotations for the political barriers (Source: Author)

53-POLITICAL Barriers	**Respondents**	**Quotations**
	15	**70**
531-The weakness of regulations	**10**	**16**
A-Gap between political will & the reality	2	3
B-Policies corruption and lobbies issues	9	13
532-Policies lack and weaknesses	**13**	**53**
A-Lack of policies-regulations	10	29
B-Policies weaknesses	9	15
C-Policies absurdity and complexity	6	10
533-Willingness to get around the law	**3**	**3**

5.3.1 The weaknesses of the regulations

A. <u>The gap between political will & the reality</u>

R05 and R08 draw attention to the fact that one of the regulation powerlessness is that there is always a gap between the political will and what is happening on the ground. The first step is the acceptance of the policies by the population and then their actual application by population. R08 emphasized these arguments by saying that imposing the new approach by regulation is the first step, but it’s not enough.

Indeed, the weaknesses of the regulation were also reported for Reverse Logistics principles and C&D waste management. Hosseini et al. (2015) reported that Buildings’ inspectors or control officer, who have the responsibility to check and validate the regulatory conformity of the building, usually discourage the use of salvaged materials in new buildings (Hosseini et al. 2015). The poor reactivity of the government for regulations’ application stressed by R12 and R08 was also reported by Rio Merino and Gracia (2010). They consider that governments are slow to apply C&D waste management plans which have been approved (Río Merino et al. 2010).

The respondent R12 is an architect who follows a sustainable approach by trying to avoid finishing works by paying more attention to the structural work during its design and the construction phase. He strongly believes that the principle of this whole construction system or industrial products is political. In his projects, he reverses the process by giving to the on-site workers the possibility to use as much as possible their know-hows. All the design and construction is rethought, and the manufacturer's role is reduced as a minimum. The project budget is re-distributed to reduce the power of the manufacturers.

> *"…the aim is to hide all the know-how that is traditionally on the site. They want to bring the know-hows completely upstream into the factory manufacturing phase. That there is a little know-hows as possible on the site but only assembly". "…all this movement, to* ***transfer the capital from the site to the factory, is only made for the benefit of the manufacturer****".*

Architect, R12

> *"…****if there is no criminal law behind*** *it; it is worth nothing. In the regulatory process, there* ***must be criminal law****…"*

Control Officer, R08

B. <u>Policies corruption and lobbies issues</u>

Seven respondents raised lobbies barriers. They all agree on the lobbyist power in the construction industry. R04 said that even the French FDES, the materials technical data sheet (MTDS) that will be useful for knowing what is the product's composition, are biased. In support of the previous argument, R09 stressed that the lobbyist power is huge and difficult to overcome. According to the three interviewees, the lobbies' barriers represents substantial political barriers that will be hard to overcome.

> *"…because, every time they try and make some environmental improvements,* ***all the lobbies organisations are there"****.*

Architect, R09

> *"…the FDES have a state approval which is issued by a* ***commission where sits all lobbies****".*

Property Developer – Engineering Office, R04

> *"…the environmental regulations embodied by* ***the FDES(French products' technical sheets) and the RT 2020 are written by lobbyists for lobbies****".*

Research & Development, R05

5.3.2 Policies lack and weaknesses

A. <u>Lack of policies-regulations</u>

a. Lack of Government approach

R10 noted that a French government approach around the reclaimed material market doesn't exist. We want them to be responsible for the choices made today for the impact they will have tomorrow. Assessing that is impossible without setting up legibility and traceability of the responsibilities. R11 gave the example of CPE, the Energy Performance Contract and assumed that could be invented in the same way a *"deconstructibility performance contract"*. Regarding deconstruction, Zaman et al. (2018) stressed that strategic commitments and national policy fare usually lacking. The benefits of government commitments are crucial for the growth of relevant business and community groups deconstruction and reuse activities (Zaman, A. et al. 2018).

b. Lack of standardisation and regulations

R06 complained that for their earth project building with excavated earth, they struggle because of a lack of standardization for earth material and also for material recovery. R19 added that due to regulatory brakes for non-conventional material and techniques, the CSTB (Centre scientifique et technique du bâtiment) and the control officer have no standards to rely on, and they prefer to refuse rather than taking risks.

The standardization is also missing for the material description and represents a barrier raised by R12. Again, based on his experience in Switzerland, he said that the fact that the lack of a homogeneous description base that will simplify the exchange of the data, raise the problem of compatibility between different software. It would also raise the problem of trust since a reference base would not be uniform. R10 gave the example of the spreadsheet used for COBie in the UK. He said that it is a simple way to get

> *"…more reliable, simple and more accessible formats to everyone". For him, it is important to have "**standardized formats imposed by the government and unified at a world level**."*

Digital Project Manager, R10

In line with previous interviewees' statement, academics' authors have reported a lack of standard building layouts for prefabrication for instance (Jaillon and Poon 2010) and standardised processes and shared best practices for Reverse Logistic (Chileshe et al. 2015a). Moreover, building codes must be adapted for approaches such as disassembly or deconstruction. Globally there is a lack of legislation for these approaches, especially DfD (Design for Deconstruction) or DfDi (Design for Disassembly) (Jaillon and Poon 2014). The lack of building codes for reclaimed materials was identified in numbers of studies, for deconstruction and Reverse Logistics principles (Chileshe et al. 2015a, Knecht 2004, Jaillon and Poon 2014, Couto, J. and Couto, A. 2010). The Recertification, legal warranties and residual performance of recovered building materials are also an area where improvement should be made (Chileshe et al. 2015a, Häkkinen and Belloni 2011, Jaillon and Poon 2014, Akanbi et al. 2018, Couto, J. and Couto, A. 2010). Some authors reported a lack of legislation mandating C&D waste reduction and diversion (Ajayi et al. 2015, Nisbet et al. 2012).

When non-conventional material is used, the insurance problem is faced due to a lack of regulation. R05 reported that for their earthen architecture projects, to get insured they must go for a “technical certification". In fact, in France, the ATEX procedure is used for innovative techniques that are not covered by regulation. This process is complex, time-consuming and costly, as described by R19:

> *“…we submit a file that must anticipate all the possible questions, and there is no discussion and exchange, as we can have in this classic site approach with a technical controller”. “…there are no possible discussions upstream…”, “… only at the end, we are invited to answer questions, but generally, it's already folded before. Because the commission meets, it makes its decision, and the claimant behind it is eventually heard.”*

Structural Engineer, R19

A rejected ATEX can push the client to stop the project because there is no real possibility of going back and forth and providing additional information. According to R19, the main drawback for the ATEX procedure is that there is no exchange with the commission bodies.

c. Lack of regulations for Contracts

Regarding the contract, adaptation should be made. If we want to achieve the aim of the project to have an asset with a SEOL, everything needs to be clearly defined right in the beginning. All the stakeholders involved in the project should sign the concept of deconstruction as stressed by the respondent R09. So, the critical part is the writing form of contract and specification that makes it clear what must be done. Many studies have stressed that the traditional contracts formats are not appropriate for reuse and recycling practices (Cruz Rios et al. 2015, Jaillon and Poon 2014). R09 concluded by saying. Because we all want these aims but

> *“…then when the contractor comes along and gets the job. They say, **no we don't do that**. This is how we build, and this **is how we're going to build it**”. “…if **they don't all sign up to it then it’s not going to happen**. But achieving that is going to be **quite difficult**”.*

Architect, R09

R20 stressed that they involve the facility manager early in the design for projects with a high energy performance goal, especially when they want to monitor the building performance in accordance with what is decided during the design phase. Their aim is to thwart the projects that are less successful in reality compared to their performance on paper.

> *"...there is a **third stakeholder** who intervenes very early in the project, he is already there in the study phase ...He has to guarantee thermal and operating performance".*

> *"This has not generated any major changes, but it has generated a bit of a transfer of responsibilities, and it is also new contracts".*
>
> Owner - Engineer, R20

B. **Policies weaknesses**

a. Current regulation weaknesses

Several respondents highlighted the weaknesses of current regulations as an important barrier. For example, R09 put into question the robustness of the UK Construction Products Directive. His thought is that it should be much stronger to face the power of the lobbies' organisation (described previously in section 5.3.1-B). Equivalently, R12 stresses the weakness of the regulations by saying that

> *"…**manufacturers are strong enough** always to c**over themselves with as few responsibilities as possible.** They still have a fairly easy opportunity to say that **the implementation did not fully comply with their specifications**".*
>
> Architect, R12

R04 supported the previous argument by saying that *"…Regulation protects them, and you can't go against that*". He gave an example of the MTDS of the product and the secret data. In fact, according to the regulations, manufacturers are allowed to keep secret part of the data and the calculation methods. A lack of transparency is observed between extraction and manufacturing in the name of intellectual protection. They can give only results (R05). However, materials composition is crucial for reusing or recycling materials, as stressed by many authors. Indeed, authors addressing the 3Rs and Reverse Logistics principles raised the necessity to give clear information for the client and the design team about the specification of reclaimed components and recycled materials that are currently lacking (Gorgolewski 2008, Río Merino et al. 2010). The regulation weakness was also pointed out by Hakkinen and Belloni (2011) (Häkkinen and Belloni 2011).

b. The waste diagnostic is not part of the building permit

In support of the previous argument, R08 mentioned that in France, the waste diagnostic document is not part of the building permit documents. Therefore, it is ignored by the administration, developers and architects. Often, the control officer asks for a waste diagnosis for a project with more than 1000 sqm. Then, this is left to the discretion of the company. There is no control or follow-up. On another point, R19 also raised the concern about the global vision and the lifecycle analysis. He considered that it is often useless. According to his experience, the results obtained lead rarely to real design and adjustment of the project. In addition to that, a lack of accuracy and details drive to inconsistent results. Therefore, R19 believed that life cycle analysis seem to be biased, and it is not a design tool that can support designers and clients in their choices. R05 also reported the bias for the FDES sheets.

"... If a building with more than 1000 m2 of floor area is destroyed, a ***waste diagnosis must be made****. It is an inventory of all the materials present in the construction with their quantities. It is a diagnosis that is made from an on-site visit, and an inventory of materials is made…Since you demolish* ***more than 1000 m2, you need the waste diagnosis****".*

Control Officer, R08

"…This tendency to have this global vision is quite recent. It's progressive. It is rather HQE and fluid offices that do these analyses. In our experience, it is often useless because we ***either quantify materials or we quantify the CO2*** *emitted and the energy consumed, but why do we do that?" "…Typically for concrete…they do not take into account what the percentage of reinforcement is. What percentage of cement will be put in. How far do the aggregates come from. Are they recycled or not? Often, they do calculations,* ***they come up with figures, but it seems like it's a bit of a breeze****".*

Structural Engineer, R19

"… We are dealing with people who have already participated in drafting the regulations upstream. Besides, they have set up environmental engineering firms to try to optimise their sheets. The ***carbon impact of stone is greater than that of concrete. That's because they cheated****".*

Research & Development, R05

c. Insurance approach by anticipation & by a-posteriori

As mentioned previously about cost barriers, R12 proposed to rethink the French construction insurance by using Switzerland as an example. Based on his experience as an architect in Switzerland, he mentioned that the skill level of construction workers is much higher due to the high quality of their vocational training centres for apprentices, the apprenticeship system. They have *"insurance by prevention rather than by distribution"*. He was involved in a study aiming to compare different insurance systems in Europe to identify if it is insurance by anticipation or by a-posteriori. The results show that the French system is an "a-posteriori" system for repairing. He added that his role is

"…to build a building ***that will last and that will only last ten years****". In France, the architect's responsibility also ends after ten years.*

Quantity Surveyor – BIM Manager, R11

"…the French system is more ***like repair****.* ***We admit that people are not very competent****. As a result,* ***they cannot be held responsible****. So we put in an insurance policy that pays for the repair of the damage. It is costly for the company".*

Architect, R12

C. **Policies absurdity and complexity**

a. Insurance liability is complicated

R12 reported that for reusing reclaimed materials, he faces insurance and responsibility issues. In some projects, companies don't want to take responsibility for reusing materials. They intuitively recognise their value, but they refuse to take the risk contractually. The French insurance system is complicated, and often, the reclaimed materials are not used for liability reasons. They said,

> *"Yes, it is true that it is stupid to throw away these materials, but* ***we can't take responsibility****".*
>
> Architect, R12

The insurance issue will depend on the material used. For example, if we ask a carpenter to reuse the lumber to do something else, he will be more hesitant because he is not sure that the wood is of good quality. For projects using Earth material, almost 80% of reuse can be achieved. People keen on that kind of material have a voluntary approach, and for them, the use of local earth rather than "industrial" earth is more than a sign of quality.

b. Regulation absurdity, complexity & strictness

The regulation's absurdity and complexity was also pointed out by several respondents. One of the biggest absurdity is the French ten year's responsibility insurance. According to R05, the complexity around regulations for the energy transition generated business and turnover. For the French construction permit, for instance, the prices don't stop to increase, years after years. Comparably, the absurdity is that even if you can prove that a technique works without causing any harm, you cannot do it because it is forbidden by the regulation. So you must go for a conventional technique or a long and costly Atex procedure (R07).

Furthermore, the strictness of the regulation can have a negative impact such as, for instance, slowing down the reuse of materials. Recycling will be preferred to reusing due to regulation. For example, for a window, it is not possible because of regulations issues. By supporting the previous respondent, R18 mentioned when he is deconstructing a building he used to reinject the recovered materials into a new project.

> *"...must have the* ***acoustic, thermal, finishing label, anti-breakage*** *characteristics of the glass, etc."*
>
> Quantity Surveyor – BIM Manager, R11

> *"…But it is still difficult to do it because* ***regulations and insurance do not yet follow*** *in many countries except Holland".*
>
> CE Specialist - Architect, R18

Many authors have come up with regulation complexity as a barrier. Indeed, the legislation rigidity may act as a hinder for sustainable building development and Reverse Logistic adoption (Häkkinen and Belloni 2011, Hosseini et al. 2015, Kifokeris and Xenidis 2017). According to Forsythe (2011), the complexity of regulation is also a brake for the adoption of the 3Rs approach (Forsythe 2011). Some authors considered that governmental regulations are inappropriate for RL approach (Chileshe et al. 2015a). Other research stressed the lack of consistency of policies for deconstruction (Zaman, A. et al. 2018). Another trend is to consider that policies are not adapted for C&D waste minimization and management (Zaman, A. et al. 2018, Río Merino et al. 2010, Ajayi et al. 2015).

5.3.3 Willingness to get around the law-Willingness to cheat

The issues with regulations are the control of their effective application. The human nature is to try to cheat and find ways to get around the laws. This was stressed by R04 who said for that

> *"…Deconstructing cleanly in a structured and ecological way will cost too much, and some will* ***display processes for communication, but behind they will do as before****".*

Property Developer – Engineering Offices, R04

The high prices of implementing the SEOL approach will push them to find ways to get around regulation. R03 took the asbestos regulation as an example and said that the constraints and prices are so high that for some of them, "…it goes to the dumpster discreetly". Others will try to get around the strictness of the regulation by using smart and ecological alternatives to achieve their aims. This was the case for the respondent R07, who wasn't able to use stone in one project due to seism regulation. To solve this problem they

> *"…****make a reconstituted stone with lime and the materials of the site*** *which we will chain in angle and which we will pre-stress with tie rods".*

Architect, R07

5.3.4 Summary

Table 5.6 summarizes the findings and which respondent has reported which barriers. The barriers related to the lack of policies and weaknesses are the most recurring. They are identified by 12 interviewees over 20 participants. In a SEOL approach, the aim is to recover material from deconstruction or disassembly, as much as possible. To be viable, the market, as discussed in the sub-section 5.2, must be set up and have a right balance between supply and demand. From the political point of view, the recovered material must be re-characterised, re-certificate to be compliant with regulations. This will help with overcoming the insurance barrier raised by several respondents and authors (Figure 32).

The willingness to get around the law was not found in the literature. It was reported by R18, the Circular Economy specialist, as a driver. He explained that for its projects, to avoid that, he defines specification and prices by taking into account what the suppliers are capable of doing. This allows them to avoid cheating on quality to be able to stay in the prices and win the bid by being the cheapest. The seven political barriers identified by the interviewees but not found in the literature are listed in Table 28

Table 28: Political barriers identified by the interviewees (not found in the literature)(Source: Author)

	POLITICAL BARRIERS
1	Policies corruption and lobbies issues
2	Contracts not adaptaed for new asset life cycle
3	Insurance problem for non-conventional techniques: Use of ATEX costly and time consuming
4	Wste diagnostic is not part of the building permit
5	Insurance approach "by anticipation" and "by a-posteriori"
6	Insurance liability is complicate
7	Willingness to get around the law

Figure 32: The word cloud frequency for political barriers (Source: Author)

Table 29: The summary of the results for the political barriers (Source: Author)

POLITICAL BARRIERS																				
BIM Users / BIM Manager																				
Roles	Designers						FM			Owners			TE	E	QS	M	SE	CO	D	R&D
Respondents	R06	R07	R09	R12	R16	R18	R02	R15	R14	R04	R20	R01	R10	R03	R11	R13	R19	R08	R17	R05
531-The weakness of regulations																				
A-Gap between political will & the reality																		x		x
B-Policies corruption and lobbies issues		x	x	x	x					x			x		x	x				x
532-Policies lack and weaknesses																				
A-Lack of policies-regulations	x	x	x	x							x		x	x	x		x			x
B-Policies weaknesses			x	x						x	x		x		x		x	x		x
C-Policies absurdity and complexity		x		x		x								x	x					x
533-Willingness to get around the law		x								x				x						

(FM) Facility Managers, (TE) Thermal Engineer, (QS) Quantity Surveyor, (CO) Control Officer, (DE) Deconstruction Engineer, (SE) Structural Engineer

5.4 Sociological barriers

Table 30 summarises the sociological barriers reported by the 20 interviewees. The barriers for the incorporation of a SEOL into the asset lifecycle are classified into five sections: The first set of barriers are the unrealistic hypothesis of the approach. The second set is the societal trend as barriers. The third and the fourth are barriers related to lack of awareness, demand and understanding. The last set of barriers are related to human behaviour. The most cited barriers are the one related to human behaviour, followed by a lack of awareness and demand. In the following section, the sociological barriers will be described.

Table 30: The number of respondents and quotations for the sociological barriers (Source: Author)

54-SOCIOLOGICAL Barriers	Respondents	Quotations
	18	**105**
541-Unrealistic Hypothesis	**7**	**11**
542-Societal trend	**6**	**10**
A-Consumer society	4	7
B-Aesthetic trend	2	2
C-Bad image of prefabrication	1	1
D-The building lives badly socially	1	1
543-Lack of understanding, Awareness & Demand	**9**	**22**
A-Lack of information - demand	4	6
B-Lack of understanding	4	6
C-Awareness of deconstruction approach	2	3
D-Lack of concern	6	13
544-Human behaviour	**12**	**54**
A-Cultural Believes	7	11
B-The scale of thinking-Lack of global vision	2	3
C-Human-Influence	2	3
D-Lack of trust	5	7
E-Impatience - Want a ROI quickly	3	5
F-Resistance to change	12	40

5.4.1 Unrealistic Hypothesis

The first impression of some respondents was to qualify the approach presented to them as "unrealistic assumption", "field of hypothesis" (R16) and "utopian" (R17). For example, R03 believes that the improbability of the approach is because

> *"…**the one who design will be responsible for what he does even several years later**".*

Design Office, R03

This argument was supported by R05 and R20 who said that if 30-100 years are considered for the scale of a building, it is unlikely that the stakeholders will have a clear vision and concern on the asset fate. He added, *"…the real clients in real life **don't care about deconstruction**".*

> *The end of life has great difficulty, that of being able to project into a **distant future, 50 or 100 years**, and imagine "**how to build to demolish better, deconstruct, disassemble the building**".*

Owner – Engineer, R20

Similarly, R06, who is an architect dealing already with the SEOL approach, reported that when he wants to reuse some reclaimed materials, he faced difficulty with making them accepted by local businesses. He gave an example of a building where he wanted to keep the old shutters.

> *"…the price was **half as high**, and the **old shutters could last another 50 years** while the **new shutters would last 10-15 years**". But he said, "…**local businesses found it completely absurd and stupid**".*

Architect, R06

To solve the problem, he asked Romanian companies who know how to do this because they are used to it. Some companies know how to do this more than others. Comparably, R18 faced the same issues for a project that was originally designed to be both a business park and offices. Even if nobody believed that we could do office work in that place, the architect proposed the "agility approach", to make the building able to be the "one or the other" or to "one and the other".This importance of flexibility was identified in the literature for 3Rs and DfDe approaches during the design phase. Indeed, Gorgolewski (2008) reported for the reuse of materials, design flexibility and adaptability are key (Gorgolewski 2008). Based on two case studies, Jaillon and Poon (2010) have identified the benefits of using adaptability and DfD approaches allowing flexibility and future extension without demolition, from the design phase (Jaillon and Poon 2014).

5.4.2 Societal trend

The societal trend is also a barrier for moving to new approaches in general. Our society is qualified as a consumer society where goods have a very short lifespan. We have the habit to "buy, use and then throw" goods away. The circular system of the SEOL is the opposite of the current linear system. Goods should be designed to have a sustainable End-of-Life and not to be dump into landfills. R01 questioned

> *"For whom would that be a barrier? It is the industrial world, which voluntarily produces elements with a short lifespan. The goal is to **push people to consume**. Today when we buy something, **we know very well that its lifespan is short. Goods are designed with that goal**".*

BIM Manager, R01

In support of the previous argument, R06 gave the example of the plasterbord partition. The current one is designed to last "…let's say 20 years, before, we made a partition that lasted 100 years". The aesthetic trend and evolving mores are important parameters (R08 & R01). R12 believes that there is also a generational issue. Another type of societal issue was raised by R20, an engineer working in the "owner side". He said that usually, the EOL of buildings destined to demolition it is not necessarily a natural EOL.

> *"Buildings that have been demolished are often for urban reasons, for reasons of bad living. Or **building socially lives badly**. So it is its configuration in the city, or its entry/exit configuration, serving housing that leads to demolition, but it's rarely due to a dilapidated condition..."*

Owner – Engineer, R20

> *"I see that architecture students have a very different relationship to all this than architects in their fifties, for example. There is also a **generational issue** that is clearly changing. Architecture students are all fans of reuse".*

Architect, R12

The societal trend was also pointed out in the literature, especially the consumer attitude, the belief and acceptance regarding reclaimed materials. Indeed, Ajayi et al. (2015) reported that there is a culture of waste as an inevitable problem in the construction industry (Ajayi et al. 2015). They also stressed the strong belief among construction industry practitioners that waste management is an expensive task (Ajayi et al. 2015, Häkkinen and Belloni 2011). The bad image of second-hand materials and the false belief of their poor quality are also barriers raised by many authors (Jaillon and Poon 2010, Hosseini et al. 2014, 2015, Huuhka and Hakanen 2015).

5.4.3 Lack of Awareness, understanding & Demand

A. <u>Lack of information-Demand</u>

Deconstruction or dismantling is not a hot topic. In France, it is just started to hear about it, but that's not the general trend to design with the end in mind (R01). This raises a lack of communication that should be overcome. R16 said that the problem is that we don't talk enough about deconstruction or dismantling, even

> *"…deconstruction represents **80% of the market in Paris**. There are very few buildings that are completely demolished to the ground to be rebuilt".*

Architect – BIM Manager, R16

B. <u>Lack of understanding</u>

R06 draw a parallel with the energy and people understanding. He explained that in his office, made with mostly reclaimed materials and structural wall are made with concrete and earth. He wanted to build in pudding gravel, but we cannot find it on site. So he had adapted his choice to what he could found on site, which was earth. So he made a concrete, metal and wood structure with walls made of earth, 60 cm thick. People don't understand that Indoor Air Quality is related to the material. They realise it when they go to his office. If we want people to be aware and understand, we should show them examples. R18 strengthened this argument by saying that

> *"Very often, real estate developers or decision-makers* ***rarely go outside to see what is happening****". "…in terms of energy savings,* ***people do not understand anything****. They are* ***not as informed as they should be****". "…So, it creates a pleasant indoor air quality in summer and winter".*

CE Specialist - Architect, R18

R01 and R02 based their answer on their BIM implementation experiences. They said both, if people don't see their interest in the new approach, they are not going to adopt it. They must have a clear picture of what they have to gain. Many authors also identified this for the Circular Economy and Reverse Logistic approaches. Indeed the studies stressed the lack of awareness and understanding' potentials and benefits of using CE and RL approaches (Chileshe et al. 2015a, Sanchez and Haas 2018, Pulaski et al. 2004, Hosseini et al. 2015, 2014).

C. Awareness of deconstruction approach

According to R15 and R01, awareness is a very important barrier. R01 believes that it is not a "hot topic" in France; he did not hear much about SEOL approaches. He thinks that not everyone is aware of this approach. R15 also stressed the awareness,

> *"The main barrier, I think the* ***awareness of the stakeholders*** *of the* ***benefits*** *of this phase. I think this is the main barrier. Awareness, really aware of it. And* ***somebody to tell people and help put standards in place****".*

BIM Manager – Facility Manager, R15

The previous arguments are in line with the literature. Indeed, awareness for several sustainable EOL approaches, Reverse Logistic, Deconstruction, 3Rs, and C&D waste management was found in several studies. For instance, for deconstruction approach, many authors raised the lack of popularity of the deconstruction techniques as a barrier. The lack of social engagement and community welfare benefits are also impediments for deconstruction adoption (Jaillon and Poon 2014, Zaman, A. et al. 2018, Couto, J. and Couto, A. 2010). For sustainable buildings, studies show a lack of knowledge and the ignorance of existing SB technologies. General awareness is a barrier, specifically client awareness (Häkkinen and Belloni 2011). Many authors pointed out the awareness as a hurdle for the adoption of 3Rs and C&D waste management approaches (Huuhka and Hakanen 2015, Nisbet et al. 2012).

D. <u>Lack of concern</u>

The lack of concern barrier was raised in many studies, whether 3Rs or C&D waste management approaches (Häkkinen and Belloni 2011)(Bouzon et al. 2015, Río Merino et al. 2010). In line with the literature review findings, the concern is also a barrier pointed out by several respondents. R13, a manufacturer said that in his company, they don't think about deconstruction yet, even if they have put a lot of efforts the last years to be able to propose a product 100% recyclable for life. He said that it might be the next step for his company to be able to propose demountable plasterboard partition. R16 and R18 reported that for most of their clients, to know how the asset will be deconstructed and the future of the planet, it's not their problem. Furthermore designing an office building to be able to sustainably manage its EOL is something that is not possible to do with most of the client. He has said

> *"…in 25 years, it will be a long time since I left my job! So,* ***knowing how we will deconstruct the building, I don't give a damn****".*
>
> Architect – BIM Manager, R16

> *"…I believe that today,* ***deconstruction is not a concern****. We are just beginning, on several projects, to think very early on about the maintenance of the building".*
>
> Manufacturer – BIM project Manager, R13

He added that in general, individual doesn't care what happens next. For example, environmental concerns have not changed much. He concluded that if one wants to change things, these things should be imposed. R06 said nowadays; concrete is used without worrying about the end of the building's life. Regarding excavation earth, he added that for the building industry, they are not yet convinced to recover it and reuse it. For material selection and the use of inflammable materials, this is also the same dilemma. Based on his building that he designed to be dismantled, R09 said

> *"…for me, it seems obvious, to use no flammable materials that are full of toxic chemicals, but I seem to* ***be one of the few people in the world that thinks that****.* ***Nobody else seems to bother about it****". "…if we start trying to do that for clients, that's much more difficult. Because* ***they're not interested****".*
>
> Architect, R06

5.4.4 Human thinking and behaviour

A. <u>Cultural Believes</u>

a. Construction associated with durability

One of the biggest challenges is to change the way we used to think. Designing buildings by thinking about what will happen at the end of their life is something hard to do and unusual. R10 and R06 agreed to say that we make houses to last, and not to deconstruct them. Following the precedent respondent, R05 proclaimed that “culturally, Human are not nomads“. In France culturally, constructions are associated with the concept of durability and the fact that they last over time. As expressed by R05,

> *“…in a builder's mind, it is not at all-natural to think that what he builds will be demolished”.*

Research & Development, R05

> *“…in fact, even on a heritage scale, it is sometimes complicated to think about demolishing your building. In the same way that as a human being, it is difficult to talk about death. Maybe it will be a "psychological break". I think philosophically it will disturb some of them”.*

Quantity Surveyor – BIM Manager, R11

b. False belief: impact of the finishing works

Construction is usually split into two categories: the structural works and the finishing works. Several respondents reported false stereotypes about their ecological impact. R05 mentioned that they struggle to get approvals for using earth as a material in their projects. The advantage of earth structural walls is that they are kept visible and not recovered with plaster, as usually made in with concrete. Therefore the finishing works are diminished. He said,

> *“…the* ***finishing work has a much more serious ecological impact*** *than the earth…”*

Research & Development, R05

> *“…we talk about the deconstruction of the structural work, but the* ***biggest part of the deconstruction is the finishing work****”.*

Design Offices, R03

c. False belief: the use of reclaimed material

Another false belief is around the use of reclaimed material. R06 thinks that sociological barriers are important. This architect has completed several projects by using the approach of reusing reclaimed materials. The issues faced are that people understand that the interest of recovering materials but some of them think that it is dirty and not beautiful. He thinks that for a lot of them, they still have a kind of belief that a material that comes out of a plant is more reliable than a material found on site. R12 stated that

> *“Yes, it's trust, it's the image, and it’s the social representation: that's all it is".*

Architect, R12

The lack of acceptance for salvaged materials was identified in many previous studies, especially for the RL and 3Rs approaches. Indeed, there is low acceptance of salvaged materials, precisely due to architects' belief that reclaimed materials are risky and have a low quality (Hosseini et al. 2015, Ajayi et al. 2015). Many authors have also identified the poor acceptance of used materials by designers, owners, contractors and regulatory agencies (Häkkinen and Belloni 2011, Nisbet et al. 2012).

d. False belief: the use of modular construction

According to R18, the modular approach has also a very bad image comes from the sixties. Nowadays, this bad image still exists, and people still refer to that time. People say

> *"Oh yes, I see, like schools that were maintained for 50 years when they were supposed to last ten years" and so on".*
>
> CE specialist - Architect, R18

B. The scale of thinking: not a global vision

Conforming to R10, a building is designed to last at least 25 years. But the reality is different. Indeed, generally from the first year, it undergoes modifications. Today, we tend to have a limited vision at 25 years, which is roughly one generation, and we leave the problems for the next generations. This lack of global vision is a real barrier to the approach of designing for a SEOL. This agreement was also reported by R11 who said that as a BIM Assistant to the Contracting Authority, I have faced this issue and told the design team

> *"...here you are **just thinking at your task's scale**...we must deal with heritage issues that are much broader..."*
>
> Quantity Surveyor – BIM Manager, R11

C. Human is influenceable

The capacity for Human to be influenced was also reported as a barrier by two respondents. R10 explained that architects generally meet many material suppliers to create their own material libraries. And a very common behaviour is that when they like material, they will "...try to use it**,** no matter what and whatever the financial impact on the project". They were influenced by the material supplier and their choice lacks to be objective. Indeed, R02 pointed out the importance of having a very structured and solid supply chain because he said that "...if you have one that brake, it slows down everybody".

D. Lack of trust

a. Lack of trust in the "as-built" documents

The architecture design of a building does a lot of drawings. Then, what built is quite different from lots of drawings. R09 explained that they often get involved in projects where there are already drawings. The owner doesn't want to pay for a new survey, and he pushes to use the existing drawings. But we disagree because we want to do our own survey. Finally, we usually find that the drawings are wrong. So, "as-built" is a problem. In the UK, it's very unusual for a client or a contractor to provide a full set of drawings when they hand over the building. For him, the BIM model will not stop this kind of issues. He stressed the fact that the builders are constantly substituting materials. He said:

> *"…very often, people* ***don't even know what material was used in the building****".*
> *"…it's only a model, and* ***it's not telling you what the actual materials are****".*
>
> Architect, R09

b. Lack of trust in the "In use phase" updating

Comparatively, R10 draw attention to the "In use" phase and the modification that might happen during the asset lifecycle. Updating the model "as maintained" must be made rigorously. Undoubtedly, we can face the case to a substitution of material during the in-use phase. We can have a building handed over "deconstructible or dismountable" but became non-deconstructible due to the non-respect of the initial requirements. This also raises the importance of the traceability of the work that will be addressed later. For example,

> *"...****the screw systems have been transformed****, during its execution phase, with elements that are* ***welded and that are no more deconstructible at all****".*
>
> Digital Project Manager, R10

c. Lack of trust in non-conventional materials

R19, R03, R04 and R12 raised the lack of trust in "non-conventional" materials such as earth or reclaimed materials. R12 extended the barrier of trust to a social representation.

> *"…Yes, because when we talk about raw earth, some people are aware that there is a significant heritage in raw earth. But there are not many people who would have the idea of building raw earth today. People* ***can easily doubt the material****".*
>
> Structural Engineer, R19

> *"…Yes, it's trust, it is the image, and it is* ***a social representation****. That's all it is. Then we try to explain to them that all that comes out of the factory is going to create Chernobyl, that's what makes the climate unstable, that's what creates unemployment. So you cannot trust them at all. And it's more of an ideological or political issue".*
>
> Architect, R12

d. Lack of trust in the workers

R18 raised the lack of trust among the stakeholders, especially the supply chain. To solve that issue and avoid struggling throughout the project with variants proposed by suppliers, he used to involve them at the beginning of the project and give them accurate specifications. The lack of workers' trust was also stressed by R09, saying that workers are continuously trying to substitute materials prescribed by the architect.

> *"…If you don't have the demolition workers, you won't have the cement workers; you won't have the concrete workers behind who will follow. After the demolition workers, there are, in fact, the suppliers. Construction companies have to trust from the start, that they have a lot of knowledge and that in general, they use it, after that to cheat. If we have **defined a price and specifications** without taking into account what they are capable of doing, they will **cheat on quality to be able to stay in the prices**, to be able to win the bid by being the cheapest. And if we haven't put in the specifications, all this notion of quality, recovery of materials, quality for health, they'll come up with anything".*

CE specialist - Architect, R18

E. Impatience - Want a quick Return Of Investment

As reported by R07, the human capacity to be impatient and want to see the results "right now" is also a significant barrier. This was observed, on a different scale by R01 and the implementation of BIM where "people think that we need a quick return on investment". Indeed, due to the lack of the global vision discussed previously, they want to save time right at the beginning (R02).

> *"...We must accept that the **result of our efforts does not benefit us** but the humanity in 5 generations".*

Architect, R07

F. Resistance to change

a. Old generation & young generation behaviour with working methods

Resistance to change is one of the most important barriers identified by twelve respondents. First of all, this resistance was observed mainly with old generation people. Based on BIM implementation experience, which leads people to change the way they work, R02 said that when you introduce new tools to the young generation, to those who *"…have known nothing else, it goes by itself, no problem"*. Whereas, for those who used to work differently by using traditional methods, it is more challenging. They tend to limit themselves to what they know. Even after training sessions, they return to their old-fashion methods. The problem is that in R02's Company, those who give instructions to others are those who have been here for a long time. He said

> *"…It is a bit **like the families problems** that are **generated from one generation to another**".*

BIM Manager – Facility Management, R02

R10 noticed for the reclaimed material acceptance that young generation are more interested in that approach. Similarly, R12, an architect teaching in an architecture school, reported that architecture students are all fans of reuse.

b. Change the way of working & resistance to Change

The incorporation of a SEOL into the asset lifecycle will oblige the stakeholders to change their habits. It is a barrier for everyone. Indeed, for instance, R12 in his approach of avoiding finishing work, he is having and asking for a level of quality requirements for certain trades such as the builder. This raises several issues, including that builders are not used to having these quality requirements. So they should change the way they work to be able to fulfil the quality requirements. Otherwise, it quickly becomes confrontational. R01 believes that those who already have a sustainable approach will not be disturbed by that but for those who aren't used to work like that,

> *"…they will struggle and **find a reason for not doing it**". They will say "…we have always built in such a way for x years, **it is not today that we will be taught to do it**..."*
>
> BIM Manager, R01

Equivalently, R09 stressed that moving towards a SEOL will be "…very difficult because the construction industry is so conservative". Builders will use every excuse. So, it will use it as a lever arm to ask to be paid more. He said "...I am just hearing them saying it. They want to get on with the project and do it on the way they use to do it". He gave the example of the use of inflammable insulation and how it is difficult to persuade architects not to use flammable insulations in their buildings. R11 based on the move towards BIM use in his company, he assumed that due to a lack of culture brings a kind of resistance to change. He thinks that

> *"…there are many people for whom **digital is more scary than envious**".*
>
> Quantity Surveyor, R11

Indeed, important barriers are related to Human behaviour and the difficulty to change their habits (R03 & R05). People are used to the traditional way of building (R15). R07 said that it's the Human nature to do things as they know how to do, staying into their comfort zone. Change is difficult, complicated and takes time.

People show resistance to the use of non-conventional material. R05 compared the stone and earth and noticed that "…the earth has more trouble… People don't trust you…many will mock, be afraid…"The acceptance of earth building is also related to the region. Some places in France concentrated more traditional earth houses. The acceptance is higher in those regions. The acceptance of a sustainable EOL approach is also due to mentalities, which, according to R18, remains one of the biggest problems. Today, organisations like the CSTB in France or others, are also quite protective of the local market and there is

> *"…**a tendency to not accept innovation that comes from outside** because it is not French".*
>
> CE specialist - Architect, R18

The resistance to change was reported in many studies, whether RL, prefabrication, deconstruction, 3Rs and Sustainable Building approaches. According to some authors, the construction sector is dominated by a change-resistant environment, scepticism and tradition (Chileshe et al. 2016, Gorgolewski 2008). Indeed, the use of new technologies or innovative approach is usually standing in the way of change (Häkkinen and Belloni 2011, Kifokeris and Xenidis 2017). This was supported by many authors who considered the resistance to change as "natural" (Jaillon and Poon 2014, 2010). The resistance of change the habit was also observed for reclaimed materials use. According to Couto and Couto (2010), manufacturers, instead of using salvaged products, prefer to purchase new products (Couto, J. and Couto, A. 2010). More recently, Sanchez and Haas (2018) have reported for the reuse of reclaimed materials a resistance from builders and owners (Sanchez and Haas 2018).

5.4.5 Summary

In total, thirteen sociological barriers were identified by the twenty interviewees for the integration of a SEOL into the asset life cycle. These barriers were, and not found in the literature (Table 31)

Table 32, a summary of the findings reveals that the most reported by the respondents is resistance to change, followed by cultural beliefs and the lack of concern for the asset EOL. The most frequent words used by the interviewees are "people", "change" and "working" as depicted in Figure 33.

Table 31: Sociological barriers identified by the interviewees and not found in the literature (Source: Author).

	SOCIOLOGICAL BARRIERS
1	The building lives badly socially
2	False belief: impact of the finishing works
3	False belief: the use of modular construction
4	Human is influenceable
5	Lack of trust into the "as-built! Documents
6	Lack of trust in the "In use" phase updating
7	Lack of trust into non-conventional materials
8	Lack of trust into workers

Figure 33: The word cloud frequency for sociological barriers (Source: Author)

Table 32: The summary of the results for the sociological barriers (Source: Author)

SOCIOLOGICAL BARRIERS																				
BIM Users / BIM Manager																				
Roles	Designers						FM			Owners			TE	E	QS	M	SE	CO	D	R&D
Respondents	R06	R07	R09	R12	R16	R18	R02	R15	R14	R04	R20	R01	R10	R03	R11	R13	R19	R08	R17	R05
541-Unrealistic Hypothesis	x				x	x					x			x					x	x
542-Societal trend																				
A-Consumer society	x			x							x	x								
B-Aesthetic trend												x						x		
C-Bad image of prefabrication						x														
D-The buildings lives badly socially											x									
543-Lack of understanding, Awareness & Demand																				
A-Lack of information - demand	x				x	x					x									
B-Lack of understanding	x						x					x								x
C-Awareness of deconstruction approach								x				x								
D-Lack of concern	x		x		x	x								x		x				
544-Human behaviour																				
A-Cultural Believes	x			x		x							x	x	x					x
B-The scale of thinking-Lack of global vision													x		x					
C-Human-Influence							x						x							
D-Lack of trust			x	x		x							x				x			
E-Impatience - Want a ROI quickly		x					x					x								
F-Resistance to change		x	x	x		x	x	x				x	x	x	x		x			x
(FM) Facility Managers, (TE) Thermal Engineer, (QS) Quantity Surveyor, (CO) Control Officer, (DE) Deconstruction Engineer, (SE) Structural Engineer																				

5.5 Technical barriers

In this section, the technical barriers raised by the twenty interviewees will be analysed. They are classified into four-part. (i) The technical barriers related to the building, (ii) the technical barriers related to the materials, (iii) the technical barriers related to the data and lastly (iv) The technical barriers related to the technologies (Table 33).

Table 33: The number of respondents and quotations for the technological barriers (Source: Author)

55 TECHNICAL Barriers	Respondents	Quotations
	20	**266**
551-Building related barriers	**17**	**82**
A-Building lifespan -duration-composition-update	9	15
B-Building composition	7	11
C-Building modification during its lifespan	2	3
D-Building type & size as a barrier	7	14
E-Projects Phases adaptation	13	46
552-Materials related barriers	**18**	**102**
A-Material composition - knowledge & reliability	13	63
B-Material recoverability	17	69
553-Data related barriers	**12**	**79**
A-Data Management	2	7
B-Data availability-accessibility	8	32
C-Data Compliance as-built-Accuracy	6	18
D-Data Exchange and interoperability issues	8	25
554-Technologies related barriers	**9**	**31**
A-Barriers linked to the use of BIM (as new technology)	6	24
B-Lack of technologies and technologies evolution	4	9

5.5.1 Building-related barriers

A. <u>Building lifespan -duration-composition-update</u>

a. Buildings lifespan

One of the most important technological barriers is the lifespan of the building from 25 years to 100 years or more. During all the asset lifecycle, from its inception to its EOL, the building will be occupied for various activities and will be partially or completely refurbished. Some parts might have been demolished or deconstructed. So, all this long lifespan is on itself a huge technological barrier. And for respondent R05, it is difficult to have a clear vision when designing a building and having thought about his fate several years later.

R16, an architect specialised into offices, said that office buildings have an average duration of 25 years. Therefore, knowing how what we are going to rehabilitate today will be deconstructed and upgraded in twenty-five years seems complicated for the interviewee. The hardest part is to manage a very long-term reflection because it's not obvious and natural. According to him, how the asset built today will be deconstructed, not many people really know that.

b. Several clients during the building lifespan

Another barrier is that several owners will own the asset throughout its lifecycle (R16). And, R13 draw attention to the fact that, for some buildings, the people who made them will no longer be part of this world when we deconstruct them. Which will raise a crucial issue in terms of responsibilities discussed later in section 5.75. R09 gave the example of a building, the Co-operative headquarters in Manchester.

> *"…They want to do a showbiz building. So, that was built by the contractors X. There was a lot of problems. But, within weeks moving into that building, it had been sold to Y, then Y have leased the building back. And then Y has a lot of financial trouble. So, it is quite possible that they've sold the building to somebody else. So, when you get to the "in Use" phase, it's all* ***complex thing about who owns the building and who is responsible for****".*

Architect, R09

The duration of the building lifespan, as a barrier was also discussed in several studies related to barriers for RL and Close Loop (CL). Indeed, many authors have stressed the challenge to have a good follow-up and ensuring the availability of information, due to the long lifecycle of building (Jaillon and Poon 2014, Hosseini et al. 2014) and usually, multiple changing ownership (Chileshe et al. 2015a, Hosseini et al. 2015).

B. Building composition

The building is also composed of several layers having different lifespans (R10). The several layers are usually classified into structural work and finishing work. Their lifespans are different. Indeed, many studies raised specific issues associated with the duration period of products and their fate at the EOL of the asset (Carvalho Machado et al. 2018, Couto, J. and Couto, A. 2010).

Based on several studies, Akanbi et al. (2018) reported that the "use of finishes on building materials reduces the possibility of reusing such materials as recovered" p.177 (Akanbi et al. 2018, Crowther 2005, Tingley 2012, Guy et al. 2006). R04 believes that the lifespan of the finishing work is shorter. Similarly, R12 supported that by avoiding finishing works you solve the problem of the subcontractor, which has a shorter lifespan than the structural work. He reported that the finishing works are "...fragile, not ecological and not very healthy".

All these parameters are barriers for the incorporation of the SEOL. Designers have to take into account all these parameters and select materials adequately. Indeed, R06 mentioned the importance of material selection by giving the example of facades coatings. He said

*"…with a classic painting, it is necessary to **remake the facade every 15 years**".*

Architect, M06

Whereas in earth projects, we keep the raw part or we use soil plaster. He decided to innovate and use techniques not yet standardised. He added some wax on the facade to avoid maintenance. Finally, the choice of materials can induce more or less long periods of renovation. The choice of material will also impact the layers of the building. R06 concluded that

*"...there are **disposable layers and layers that are "noble"** and stay in place for a long time". "…For example, lime paint. In one house I used lime paint and on other walls acrylic or silicate paint. The facade made of lime is still clean, the other has been re-done twice. There's one you can let live. The other one is dirty, and you must do it again. The difference between the two is the **choice of material, willingness and knowledge**. People say that things with lime don't last, they make colour variations etc. but what he doesn't notice is that an acrylic façade, after six years it's disgusting and you must redo it. **A lime facade can be kept for 60-70 years without any problem**".*

Architect, M06

C. Building modification during its lifespan

a. Modifications during the building lifespan

Based on the literature, we used to consider that the asset lifetime is between 25 - 50 years. But R10 noticed that reality is much different. It doesn't affect the structural work, but mainly the finishing works. It could be painting, windows change, carpets or re-partitioning. Also, fashion, comfort and technology are changing. So, over a long lifespan, the asset will be modified to fit evolving requirements. The finishing work and decoration of a building will be brought to be modified just a few years after their installation. (R10). He said

*"…I don't have a building that **hasn't been completely redone after ten years**".*

Digital Project Manager, R10

R20 raised another issue related to the building lifespan, and the modifications that occur or that must be anticipated. As an owner, he noticed that the new tendency is to have reversible and modular buildings. He gave the example of the Olympics Games (JO) planned in Paris in 2024. Thinking about reversibility, adaptability or modularity is a way to tackle the fate of the building. He said that most of the buildings that are planned for demolition are not due to their dilapidation. He highlighted the issue of premature EOL.

*"…the end of life of buildings that have had to be demolished **is not necessarily the natural end of life of buildings**. Buildings that have been demolished are often for urban reasons, for reasons of bad living. Or building socially lives badly. So it is its*

*configuration in the city, or its entry/exit configuration, serving housing that leads to demolition". "… the subject of buildings for the Olympic Games, it is to have **spaces that are reversible** so that what will be used for three to five months, will then be used for **something else for 30, 40, 50, 100 years** in dense territories, like Paris where it is more difficult to demolish and more difficult to rebuild".*

Owner – Engineer, R20

b. Full lifecycle analysis: modifications distort the calculations

Generally, a building is designed for twenty-five years, it lasts fifty years, but from the first year, it undergoes modifications (R10). The modifications that the asset will have during its entire lifespan will completely distort the global cost calculations. The calculation is made on an average of 25 years. Therefore the choices and recommendations are made based on that. But the reality turns out to be different from the forecasts made. Changes are coming sooner than expected. And the calculations turns to be wrong. So this is a crucial barrier that must be overcome to limit the over costs and the waste generated during the refurbishment phase.

D. Building type & size as a barrier

a. Buildings type

In addition to the lifespan of the asset and the modification that occurs during it, the type and size of buildings are also barriers. Generalisations are not possible. Indeed as reported by Hosseini et al. (2015) and raised by R03, every project is unique, even inside the same type (Hosseini et al. 2015). Barriers are because buildings are heterogeneous (Carvalho Machado et al. 2018), made of multiples materials (Gorgolewski 2008)(Chileshe et al. 2016) and destined for different activities (Hosseini et al. 2014). Every owner will also have different requirements. The difficulty in implementing the new approach will depend on the type of buildings. R03 said that for industrial buildings,

*"…it seems pretty easy to sort. It may be **more laborious for housing or other building projects**".*

Design Offices, R03

b. Existing buildings & new buildings

A distinction should also be made between existing and new buildings. They have different barriers. R13 said that the main barrier for considering the entire asset lifecycle for an existing building is the lack of data available. We do not know what they are actually made of. For some buildings, we don't even have a plan at all, and they weren't designed to be deconstructed. Existing buildings must be considered because, according to R13, it represents 40% of their activity. This was also supported by R20, who stated that the building context is important, especially in an urban area and in rehabilitation when the building is occupied.

c. Size of the project

For the 3Rs approach, Carvalho Machado et al. (2018) reported that the size and complexity of buildings are hurdles for the 3Rs approach adoption (Carvalho Machado et al. 2018). Following the previous authors, R09 considered that the approach of integrating a SEOL into the asset lifecycle could be applied for small and large projects. For instance, Segal Frame principle was used for small, but it could also be applied and used for bigger buildings. Segal frame principle is a self-build approach to construction is uniquely organised to enable anyone to build a house. On the contrary, R03 said that the SEOL principle is a great thing for nuclear projects, but it will be difficult to use it for a standard project due to the cost of deconstruction. R09 gave the example of one of his building designed with hempcrete that could be taken out becoming waste that hasn't any harm for the environment. It is designed in such a way that you can dismantle things. That's all done with plywood, and that's all screwed and therefore be easily unscrew. He concluded that

> *"…Segal Frame houses concept can be* ***completely dismantled and reused****, taking somewhere else".*
>
> *"…it's easier to do with small buildings but* ***much more difficult with other buildings****".*

Architect, R09

Similarly, R16 thinks that the ideal is to start to implement the SEOL principle in small scale building. He added that the circular economy principle should be applied first at a local scale by working with local materials and recycling also locally. The idea is to work with local materials and think about recycling on local scales. This must remain on a small territory scale. He thinks that

> *"…working on large scales, national or international, is too complex and cumbersome".*

Architect – BIM Manager, R16

E. Projects Phases adaptation

a. Design adaptation

1. *Architect practice - add constraints*

The adoption of a SEOL for buildings will add a constraint to designers that should adapt their design (R04 & R11). It might slow down the designer creativity, but they both consider that constraints are not negative. Similarly, R09 considered that the design stage is crucial for deconstruction.

> *"…they have designed that building. So, they know what they can dismantle. It's fundamental to the design concept of the building. I think to me it's the initial design stage.* ***If you don't get right at the design stage, forget about it for the rest****".*

Architect, R09

2. *Change approach and the design*

As mentioned by R12 and R14, the design phase will need some adaptation. For instance, for the use of prefabrication, improvisation on-site cannot work anymore. The design needs to be more advanced to be able to save time on implementation. For the use of non-conventional materials, such as earth, the design and the methods used should be adapted. Indeed, R04 explained that you must take the material constraints into account when designing the project. R05 added that the role of the architect is crucial. R06 didn't see many barriers when adopting a SEOL or the reuse of reclaimed material unless the design that needs to be completely changed. The design is made with materials that are already pre-dimensioned. Equivalently, R09 faced the same issue for an extension of a house where he used salvaged windows from a window supplier. They should wait for the dimension of the windows before completing the design. R13, as a plasterboard manufacturer, also considered that the design should change a bit. Indeed, the incapacity to some material to be eco-friendly and easy to recycle or reuse push some designers to adopt the finishing works avoidance. R12 said

> *"…instead of making a box into the box, you* ***make a box with good quality materials that cost more than a standard basic box****. As we do not put a second box inside, the saved price of the 2nd box allows us to pay more for the first box".*
>
> *"If we decide to use very little plasterboard, our main actor will be the mason. And, we will be* ***more demanding with the mason*** *so that he has a quality of concrete finish that allows him to paint without adding a lining. So in fact, the requirements are moved to the upstream phases as well as to the downstream phases of the site. So* ***we change interlocutors, and even some interlocutors are reduced or even deleted****. Yeah, maybe a little more design time. We do a lot of wooden things, so we have a lot of prefabrication. So the same, whether for the companies that will do it, to prefabricate or for us, we can't improvise on the site. We need to have a more advanced design that saves a lot of time on implementation.*

Architect, R12

> *"…**the design was done around the windows**".*

Architect, R09

> *"…if I am told that I only need demountable partitions, at the moment* ***I do not know how to do it, and obviously it has a colossal impac****t".*

Manufacturer – BIM project Manager, R13

In a classical approach, we use plasterboard that hides everything. As soon as you no longer put plasterboard to hide things, it has to fit in well with the structure. He precise that to be able to do without plasterboard, the designer must stop sticking on space and ambiences approach because, he added by doing that, "…we are far from construction' concerns".

Many studies for RL, deconstruction, 3Rs or Temporary Buildings (TB), have identified that existing buildings are not designed to be easily dismantled or deconstructed (Carvalho Machado et al. 2018, Chileshe et al. 2015a, Chini and Bruening 2003, Crowther 2002, Jaillon and Poon 2014, Xanthopoulos et al. 2009). The lack of deconstructability is also due to components that have not been designed for disassembly and recycling (Jaillon and Poon 2014, Couto, J. and Couto, A. 2010, Huuhka and Hakanen 2015). Moreover, the joints design, often welded and not bolted, are not conducive to deconstruction. If the deconstruction is made despite the lack of demountable connection and sometimes the lack of drawings explaining the connection between components, it is done laboriously (Carvalho Machado et al. 2018, Jaillon and Poon 2010, 2014). Furthermore, the connections are usually designed to be hidden and therefore, inaccessible (Couto, J. and Couto, A. 2010).

3. *Lack of clear requirements to integrate them into the design*

In the SEOL approach, the design phase is crucial. During this phase, all the stakeholders involved in the project have to be around the table. Their requirements should be clearly defined to be integrated into the design phase. R19 reported that the main barrier they encounter as structural engineers is that the owner sometimes has some requirements for "adaptability or reversibility" ...they may not have a very clear idea of what they expect". R20, an engineer working in the “owner side” reported that discussion with the stakeholders is key.

> *“…it is to take a **little time to discuss openly** and we too, **adapt our specifications, adapt our expectations** to the BIM so that they are realistic, but realistic with a little more”.*

Owner – Engineer, R20

R18 bring up that requirements about the notion of quality, recovery of materials, quality for health, must be clearly expressed in the specifications. If not, "...they will come up with anything". Similarly, R11 said that information about materials should be provided to the design team to integrate them into their design process. He added “…that is what they lack today. How is wood or concrete recycled?"

4. *Material quality and thermal inertia*

Prices and specifications are defined without taking into account what suppliers are capable of doing. This led them to cheat on quality to be able to stay on their prices and to win the project by being the cheapest. The buildings' lack of thermal inertia is a barrier highlighted by R18 who considers that we "we do not dare to expose concrete". Contrastively, the high wall thickness could also be a barrier. For instance, the use of non-conventional materials and steel avoidance approach leads to having higher wall thickness. Due to the consequently high volume, the quantity of cement added is much important than a traditional reinforced concrete wall. And if we aren’t considering the entire asset lifecycle in terms of costs and environmental impact, it could be seen as less advantageous to use earth materials from excavation (R04).

b. Construction method adaptation

1. <u>Change the construction methods</u>

As shown previously, the design phase will be a barrier. The construction phase will also be impacted by the asset lifecycle reconsideration. Indeed, R14 said that

> *"It will certainly **change the way we execute the construction of a building**…DIY system will not work anymore".*
>
> BIM Manager, R14

R04 also stated that when they decided to adopt an eco-friendly approach, and they had to adapt their construction methods. In fact, for a project based on the use of excavation earth from the site and stone, they scheduled the construction

> *"...little by little, a bit like building a tunnel. **It changes the system**".*
>
> Property Developer – Engineering Offices, R04

2. <u>Construction method limitation as barriers</u>

One of the most challenging requirements in a building is airtightness. Traditionally, the easiest and cheapest way to get airtightness is to use wet plaster. So, in the case of SEOL and specifically for deconstruction or dismantling, the more buildings could be bolted together in the way that they are not stuck together, the best it is. But what R09 a very experienced architect in the sustainable buildings reported is that even with steel frame buildings, very often they cast concrete around anyway, because for fire safety or whatever. Hence, the building becomes much more difficult to dismantle.

There are also limitations of some construction methods. Indeed there are different ways of building. According to R15, maybe not all of the construction methods will support the deconstruction or dismantling. For instance,

> *"…**is it built by using a traditional way of building**, is it built on-site itself, like floor by floor or is it built off-site as modules and then being built? In regards to the modules, they can be **volumetric modules**, like boxes assembled onsite. Or, it can be **flat packed**, so maybe like walls flat packed and then assembled on-site".*
>
> BIM Manager – Operation & Maintenance, R15

3. <u>High quality of the structural work as a barrier</u>

Related to R12's approach, which is avoiding finishing work, the quality of the structural work will be a huge barrier. Indeed, architects following this approach will ask for and have levels of quality requirements for certain trades that are not used to having these quality requirements. The requirement and strong attention of the architect on the realisation of these concretes will be a difficult barrier to overcome. Similarly, R19 insisted on the same barrier that is, to have a high quality of the earthen structures because they will remain rough.

This approach will lead to change the importance of the various stakeholders involved in a project (addressed deeply in sub-section 5.7.6). Indeed, one will be more demanding with builders, which is unusual due to the plasterboard traditionally used to cover their work. Indeed the concrete is usually badly finished as mentioned by R18. That's sometimes braked the owner to keep the concrete visible.

R09 reported that the builder would have to take much more care to make it possible for it to be dismountable and make sure that's not compromised. R12 reported that in his projects, his main actors are masons. As the architect of the project, he aims to obtain a high quality of concrete that allows painting without adding a lining. So, he noted that the requirements are moved to the upstream phases, those of the structural work and not finishing's. A whole reorganisation of the actors of a project and their role and responsibilities is required. In support of the previous argument, R19 said that

> *"...it is the* ***mason who carries out the final work*** *which will be the facing and the image of the building".*
>
> Structural Engineer, R19

c. Deconstruction processes implementation (storage, facilities)

Obtaining updated documents or even any documents is very challenging. In addition to the data availability, the deconstruction process itself is also complex and requires, according to R06 *"…sorting, cleaning and standardising recovery"*. R11 described the deconstruction/demolition process. He said

> *"…**we sort out what is not inert**, **we remove what must be recovered and what must be valued**. Then we also **decontaminate lead asbestos buildings mainly**. And then, all that is **demolished is the structure, the concrete and what is inert**, either with pliers or large machines".*
>
> Quantity Surveyor – BIM Manager, R11

Indeed, logistics are complicated to set up. It is necessary to be able to separate each of the materials, take care of the materials, and store the materials with a lack of space for storage, especially in urban or peri-urban sites. According to several authors, the accessibility to the site and its dimension are key parameters for planning deconstruction activities (Chileshe et al. 2015a, Jaillon and Poon 2010, 2014). Furthermore, according to R10, the scheduling truck rotations are also very challenging. Today the availability of temporary space lacks, whether to manage the delivery of materials or manage the storage of materials for deconstruction. This makes R10 doubt on the feasibility of a SEOL in urban areas because of today

> *"...if you want to deconstruct a building in the city. You can't do that. There's* ***no space available"****. R10 concluded that for moving towards the SEOL, "…today it's really the* ***logistical aspects that are immature****".*

Digital Project Manager, R10

The storage issues were also raised by Jaillon and Poon (2010) for prefabrication approach. Several studies, whether on RL or deconstruction approaches, have identified the on-site space issues (Zaman, A. et al. 2018, Hosseini et al. 2014, 2015, Xanthopoulos et al. 2009). As reported by R17, a deconstruction engineer, one of the barriers associated with deconstruction or dismantling, is that materials do not fall in the right place nor at the right time.

The lack of technology reported by Hosseini et al. (2015) is also a barrier highlighted by R18 (Hosseini et al. 2015). He gave the example of a building where asbestos should be removed to be able to proceed for the refurbishment of the asset. After a first catastrophic tentative for the asbestos removal, it was necessary to do it by setting up compromises and limitations. R18, responsible for this mission, set the limits of this asbestos removal so that it would be plausible. The limitations were due to a lack of technologies for removing the asbestos included in the screeds. They did some tests by using a new machine designed purposefully for that but

> *"...the machine exploded on the site because it was overheating and t****he system didn't work****". Finally, R18 bet "...perhaps in 30 years' time,* ***we will have other methods that will make it possible to remove asbestos in screeds*** *without risking everyone's health".*

CE Specialist– Architect, R18

R06 also reported the lack of tools for assisting him in his day to day practice. He said at the moment he designs sustainable building intuitively. The lack of tools for assisting the SEOL approach was also raised by R19.

5.5.2 Materials related barriers

A. Material composition - knowledge & reliability

R13 explained that they have, for four years, set up a process, to be able to offer to the market a product 100% recyclable for life. If they want to use their current process to the SEOL approach, they should adapt it.

a. Manufacturers need to give product information

The manufacturers have to find other assembly systems. They also must give the composition of their material and recommendations for how to the product's EOL can be managed? What is the recoverability of their products? Indeed, according to many authors, the unknown materials composition is a critical barrier, especially for reuse and recycling (Diyamandoglu and Fortuna

2015, Hosseini et al. 2014, Kohler and Yang 2007). This was also pointed out by R04, who said that the information about the EOL of the product should be found in the manufacturer' specifications. R06 expressed the necessity for manufacturers to give the technique to recover the material or recycle it. In accordance with the previous respondent, R10 reported that there is a real lack of readability regarding the reuse capacities of materials. For instance, for the case of partitions with insulation, what is best to do: Do we throw everything at the same time or do we recover? What is the process to recover each component of the partition? R13, a plasterboard manufacturer confirmed that

> *"…today, there is **no specification on how to deconstruct partitions properly**".*
>
> Manufacturer – BIM project Manager, R13

> *In parallel, "As a result, they multiplied and never managed to coordinate. So, there are scattered actors, and there is a real **lack of readability regarding the reuse capacities of materials**. Where do the deconstructions take place? Where do I want to build? What do I need? What do I make available?"*
>
> Digital Project Manager, R10

According to R01, knowing the composition of products will be a crucial challenge. Manufacturers will keep their recipes whatever their motivations are: for a patent reason, confidentiality or other strategic reasons. Especially, the regulations tolerate keeping secret the calculation methods. They can give only the results. For example, it is not possible to get information about a product between extraction and manufacturing, under cover of intellectual protection. It is completely opaque. This is a barrier when you want to compare some product by using the FDES sheets, for instance (R05). This was reinforced by R18 who experienced the materials passport creation. He said the barrier is the access to data among suppliers.

> *"...very often companies, suppliers **keep secret what is in their products**. It's a bit like the Coca-Cola phenomenon: we don't want to give the recipe. It is this information that is difficult to obtain, but we will say that the market is beginning to understand".*
>
> CE Specialist– Architect, R18

Having an accurate view of the building constitution **throughout its entire lifecycle,** including the "in use" phase is also a huge challenge. R10 said that today,

> *"…the major obstacle is to be able to identify not only the quantity but also the **nature of the materials used in the design and construction phase but also the operating phase** of the building. Today, there is no follow-up with finesse, of a replacement element".*
>
> Digital Project Manager, R10

b. Material Technical Data Sheet (MTDS) information

Getting data about the products is one thing, but the reliability and the consistency of data is also an issue. The FDES, set up by the French government is not mandatory, manufacturers are free to produce the FDES or not. Because the FDES is not accurate enough, R10 gave the example of two types of wools. Comparing them will not be possible due to the lack of details. Because they are generic cards, both will have the same specifications. "The FDES sheets can be download via the INES website, set up by the government. As said previously, to be able to select the material purposefully, The FDES sheets must be more detailed. Indeed, R05 reported that the EOL of the product is considered very imperfectly *"…for example, there is no detailed calculation of the energy it will take to crush the concrete and wash the result to be able to repeat a cycle"*. R18 raised an important barrier that is the lack of knowledge of the companies about their products. He said the companies

> *"…**had no idea of the fibre sizes** in their products…"*

CE specialist - Architect, R18

R20, an owner, leader of social housing in France, explained that today, in their specifications, they have to indicate their requirements in terms of products. They use the technical sheets, FDES but they don't go further. Afterwards, with the current tendency, we will be forced to innovate and propose innovative projects and to put prescriptions that go beyond the current specifications.

c. Lack of knowledge of reclaimed materials

Several respondents who are using the soil as a construction material (R04, R05, R07, R12 and R19) raised the lack of on how the excavation soil can be reused. R09 believe that knowing the quantities of the recovered materials will be useful. T

> *"…if I can identify the **number of tonnes of recoverable plaster** if the sector exists that would be useful information. If I know that at the exit of such a crusher, I can recover clay from sand mixed with aggregates that I can reuse in a platform to make compacted raw bricks, I can invent a new material with it"… "It's not so much a question of data; you've to go to **inspect it and engage with it physically**. I mean the story about the cheap insulation that we used. We were able to recover that and reuse it, but no one knew where it to come from. **We didn't know the suppliers**. We didn't know whether to be healthy, toxic chemicals. So, it sent a sample to an expert. So that's kind of **getting data**".*

Architect, R09

Two respondents, from the UK and France, gave an example of actions that are started to set up to help with the issue of reclaimed component identification. R09 said that demolishers recover materials, store them and he started to catalogue them. R20, an owner explained that they are already working with a start-up "Cycle UP" specialized in the reuse of reclaimed materials. They look at the deconstructed elements and puts them on a platform of exchange, sharing and selling. The platform is not proposing any storage services. The person interested in the product goes to take it from the site. They used to be assisted by this company on projects destined for deconstruction. He said

"...they help us to **anticipate what could be reused**. **Anticipate the storage** means that could be available on-site to try to re-use certain elements as best as possible. So it's new for us. But *we are on one or two projects, in this case, or we are trying to reuse on-site or reuse for companies that are close to the site". "Cycle Up* ***do not have a physical storage platform,*** *but conversely, there* ***is no transport to this platform****. So it's really* ***an opportunity****,* ***during the study phase*** *to find people who might be interested in something that will happen in six months or during the construction phase, to highlight, with photos to support it."*

Owner – Engineer, R20

Many studies have identified the lack of knowledge of reclaimed materials as a critical barrier. According to Gorgolewski (2008:179), "reclaimed materials do not show up at the right time, in the right amount or the right dimension" (Gorgolewski 2008). Huuhka and Hakanen (2015:216) reported that "barriers hindering reuse include cost, quality, quantity, perception and trust, among others" (Huuhka and Hakanen 2015). The adaptive reuse for buildings can be hindered by knowledge gaps about reclaimed materials (Yeung 2016) and the under-estimation of the embedded resources in the building components and materials (Schultmann and Sunke 2007, Teo and Loosemore 2001).

B. <u>Material recoverability</u>

a. No request on what will happen after the deconstruction

R14 explained an ongoing project where he is mandated to be the Assistant to the Contracting Authority. A building needs to be deconstructed first before the new project. They will apply BIM methods for the deconstruction. They didn't have a completed deconstruction file. They will assist the client during several phases (deconstruction, Construction permit, construction…). They also have the task of deliverables control at the end of the project. For this mission, there is no request on what happens after the deconstruction. This a barrier because the Client should have a global vision and not stopping with the deconstruction.

b. Material selections for deconstructability as a barrier

According to R09 and R15, the selection of the materials is very critical. Some materials are going to be avoided because they will make the deconstruction much more difficult. R10 said that we should go towards bio-sourced materials, local materials and those with nearby recycling channels. Therefore, we must choose materials that have the deconstructability intrinsically. Material that is not removable is difficult to recover and should be avoided (R8)

c. Difficulty to recover materials

1. Materials' complexity

As we discussed previously in sub-section 5.5.1, the building is composed of several layers. R09 considered that the current new low energy building

> *"…got such a complex build-up of layers.* ***If that's going to be reused or dismantled in the future, it will be difficult****".*
>
> Architect, R09

The components of the building are also composed of several layers and are complex. Finally, the more complex is the material, the less they are recyclable easily. R12 believe that "…materials that are difficult to reuse, to deconstruct are industrial materials because they are complex materials". All those complex materials are assembled and glued together, which make them not conducive to any type of recovery and will end up in the landfill. R13 explained the difference between plasterboard and a partition. He said that "… we do not demolish plasterboards, but we demolish a partition". In this wall, we have several materials, for instance, we have metal frames with screws, and we have joint strips used to join the plates. In the same way, when RFID chips containing copper, antennas, are not part of the plasterboard recycling process. All these materials added are the partition that should be recycled. Hence, depending on what is incorporated, their product, that was initially 100% recyclable, may no longer be recyclable.

Existing buildings and their unknown materials' composition make them difficult to recycle. R18 reported that they try to upcycle the concrete but usually it is downcycled. He added that concrete will never reach the 100% recyclable because the old concrete buildings have been made with everything and anything. This difficulty to recycle is also observed for electronic equipments that are recovered, plugs, cables, etc. Especially materials that contain both copper and plastic, such as electrical wires. R18 revealed that today, we could separate some composites by using laser or waterjet cutters or whatever, but all these techniques are expensive and not easy to use.

The difficulty to separate buildings components was also highlighted in many studies addressing deconstruction, RL or 3Rs principles. Indeed, separating buildings' components without damaging them is very challenging (Forsythe, 2011; Densley Tingley and Davison, 2012; Chileshe *et al.*, 2015) This could be due to either their complex composition or their implementation (Couto, J. and Couto, A. 2010, Nisbet et al. 2012).

2. Lack of recoverability due to product implementation

First of all, the un-recoverability could be due to the assembly system. R13 pointed out that today, the wall made with plasterboard is not recoverable because of the assembly system. R13 reported that

"…the screws are not removable. They can only be used once ***if you unscrew, the screw is dead.****"*

Manufacturer – BIM project Manager, R13

R09 mentioned that one problem with deconstruction or dismantling is that the insulation cannot be recycled or recovered because of the way it's used. Indeed, everything is covered in and *"...to get at it; you make such a mess that you can't use it again."* Comparatively, for carpet recycling, the main problem is also the way components are glued together. According to R10, some carpet manufacturers started to use different glue to be able to separate the component and recycle them separately. He said

"…"fish type" glues are used, which cost the same as conventional glues. ***This is part of the manufacturer's recommendations for interface carpet users****".*

Digital Project Manager, R10

Another example of hot-welded materials was taken by R12: the bitumen waterproofing and when the bitumen waterproofing are glued to wooden plate support. These combinations of products cannot be dismantled. They cannot be dissociated during deconstruction because the wood, for instance, is polluted by bitumen. R12 supported the non-recoverability of materials by giving the example of plastic coverings and PVC floors. In addition to the fact that they are very harmful in the event of a fire, due to their toxic fumes, these materials are often glued together and hence cannot be reused.

3. *Due to Material toxicity-harmfulness-Indoor Air Quality*

The hazardous components issue was discussed in many journal papers. Indeed, according to Knecht (2004), existing buildings are rife with hazardous materials (Knecht 2004) requiring pre-planned and careful deconstruction techniques (Nisbet et al. 2012). Toxic materials and their complex process for removal are an important barrier highlighted by R11. R13 added that their 100% recyclable plasterboard *"… as long as there are no hazardous components or additives*". This was also pointed out by Forsythe (2011) regarding the timber treatments and the contamination brought by paint coatings (Forsythe 2011). The lack of recyclability could also be due to pollution as reported by R17. For example, a slab containing hydrocarbons cannot be recovered. This type of waste goes into different channels and is much more expensive. R12 raised the issue of asbestos in existing buildings. They usually recommend to the owner to remove 100% of the asbestos even if regulation allowed 80%. Asbestos and lead issues were also discussed in several studies (Bradley and Scott, 2002; Chini and Bruening, 2003; Guy, 2006; Kleemann, Aschenbrenner and Lederer, 2015; Tatiya *et al.*, 2017).

"…there are many projects in which we are confronted with asbestos. So there must be ***asbestos removal****. That's demolition.* ***Nothing can be reused*** *(…) we will often*

advise the project owners to remove as much asbestos as possible…", if possible so that there is no trace at all. When he has an asbestos removal project underway, removing 80% or 100% does not change the cost much".

Architect, R12

R20 also raised the issue related to layers of materials that are inseparable. He said the asbestos that is embedded in concrete, embedded in plasters comes to pollute the plaster and the concrete and make them impossible to dissociate. Using materials that would not be with layers will ease the reuse or recycling.

R12 explained that the plastic coverings, PVC floors are very harmful regarding their VOCs (volatile organic compounds) but also in the case of fire. According to him, the cause of death is mainly due to toxic fumes from finishing materials than from burning materials. He believes that their approach of avoiding finishing works is less harmful for end users. He added that even the use of concrete, which is not a super-ecological material, will not generate VOCs like PVC floors or glues in furniture (Rommée and Vrijders 2018).

4. *Material type (structural and finishing works)*

According to R06, R10 and R12 distinction between the finishing work and the structural work should be made. Their different reuse and recyclability were reported by Poon et al. (2004) and Rommée and Vrijders (2018). According to Poon et al. (2004), the "wet trades of finishing work such as screeding, plastering and tile laying collectively were identified as the second major waste generator, at 20%", p.463 (Poon et al. 2004, Rommée and Vrijders 2018). R10 have noticed that manufacturers of finishing work (carpets for instance) are currently working on their recycling processes. The structural work manufacturers began this assumption of responsibility a long time ago. According to R10, in the construction sector, it is more of a finishing work problem than a structural work problem.

d. Reclaimed material quality

According to many authors, the critical barrier hindering reuse of reclaimed material is the quality. Due to their lack of deconstructability, components are damaged during the deconstruction process. The quality of reclaimed components is then reduced (Cruz Rios et al. 2015, Huuhka and Hakanen 2015, Sassi 2008). The quality of reclaimed materials was also reported by eight respondents. However, R06 stressed the higher quality of reclaimed materials. He gave the example of recovered shutters used in a new house.

"… Local businesses found the idea of recovering shutters completely absurd and stupid. It was better for them to change and put in new shutters. But the price was half as high, and ***the old shutters could last another 50 years while the new shutters would last 10-15 years****".*

Architect, R06

5.5.3 Data related barriers

A. <u>Data Management</u>

a. Building Data Centralization

As mentioned in the Local Government Waste Management Manifesto of New Zealand, "one of the keys challenges in seeking to manage better or minimise C&D waste in New Zealand is that national data collection and reporting remains poor" (2018: 3432) (Zaman, A. et al. 2018). Indeed, data management is a very challenging part of asset management (R13). R14 reported that today, the two main topics are "central facility repository" or the "building operational system". These are the two main visions of the data centralisation of the building.

> *"…The data should be managed in an environment that knows how to* ***deconstruct these data and especially organize them****". We will have data related to regulations, data coming from connected objects. We will have building performance data, BREAM, LEED...* ***All this will come together but not in a model****".*

BIM Manager, R14

Indeed, all the data will be managed in a Common Data Environment (CDE). The use of several CDE on a project is also a barrier highlighted by R15, a BIM Manager for the states. Based on her current projects, he gave the example of the state that wants to buy a CDE that can host information from design to full use and, also maybe through deconstruction. However, it will not solve the problem of the multiplicity of CDEs.

> *"…there will also be a problem because the* ***CDE that has all of this information might not exist everywhere****". Indeed, usually "…the architects have a CDE, the contractor has a CDE etc. because* ***each company might buy a CDE and they say: no we want our information there****".*

BIM Manager, R15

b. A decentralised view of the data: Model View Definition (MVD)

According to R14, the view of the data is decentralised. He considered that deconstruction, for instance, is a particular business view: the "deconstruction business view". It is acting as a filter that must be applied to get only the data associated with deconstruction. It can work like COBie.

> *"…we are on a* ***Model View Definition*** *(MVD) that will be a deconstruction MVD". "…to be able to get as much MVD out as possible, there must be as much data as possible. If you need a* ***Business view that is linked to regulations****,* ***the business that is linked to specific maintenance or deconstruction****, I make sure that in the AIM, I have all the data that will be use for the business view, for example, deconstruction".*

BIM Manager, R14

B. <u>Data availability-accessibility</u>

a. Data Structuration, Traceability, and Availability

For the respondent R13 the data is the biggest challenge that everyone is facing today. And considering a building from its inception to its SEOL, the quantity of data generated during this new asset lifecycle is huge. All these data should be structured to facilitate the exchange and avoid the "wording issue" that is encountered regularly. R13 added

> *"…because all this information will circulate and **must be guaranteed throughout the process. No loss of information should happen**".*

Manufacturer – BIM project Manager, R13

All these data will refer to all the works done in the building during its lifetime. We must ensure the fluidity of the data from the beginning to the end. The data traceability is also another part that needs to be considered scrupulously and is reported by R16. In the same direction, R10 expressed that the data history and its format, are important technological barriers. Which format will be able to work even after years? The data traceability, the interoperability, the storage of the data and making it available over time are important challenges for the feasibility of the approach.

b. Lack of data required for SEOL management

One of the biggest barriers is that to deconstruct a building, *"...from the data point of view, we are rather poor..."*(R10). R17, the deconstruction engineer explained their process when they plan the deconstruction. First, structural diagnostics are often required. Then, the network plans are imperatively needed. To get them is usually very challenging.

The data required is at least all the data provided to the Asset manager to maintain the building (R13). Based on his latest ongoing project, he reported that the data is a huge barrier. For that project, the project manager hasn't provided the information sufficiently in advance to be able to set up the computer-assisted maintenance management (in French "gestion de maintenance assistée par ordinateur" (GMAO)). Indeed for the incorporation of the SEOL, in a new project or the renovation of the asset, SEOL requirements should be specified in the prescription. For example, if the client wants demountable and reusable partitions,

> *"…this will have a significant impact on the **prescription phase of the solutions proposed in the call for tenders**".*

Manufacturer – BIM project Manager, R13

According to R13, deconstruction or dismantling activities may need more information than construction. For example, a partition is composed of frames behind it. Hence, we need to have a model reporting where the frames are, what the distances are, where the screws are needed. All these data will be required to be able to deconstruct the partition. There is a real lack of readability regarding the reuse capacities of materials. Where do the deconstructions take place? Where do I want to build? What do I need? What do I make available?

R15 talked about a grey area that we need to face when we want to deconstruct an existing building. A lot of research will be needed with the risk of getting nothing useable. In asset information, getting the right information really on time is a real challenge. The difficulty to get the information about an existing building was also highlighted by R17, the deconstruction engineer. In the literature, authors have also identified the lack of data to carry, for instance, an LCA towards the EOL stage during the design stage (Blengini and Di Carlo 2010) or data on deconstruction projects and process. In general, national data on C&D waste is lacking (Diyamandoglu and Fortuna 2015, EEA 2008, Zaman, A. et al. 2018). Similarly, it is generally difficult to know the composition of existing buildings at the end of their life (Hosseini et al. 2015). However, to be able to decide to recover a product from an existing building planned for deconstruction, we should know the quantities and sanitary qualities and if they are still aligned with current regulations (R16). For one project, a 3D model has been provided in addition to the "completion of works" file. According to him, this was helpful because it made it possible to locate spatially, but it did not contain reliable information, even not the geometrical data. R10 named two types of data that are needed, visible data and invisible data as quoted. Very often, as highlighted by several respondents, there is a loss of information because the asset is not well archived or stored. Due to that, the recovered material is downgraded. Related to how to get the data for an existing building, R19 said that it is much easier when they have precise information on the existing system. Otherwise, he said

> *"…we must go for probe everything to make diagnoses, load-bearing capacities". "…There are relatively classic geometer surveys. Not 3D readings or point clouds. Then* ***destructive surveys are carried out****, if necessary, to take cores or reinforcements to carry out tensile tests, to take geometries, sections".*

Structural Engineer, R19

> *"…I think there is a need for what is called* ***invisible data****. As much as we need visible data, their volume, volume measurement characteristics, weight. But, we will also need the induced data:* ***What is the shear strength of a beam, what is its bearing point. How was it used****? So,* ***his whole history. What is the permissible load? What is the moisture level of a wood beam used?"***

Digital Project Manager, R10

C. Data Compliance as-built – Accuracy

The data update barriers were pointed out by several respondents (R15). The data will be passed from "hand to hand", from one stakeholder to another using different software's and one should make sure that no data will be lost. Furthermore, the second concern is to make sure that the changes happened during the asset lifetime have been updated into the model. Today we are still trying to implement the data update during from the delivery phase to the operation phase.

> *"...the hardest part is to **maintain and update the model correctly until the end**".*

Architect – BIM Manager, R16

> *"…One of the big issues is **updating, and it is essential** to be able to push the operators until the integration of the update."*

Digital Project Manager, R10

He gave the example of elements' replacement during the "In use" phase. The technician will not wonder about the exact composition of the insulation used in the replaced wall. If he doesn't have clear specifications to follow and somebody who will check the work, he will use the cheapest insulation material. R10 pursuit by saying

> *"…today, the major obstacle is to be able to identify not only the quantity but also the nature of the materials used in the design and construction phase but also the operating phase of the building. Today, there is **no follow-up with finesse, of a replacement element**".*

Digital Project Manager, R10

In support of the previous argument, R16 draw attention to today; assets are more or less well exploited and managed. The 2D plans that are not well updated. Therefore, he said,

> *"…**we're going to find the same thing with the models**, that's not going to change".*

Architect – BIM Manager, R16

In accordance with the previous respondent, R09 raised the issue about the as-built drawings. He pursuits by saying that usually the drawings are not compliant with what was actually built. Furthermore, during the handover phase, a full set of drawings is usually not provided. Based on the example of the tragic end of life of the Grenfell tower, nobody really knew the components of the building. He concluded by raising the checking and accuracy issues.

> *"…one of the things which are coming out of the Grenfell inquiry is **that nobody really knew what had gone into that building**. So, for instance, the whole section of the building was insulated with **Polyisocyanurate** (PIR), and another section was insulated Polyurethane (PUR). And nobody knew that until the cladding burned off and the stuff was exposed".*
>
> *"…even if you've got a lovely BIM model, it's only a model, and it's **not telling you what the actual materials are**. So, someone's got to put that information in. Because the builders are constantly substituting materials".*

Architect, R09

The update should be made accordingly to the changes made to the asset but also technologically. The challenge is to be able to read an IFC dated from 2019 in 2040! The big challenge is that the technologies are evaluating very quickly and nobody can predict where we will be in 20 years.

D. Data Exchange and Interoperability issues

Data exchange and the barrier of interoperability was raised by three respondents (R02, R15 and R13). R13, a manufacturer reported that today we are far from being able to exchange our data accurately, quickly and easily. He said

> *"Today we are talking about interoperability. Machine information "readable" exists, but 100% is far from it. But also it is necessary to be able to ensure that the* ***information I communicate can be integrated quickly, without interpretation, and with proof of its validity****".*

Manufacturer – BIM project Manager, R13

R15 supported the previous argument and added that for her day to day activities, exchange formats are the biggest problem. He noted that the issue of the lack of interoperability between software is that sometimes you should remodel some parts to get them in the right formats. He reported that it's not possible yet to have a round trip of the data.

> *"I think the main one was the* ***interoperability between the designs that we get from the architects and how we can modularise it*** *and then how we can* ***send it for pre-fabrication*** *because we used to deal with a steel fabricator to manufacture the steel. Some BIM issues also,* ***interoperability issues, between the exchange formats of the models****. Everything was done in BIM. Some exchange formats didn't quite work".*
>
> *"…because the standard COBie format is not acceptable by our CAFM system (Computer-aided facility management). So, we have to have a special format for it. So, we end up* ***copying and pasting from COBie into our asset import sheet****".*

BIM Manager – Operation & Maintenance, R15

Respondent R02 precises that specifically, the round trip of the data is a challenge. R11, the Quantity Surveyor (QS) said that in his company, mainly all the QSs redraw everything. However, he noticed an interoperability issue that makes the calculations wrong.

> *"Now we're in that back and forth all the time. That's a nice concept, but it doesn't work like that. You cannot say that you will create a model, build and manage it. You*

are not moving from one phase to another. You ***need to go back and forth all the time. And today the back and forth don't work****".*

BIM Manager – Facility Management, R02

"…95% of the Quantity Surveyors have their own models. I'm the only one that doesn't re-draw anything. I work on other people's models. However, I notice that the basic quantities that are in the models ***have a large part of the quantities that are false****…" "…when you click on the beam object, you take its width x length x height: you do not get a result of the volume of the beam.* ***I'm recalculating everything****. I do not redraw everything, but I recalculate all the quantities…" "…I don't know if it's IFC, the software****, I don't know what it's due to, but it's not true****. I don't know the origin. But it still makes my work easier".*

Quantity Surveyor – BIM Manager, R11

R12 added that there are software incompatibility issues. Due to that, they don't enrich the model with materials' data because they know that it doesn't work properly when they send the model to another stakeholder involved in the project. They exchange in IFC, only when all the project team is using the same software. He reported that the lack of a **homogeneous description** base is the reason why the imports they make are complicated from 3D software to another.

"…There are ***software compatibility issues****. The fact of having libraries of materials, of objects that will reference materials that are compatible with several multiple software is quite complicated. It is managed traditionally.* ***The nature of the materials, the prices of the materials will be managed rather with sending Excel files, but not in the model****". "…it's software compatibility issues. As* ***no compatibility has been found to transmit the data****, everyone starts manufacturing their data again. On the question of data, this is done traditionally".*

Architect, R12

5.5.4 Technologies related barriers

A. **Barriers linked to the use of BIM, as new technology**

BIM is a new technology used to improve the construction from design to facility management. The new approach proposes to integrate the SEOL as a phase into the asset lifecycle. According to the fact that a huge quantity of data is produced in BIM, from the inception to the maintenance phase, we propose to use those data for the management of the End-of-Life of the asset in a sustainable way.

a. Lack of demand for BIM

One of the problems highlighted by respondents is that the BIM process is not very widespread and not well used for every project. There is a lack of demand for that due to the cost and the radical change needed in the approach. R12 reported that

> *"The project owner who can receive a BIM model**, there are not many**. **And then the Building Manager who manages his building in BIM is even further away**.*
>
> Architect, R12

The same respondent added that all the stakeholders are sensitive to the use of BIM in France. The small architectural offices are not yet using BIM as well. At this moment, it's only big companies that are using BIM process.

b. Difficulty to move towards BIM

In addition to the previous barrier, the difficulty to move towards the use of BIM is another barrier. As said previously, the size of the company slows down the BIM adoption due to the investment that should be done in the beginning. R09 said

> *"…If you're doing conventional architectural work, you wouldn't be doing a 3D Model of this area unless you are using BIM. And **we can't do that in a small architecture practice because affording the software**. We do use 3D model, mainly as a design tool".*
>
> Architect, R09

Some architectural practice moved to BIM because they were already using BIM software since ages. So the investment should be made on the training and the change in the way work used to be done. R12 reported that

> *"… ArchiCAD has been used for 15 or 20 years. So the transition to BIM was done because **our tool allowed us to switch to BIM**. **The most important issue was in management**. We saw that in the few projects we did with BIM design offices, it was that it did not change our tools. **It changed the way we worked** in the sense that **we had to be more rigorous in managing the initial interfaces**. For example, name layers. It is more in the way the basic elements of the software are laid out, **where you have to be rigorous so that it can be easily transferred to others**".*
>
> Architect, R12

c. Lack of consistency: the use of technologies is not correct

The rigour is very important when you are working in BIM because it enables to avoid inconsistency in the data. It also avoids the loss of data when we exchange it. This leads to another lack pointed out by several respondents, which is the homogeneous classification. In BIM, one part of this new approach is that the client should clearly express his requirement right at the beginning of the project. This is a barrier reported by R13 who experienced one of his project the lack of requirements at the beginning of the project. R19 draw attention to the fact that sometimes, the use of BIM is incorrect and that, also represent a barrier. He said

> *"The fact that* ***we do not have this homogeneous description base*** *means that the imports we make into 3D software, which themselves are not the same software, is complicated. Then it's software compatibility issues".*

Architect, R12

> *"…the client* ***did not set us the requirements at the beginning****. It caused us to work overtime. They finally said that all the details of the model we don't want for maintenance. But it would have been nice to tell us before because we would have organized ourselves differently".*

Manufacturer – BIM project Manager, R13

> *"Everyone has BIM software in a drawer. Everyone knows how to do BIM. But behind it when you take a model that you* ***open and try to understand...there are often*** *surprises".*

Structural Engineer, R19

Based on their experience with the implementation of BIM, R20 reported a lack of homogeneity between the stakeholders and how to push up the "cursor of the BIM maturity level"? He believes that there are two types of difficulties, one related to the software and the other related to the use of the software. He also stressed the lack of maturity for the use of As-Built Digital Record. Even if the advantages of it are promising, the use of it is still very laborious and difficult for the project management teams. According to him, the handover phase is the hardest in the construction project. For the traditional As-Built Record, they struggle to receive a complete version.

> *"...We notice that they are* ***incomplete****, not when the As-Built Record is received but when there is a need to pick up a part during the "In use" phase. So* ***we may have the same problems with digital As-Built Record****".*

Owner – Engineer, R20

d. Two types of worlds: connected and not connected

Another barrier highlighted by two respondent (R16 & R19) is the fact that in BIM projects, we will prescribe preferably the products that are available in BIM. R19 said that:

> *"…the model will* ***encourage the use of a block and an element that is already in a product catalogue, and this will favour industrialists.*** *This will hinder craftsmen from being able to respond to the market and draw up plans in accordance with the BIM convention or the BIM protocol".*

Structural Engineer, R19

In support of the previous argument, R12 raised the arrival of new technologies such as the use of BIM could create two worlds: those who are using it and those who aren't. He said:

> *"…I think the question will also be "how to avoid creating* ***two worlds that are totally divided between them****". The world of those who are connected, who are computer literate and those who are not".*
>
> Architect, R12

B. Lack of technologies and technologies evolution

a. Lack of technology

The lack of technology was pointed out by two respondent in different areas. According to R02, there is a lack of Facility Management software's, and the one that is available are not ready to enable a good exchange result. This represents a real barrier for the handover of the data from the "in Use" phase to the SEOL phase.

In another area, R05 expressed a lack of technologies for the use of non-conventional materials for structural walls, such as earth. The use of earth as a circular material is limited to the small building due to the lack of technology around this material. He said:

> *"…we don't know how to make earth* ***walls insensitive to water****. We don't know how to make* ***tall buildings*** *out of earth".*
>
> Research & Development, R05

b. Technologies evolve quickly

The quick evolution of the technologies is also a barrier reported by R16. He explained that he is working on a project and they have to think about the Operation & Maintenance with BIM. The project will start in 2019 and will be completed in 2021. So the real question is how we will manage a building in 2021? He said:

> *"…technologies and everything, in general, evolves very quickly. Everything we can talk about in 25 years' time is about to be* ***completely abstruse and completely over****. I tell them to take it easy because, in 2021, we will have* ***a lot of new processes, new things that will appear****. Everything is* ***moving at high speed****. The models must follow the evolution of software and other technological developments".*
>
> Architect – BIM Manager, R16

In the same way, R18 explained that in the circular economy context, we might need types of material that don't exist yet. Therefore the market should be prepared upstream to each CE project. He said if we don't do that:

"…When you want to do Circular Economy, if you don't ***prepare the market for what you asked for****, you will never have a solution".*

"…so if you ***notify the market****, and you can interview several of them. I have fun putting around the competitors' table. By saying "here you are all here, that's what we're going to ask". We will ask you to stop making toxic products".*

"…If I hadn't done that, ***I wouldn't have had the necessary materials three years later****. Or at least they couldn't have proven that they had the right fibre size because they hadn't even measured it".*

CE Specialist& Architect, R18

5.5.5 Summary

Participants have identified twenty-three barriers for the incorporation of a SEOL into the asset lifecycle that are not in the literature, listed in Table 34. Table 35, a summary of the findings reveals that the barriers the most reported by the respondents are related to materials, buildings and data. For the data, the most important barriers are the data unavailability, exchange and accuracy. The most frequent words used by the interviewees are "building", "material" and "information" as depicted in Figure 34.

Figure 34: The word cloud frequency for technical barriers (Source: Author)

Table 34: Technological barriers identified by the interviewees and not found in the literature (Source: Author)

	TECHNICAL BARRIERS
1	Modifications during the building lifespan
2	Premature buildings' EOL - components are not obsoletes
3	Full lifecycle analysis = modifications distort the calculations
4	Architect practice - add constraints
5	Change approach and the design
6	Lack of clear requirements to integrate them into the design
7	Material quality and thermal inertia
8	Change the construction methods
9	Construction method limitation as barriers
10	High quality of the structural work as a barrier
11	No request on what will happen after the deconstruction
12	Material selections for deconstructability as a barrier
13	Lack of recoverability due to product implementation
14	Building data centralization
15	A decentralized view of the data: Model View Definition (MVD)
16	Data Compliance as-built – Accuracy
17	Lack of demand for BIM, so BIM for EOL will be difficult
18	Difficulty to move towards BIM
19	When BIM is used, lack of consistency: the use is not correct
20	The use of As-Built Digital Record is not mature
21	Two types of worlds: connected and not connected
22	Lack of technology
23	Technologies evolve quickly

Table 35: The summary of the results for the technical barriers (Source: Author)

TECHNICAL BARRIERS																				
BIM Users / BIM Manager																				
Roles	Designers						FM			Owners			TE	E	QS	M	SE	CO	D	R&D
Respondents	R06	R07	R09	R12	R16	R18	R02	R15	R14	R04	R20	R01	R10	R03	R11	R13	R19	R08	R17	R05
551-Building related barriers																				
A-Building lifespan -duration-composition-update	x		x	x	x					x			x			x		x		x
B-Building composition	x		x	x		x				x	x		x			x				
C-Building modification during its lifespan													x					x		
D-Building type & size as a barrier	x		x		x						x		x	x		x				
E-Projects Phases adaptation	x		x	x		x		x	x	x			x		x	x	x		x	x
552-Materials related barriers																				
A-Material composition - knowledge & reliability	x		x	x		x			x	x	x	x	x			x		x	x	x
B-Material recoverability	x	x	x	x	x	x	x		x		x	x	x		x	x	x	x	x	x
553-Data related barriers																				
A-Data Management								x	x											
B-Data unavailability and inaccessibility					x		x	x			x		x			x	x		x	
C-Data Compliance as-built-Accuracy			x		x			x					x			x	x			
D-Data Exchange and interoperability issues				x			x	x			x		x		x	x	x			
554-Technologies related barriers																				
A-Barriers linked to the use of BIM (as new technology)			x	x							x			x		x	x			
B-Lack of technologies and technologies evolution					x	x	x													x
(FM) Facility Managers, (TE) Thermal Engineer, (QS) Quantity Surveyor, (CO) Control Officer, (DE) Deconstruction Engineer, (SE) Structural Engineer																				

5.6 Environmental barriers

Another theme is environmental based barriers. These are the barriers the less important for the 20 interviewees. Four types were raised: (1) the site constraints (ii) the use of non-recoverable materials (iii) the carbon footprint and (iv) storage for salvage materials. All these themes will be discussed in the following sections (Table 36).

Table 36: The number of respondents and captions for environmental barriers

56-ENVIRONMENTAL Barriers	Respondents	Quotations
	11	**28**
561-Site constraints for SEOL implementation	**4**	**6**
562-The use of non-recoverable materials	**11**	**22**
A-Quantity of polluted waste	7	10
B-Use of finishing works	2	3
563-Storage facilities for materials salvaged	**4**	**9**

5.6.1 Site constraints for SEOL implementation

To implement a SEOL for the asset, the most important environmental constraint is the **site constraints**. Indeed, as highlighted by several respondents, the SEOL process is complex and time-consuming. The reclaimed materials should be stored on-site or elsewhere for waiting to be reused or to be processed for the reuse or recycling. The SEOL of a building is also **space consuming**. This environmental impact should be taken into account. For example, R06 said:

> *"…For that, there must be people who store the materials somewhere to resell to someone else. You'd have to* ***have a lot of free space to store****. It is a little what we saw with MXXX when we studied the crushing of materials to crush them. W****e need huge places because we use big machines****".*

Architect, R06

The demanding of spaces is not only when you are deconstructing or dismantling the building. It is also the case when you are using non-conventional material. For a project of 12 houses, the approach was to reuse the excavation earth and stone on-site. As reported by R06, this was a project very demanding in space for storing the excavation earth and also for machines to crush materials on-site for reduction of the carbon footprint of the project.

In the same way, R10 said that the logistics for a SEOL implementation are complicated. To obtain authorisations, in urban or peri-urban areas, allowing the storage of materials is difficult. The use of trucks for sorting materials and their required rotations must be rigorously scheduled. He added that the logistic around the SEOL implementation is not mature enough.

In the literature, the site dimensions and access were addressed in many studies dealing with deconstruction, RL and prefabrication approaches (Chileshe et al. 2015a, Jaillon and Poon 2010, 2014). The storage and the necessity to provide on-site space are also considered as barriers (Zaman, A. et al. 2018, Hosseini et al. 2015, 2014, Xanthopoulos et al. 2009).

R17, a deconstruction Engineer, reported that the constraints of the site are a very important parameter determining the complexity added to the deconstruction project.

> *"…It really depends on the* ***constraints of the site****" "…we have a 13-storey building to deconstruct. With a 13-storey building,* ***a school nearby and a very busy road.*** *The* ***main problem is the environment****. Either* ***we don't have the space to install the machines and skips****, or we have* ***too many too sensitive neighbourhoods****. It's not related to the building itself because with all the studies we do beforehand, it's possible to deconstruct it well. For us, it is* ***the environment that bothers us the most****".*

Deconstruction Engineer, R17

5.6.2 Use of non-recoverable materials

The use of non-recoverable materials is also a barrier highlighted by eight respondents over the 20 interviewed. They can be broken down into two parts, the removal of polluted materials and the use of finishing works.

A. <u>**Quantity of polluted waste**</u>

In the literature, many authors have identified the drawbacks of the existence of asbestos or lead in existing building that increase the overall project costs (Knecht 2004, Hosseini et al. 2015, Río Merino et al. 2010, Nisbet et al. 2012). R03 also raised the asbestos issue as a very challenging part of his activities. The cost and the complexity of asbestos removal lead to human irresponsibility's and misbehaviours that are impacting the environment very badly. According to R12, there are many projects that need asbestos removal where only demolition can be used.

The impossibility to recycle some waste was also reported by R17 mentioning that they have on their projects sometimes polluted waste that can no longer be recycled. Supporting that argument, R06 gave the example of roofs containing asbestos cement; they are not recycled but simply destroyed. All these processes for asbestos removal have huge environmental impacts that should be taken into account when designing new projects with a SEOL. Dealing with the asbestos issues sustainably is just impossible.

Furthermore, as mentioned by R08, asbestos can be found in a plethora of materials. He explained that the process to remove asbestos is expensive, tedious and regulated. The simplest process is to recover and store these materials and then send them to specialized plants. He added that

> *"…Asbestos can be found in glues for floor or wall coverings, wall plasters and also in exterior joinery. These are the joints that seal the glazing with the wooden or aluminium frame".*

Controller Office, R08

B. <u>**Use of finishing works**</u>

As seen previously, polluted materials are very difficult to recycle, and most of the time, they are destroyed. However, drawing attention only on that type of materials is not enough. R12 proclaimed that the finishing materials are usually environmentally not very good, and their health and safety aspects are harmful. He said

> *"...from an environmental point of view because they **contain a lot of petroleum-based inputs**". "...there are **many more deaths due to toxic fumes from finishing materials** than from burning materials*

Architect, R12

5.6.3 Storage facilities for materials salvaged

In the countryside, the storage might not be a reel issue, because the land is available but in urban areas, storage is a real issue highlighted by R10

> *"…Today, people have spaces that are not valued. Others **need temporary space**, whether to **manage the delivery of materials or manage the storage of materials** for deconstruction. We see an evolution among logisticians. Today we have more temporary availability issues".*

Digital Project Manager, R10

Storage facilities should be organised because at this moment people dealing with reclaimed materials are facing a lack of space. R09 reported the story of the demolisher in his city, and he said:

> *"…We have a demolition Contractor, on the next road from us in the countryside. He recycles everything. All they want is for him to take the stuff away. This is about two kilometres from where we live. These are all reclaimed materials. Then he sells them". "…so, when we do a project, we try to use reclaimed materials we go and see KXXX. And we say, KXXX, have you got some bricks or wooden beans**? And then, you walk around here until you find it. I think that he's starting to catalogue what he has**".*

Architect, R09

The lack of storage was also stressed by R20 based on several projects where they try to reuse some elements. He explained that they work with a company “Cycle Up”, specialized in the management of reuse and reclaimed materials, but the company is not yet proposing storage services. Therefore, they must synchronize the project from which they extract the materials and the one that reincorporates the recovered materials. Storage is important and organization as well. Anecdotally, he said that on one project, they could not synchronize with another.

> *"... I had to dismantle external candelabras. Some were very old, and others were replaced a year or two ago... those that were almost new could be reused. So we **stored them in a cellar**, saying "if I need them, they are there" but it has been forgotten”.*

Owner – Engineer, R20

The lack of storage was also reported by the deconstruction Engineer, by saying that it depends on the number of materials they will have. They can send everything to the same place, but sometimes, they can’t. They should look for a different location without compromising their project's carbon footprint. R17 said

> *"...we have to try to send our waste as close as possible to the site to **limit our carbon impact**. Afterwards, we can have polluted waste that we can no longer recycle...this type of waste goes into different channels and is much more expensive". “…**Centres that accept waste have no more space**. This happens very frequently in Ile-de-France. There are many projects at the same time, and **storage facilities do not follow**”.*

Deconstruction Engineer, R17

Jaillon and Poon (2014) have also identified the lack of storage and transportation as barriers for prefabrication. Indeed the author stressed that the transportation by trucks from factories to construction site plays a key role during the design phase. Indeed the dimension of prefabricated elements depends on the trucks' dimensions (Jaillon and Poon 2010).

5.6.4 Summary

Table 37, a summary of the findings reveals that the most reported by the respondents is the quantity of polluted waste, especially asbestos and lead. The most frequent words used by the interviewees are “asbestos”, “material”, removal” and ”storage”, “as depicted in Figure 35. All the environmental barriers identified by the respondents are similar to the environmental barriers found in the literature.

Table 37: The summary of the results for environmental barriers (Source: Author)

ENVIRONMENTAL BARRIERS																				
BIM Users / BIM Manager				■	■		■	■	■		■	■	■	■	■	■	■			
Roles	Designers						FM			Owners			TE	E	QS	M	SE	CO	D	R&D
Respondents	R06	R07	R09	R12	R16	R18	R02	R15	R14	R04	R20	R01	R10	R03	R11	R13	R19	R08	R17	R05
561-Site constraints for SEOL implementation	x										x		x						x	
562-The use of non-recoverable materials																				
A-Quantity of polluted waste	x			x		x								x	x			x	x	
B-Use of finishing works				x													x			
563-Storage facilities for materials salvaged			x								x		x						x	
(FM) Facility Managers, (TE) Thermal Engineer, (QS) Quantity Surveyor, (CO) Control Officer, (DE) Deconstruction Engineer, (SE) Structural Engineer																				

Figure 35: The word cloud frequency for environmental barriers (Source: Author)

5.7 Organisational barriers

In this section, the organizational barriers raised by the 20 interviewees will be discussed. They are classified into seven-part. Barriers related to (i) Working methods & approaches, (ii) The activity sector and public/private type, (iii) the teamwork, multidisciplinary and management, (iv) Communication' issues, (v) Several levels of responsibilities and traceability, (vi) Key players and key roles and lastly (vii) Lack of skills and education for skills improvement (Table 38).

Table38: The number of respondents and captions for organizational barriers (Source: Author)

57-ORGANISATIONAL Barriers	Respondents	Quotations
	17	**171**
571-Working methods & approaches	**9**	**24**
A-Issues associated with the current approach	4	7
B-Issues associated with the quality of the architecture	3	5
C-Issues associated with the project management	1	1
D-Issues associated with professions	2	4
E-New approaches issues	6	7
572-Activity sector - public/private type	**5**	**7**
573-Team work, multidisciplinarity and management	**7**	**22**
A-Current project management not adapted	4	8
B-Multidisciplinary Team	3	10
574-Communication issues	**7**	**15**
A-Define & respect collaboration boundaries - know When to say stop	3	5
B-Late communication between designer-contractor	3	4
C-Lack of common classification	3	7
575-Several levels of Responsibilities and traceability	**9**	**33**
A-Territorial Level and Individual of Responsibilities	2	4
B-Stakeholders Level of Responsibilities	5	15
576-Key players & New roles	**14**	**51**
A-Architects role	11	18
B-Key players – manufacturers	4	7
C-Owner	5	7
D-The key role of the control offices	2	6
E-Facility Managers	3	5
F-Lack of profession	2	6
577-Lack of skills and education for skills improvement	**12**	**50**
A-Lack of competences - skills	8	29
B-Competences improvement	9	26
578-Urban planification	**1**	**3**

5.7.1 Workings methods & approaches

A. Issues associated with the current approach

R19 reported that the classical method in the construction industry in France is organised in such a way that the project owner controls his budget, his building and the project timing completely before awarding a contract. Also, the roles of the stakeholders are much more divided in comparison with other project using a sustainable approach. He said that it frequently happened that the execution plans made by the design office "freeze everything" before the construction. Then the companies have to manage to build with that execution plans. The dysfunction of the project organisation leads to several issues onsite. As an architect, R18 reported that the main issues in the construction industry are that:

> *"…the architects **fight throughout the project** and waste a lot of time and money trying to fix "**the bullshit that was done at the beginning**".*
>
> *"Yes, when it is designed to be disassembled **it improves the "in use" phase**. Because from the moment everything is built so that it can be disassembled. If you want to change a luminaire, **you don't have to break the entire plaster ceiling**. If you want to update techniques (ventilation or renewable energy techniques or simply wiring, etc.), it is easier".*
>
> *"When everything is accessible and built to be disassembled, 1) we will **stop wasting these raw materials copper** (etc. with miles of cables left in the buildings). 2) In addition to that, we will **optimize the space**; we will be able to reduce the heights necessary to build etc. Because we'll need smaller ducts, and above all, if everything can be dismantled, it means that **everything is accessible** also for cleaning, for maintenance for these elements. It's going to be thought of as such from the beginning. It doesn't necessarily change the architecture; **it changes the way and the art of building**".*

CE Specialist - Architect, R18

The other barrier highlighted by two respondent is the asset lifecycle vision**,** which is not global and a very short-time vision. This lack of global vision is a crucial barrier for the SEOL approach, which is the opposite. They said:

> *"...today there is **no vision on the life cycle of the building**".*

BIM Manager, R14

> *"...We have some of the promoters that build and sell. Their objective is a **very short-term vision.** Indeed, their objective is to be extremely short term minded".*

Digital Project Manager, R10

Hosseini et al. (2015) have identified a lack of coordination among the stakeholders involved in a project. They believe that in general, the construction industry suffers from poor communication and disconnection between project phases (design, construction and "In Use" phases) (Hosseini et al. 2015). Gorgolewski (2008) and Crowther (2005) considered that existing design and construction processes are not appropriate for reuse. Other studies have identified that the current construction practices are not adapted for disassembly approach (Gorgolewski 2008, Crowther

2005). Regarding the prefabrication approach, there is a "lack of suitable methods or principle considering the requirements of the manufacturing stage and construction stage in prefabricated buildings" p.13 (Yuan et al. 2018).

B. Issues associated with the quality of the architecture

R05 questioned the quality of modern architecture. He said that the architecture doesn't have enough constraints and there is, a lack of artistic. He pursuit by saying that the architecture was transformed as technique feat and drawing. In support of the previous argument, R18 said that the architectural quality should be one of the parameter or requirement of the project. The difficulty in measuring the architectural quality due to its subjectivity and relativity is a real barrier. He gave several examples, such as:

> *"…When you look at the passive buildings that have been made or the zero energy buildings, have been made. I saw magazines…, where there was a big article about the fact that we made a first zero-energy housing building.* ***But there were no windows****. It was* ***unbearable, it was bullshit, and it was ugly****. So for me, it was already good to tear down".*
>
> *"…Architectural quality is essential because* ***a bad building is a building that will not be used properly and will not be rented****. I think that architectural quality, in a sense I almost want to say sensory of the term, is very important.* ***Wrong space will be misused****. We see what is being done in the suburbs. We have to count on that in public spaces".*

CE Specialist& Architect, R18

R20 raised another issue related, inter alia, to the quality of the architecture. He noticed that, often, buildings are not demolished due to their dilapidation. Indeed, their EOL is usually premature. One of the reasons, among others is their configuration in the city or the design of the entry/exit of the building. He also pointed out that the asset must anticipate changes of use or functions by being designed with modular or reversible principles.

C. Issues associated with the project management

R12 drawn attention to the approach he has observed in France and England that architects don't follow-up the construction. They give the job to others who will take care of the site leading to a lack of consistency in the management. This is a huge barrier and make the holistic vision of the asset lifecycle more difficult.

> *"…There is a very strong interaction between the design phase and construction.* ***Architects are less and less involved during the construction phase****... Those who do the design must also be involved in the implementation".*

Architect, R12

Several authors has addressed the project management issues. For instance, based on a survey with the construction Lebanese stakeholders Shibani et al. (2010) explored what are the main factors influencing the implementation of quality management systems in the construction sector. The findings revealed five quality management constructs to improve quality in construction projects: (i) top management commitment, (ii) communication, (iii) teamwork, (iv) employee empowerment and involvement, and (v) work environment and culture (Shibani et al. 2010). Few years later, Shibani et al. (2012) have developed a generic company-wide framework aiming to help construction practitioners to improve the Total Quality Management (TQM) of a project (Shibani et al. 2012). Indeed, Andersson et al. (2006:284) reported several definitions of TQM and tried to find out the difference between two close principles: Lean and Six Sigma. One of the reported definition considers the TQM as "…*a continuously evolving management system consisting of values, methodologies and tools, the aim of which is to increase external and internal customer satisfaction with a reduced amount of resources*" (Andersson et al. 2006). To further explore the leverage for construction project improvement, other studies focussed on the quality of project managers' leadership. Findings show the people' surrounding environment and communication as key factors for success. (Zulch 2014, Al Kazaz and Shibani 2016).

D. **Issues associated with the architect's profession**

Several respondents have given their opinions on some issues related to their roles. Based on her projects design with the BIM process, R16 said that the time spent to assist the client with the new BIM approach is tremendous. But this is part of their approach within their architectural practice. However, he noticed that the design office doesn't have the same approach, and they stick to their mission. So this double "strategy" with the client for the same project team, is directly due to professions themselves and can be a barrier.

> *"…we notice that* ***the design office does not think at all like us, architects****. The Design Office says "I sold you a mission" all that also comes, as a complementary mission. The design office is very factual in general. As an architect, it is the profession that also wants this; we always submit a little more".*
>
> Architect & BIM Manager, R16

The deconstruction contractors will face specifications that they don't have in traditional projects. R14 reported that for a SEOL approach, the Operation & Maintenance operators would encounter similarly some specifications that they don't use to have. Indeed, they are usually more concerned with specifications in expectations in terms of performance, such as thermal performance, acoustics, comfort or air quality, etc. R14 said they are not used to have specifications impacting the implementation of equipment, for example. He added that similarly, the manufacturers' approaches, closely linked to system approaches, are barriers for the implementation of a SEOL approach. Indeed manufacturers tend to make composites more and more complex to improve their performances. He added that:

"…Potentially, ***this can be a brake*** *unless manufacturers manage to make constructive systems that are also deconstructive systems. This will necessarily be an approach".*

BIM Manager, R14

E. <u>New approaches issues</u>

a. New approaches as "a niche": the use of non-conventional materials

The seven architects interviewed explained their approaches that are all different but with the same aim, which is reducing the EOL waste or extending the asset lifecycle. Some of them are approaches linked with the choice of non-conventional material. The use of existing waste or reclaimed materials as a material for designing a new building or refurbishing an existing building. But many of these architectural approaches are considered as a "niche" due to a lack of awareness and understanding. For example, the Structural Engineer R19, who is working on several projects using Earth materials for the structural walls said that

"It's a small industry that survived. Yes, ***it's a niche market****".*

Structural Engineer, R19

"The earth probably has ***no great future other than in a small niche****…"*

Property Developer – Engineering Office, R04

b. Complexity to implement new approaches

The implementation of new approaches, such as the use of the BIM process, is discussed in subsection 4.3. For the incorporation of the SEOL into the asset lifecycle to be able to move towards the circular economy principle, changes should be applied in the way practitioners used to work. The complexity to implement new approaches was raised by several respondents. For instance, R07 explained his two important projects that are going on. One of them is in a very dense urban area, with difficult access. He based his approach by the one used previously for the construction of the asset which is now planned to be refurbished. The approach is to build with what they will found on-site. This is the client demand, to use as minimum as possible new materials. R07 linked the complexity to implement his approaches with the cost and duration of the project. Therefore, he also pointed out the client will as an important driver for the use of an innovative approach. He said that for the ongoing project discussed above, the client believed in the approach and was open to discussing.

"There is an impact on the cost and duration of projects. That's the complexity of implementing it. ***Investors will continue to build fast and cheaper. They will represent a barrier to implement it****. This is the strength of large groups".*

> *"The nuns built the buildings cheaply. So, we can do it too. We are lucky to have a very good client who believes in us. For me, a good client is the one who understands and believes in our approach.* ***What interests him is to build clean and durable for 500 years and not to make money. It is because the Client has that spirit that we can have a discussion****".*

Architect, R07

R20 explained that they wanted to adopt new insulation for a 13-storey tower by using hemp concrete as exterior insulation. This insulation is already approved and used for up to R+3 buildings. They worked with the architect, the manufacturer and the control office. Unfortunately, it was not successful due to multiples factors, but the main barrier was the time needed to set up new materials. Industrial time to make the material, getting the acceptation and certification is enormous. So this time must be taken into account when the use of a new product is targeted. This issue was also stressed by the CE specialist, R18, who explained that the market must be prepared. He has the habit of accurately specifying what his expectations to manufacturers are, right when the project is launched. So they will have time to make products that suit the project's expectations.

The difficulty to adopt new approaches was identified in several studies, whether Sustainable Buildings, RL or CL approaches. Chileshe et al. (2015) believe that the complexity and the temporary nature of projects are the reason why it is difficult to implement the RL approach in the construction sector (Chileshe et al. 2016). Similarly, the adoption of a CL approach for the construction sector is harder than other industries (Kibert 2003, Crowther 2005). Based on a literature review, interviews, expert workshops and case studies, Hakkinen and Belloni (2011) have studied the barriers and drivers for Sustainable Buildings. They concluded that "SB is not hindered by a lack of existing information, technologies and assessment methods, but because it is difficult to adopt new processes and working methods to apply new technologies" p.240 (Häkkinen and Belloni 2011). Bouzon et al. (2015) reported that the RL approach is one of the most difficult initiatives to implement compared to green purchasing and design for environment p.1368 (Bouzon et al. 2015).

The SEOL approach is leading to pay attention to the components of an asset and to make sure that they can be reinjected for another lifecycle. This can be directly reused or recycling them. As mentioned by R14, we should move from an economic vision to a recycling vision. And that should be integrated from the programming stage. The complex part came from the fact that all the supply chain that will be involved in a SEOL approach, (from the client to the material recycling contractors) are not familiar with specifications. He said:

> *"In design, architects, design offices and economists are used to having requests, to taking into account the requests of the project owner. Very often, for important*

projects, they are provided with architectural charters that they must respect. So they are used to this exercise. ***In operation, operators are not used to having specifications that impact the way equipment is implemented". "…It is something that will be much more complicated to integrate. It will be a new angle for them****".*

BIM Manager, R14

A structural engineer, R19 also supported **the importance of the client.** He is working on an ongoing project that uses earth as a material for the structural wall. He explained the difficulty to get the insurance for that kind of material. The process is complex, costly, and client support for the approach are crucial. He said:

*"***It doesn't work if the project owner doesn't want to***, but if the project manager doesn't want to either".*

Structural Engineer, R19

R18 stressed understanding as an important part. Clients should have a global vision of the project and understand that they are investing by using the SEOL approach. Based on the example of modular buildings, he explained that the modular approach must be discussed and planned and designed to be modular. He added that the Assistant Contracting Authority should explain that:

"…if we don't make this investment in the first place; it will cost them a lot later. If we do not integrate, from the design stage, whether it is a new building or under renovation, these concepts and move the project forward (we obtain permits, etc.), ***we will not be able to integrate them.*** *As usual, and we say "we'll see with the design offices how it can be done"),* ***it's already too late****".*

CE Specialist - Architect, R18

The lack of a global vision or holistic approach was also identified as a barrier in many studies. Indeed, for instance, Ajayi et al. (2015) have identified a lack of a holistic framework for effective diversion of waste from landfill. They consider that the existing waste management strategies are not a holistic approach (Ajayi et al. 2015) p.106. Hong-Minh et al. (2001) reported the lack of a holistic view of the supply chain. According to the authors, the functional silo approach hampers the companies' abilities to be fully end-customer focused (Hong-Minh et al. 2001) p.56.

5.7.2 Activity sector – public/private type

Barriers were also observed depending on the activity sector and for private /public projects. The new approach will not be welcomed similarly everywhere. R19 pointed out that in public procurement, everything is frozen when the procurement contract is awarded. So the contractor cannot change what was initially planned. Therefore, during the construction phase, there is no longer really any latitude to make modifications. This is a crucial barrier, and that's why several respondents that have different approaches insisted on the necessity to put every stakeholder involved during the asset lifetime around the table at the beginning of the project. R19 reported that

> *"Typically if we wanted to design construction in raw earth calmly if we want to reuse the earth from the excavation of the site. The most suitable will be, a little bit, to mix the design phase and the construction phase, because we have to start characterizing the earth, to know the company to know the mechanical performances of the material that will be used and adapt the design to its capacities. And perhaps also to adjust, at the beginning of the construction site, the geometry of the structure. So,* ***it is almost impossible to do with a traditional project owner who wants to completely control his budget and his building before awarding a contrac****t".*

Structural Engineer, R19

According to R20H, in France, we start to see some tenders around the Circular Economy approach or recycling requirements, but it's still at the infancy. It's observable mainly for public projects. R16, who worked as an architect for more than 15 years, mainly with private clients, said that the market is not mature at all.

> *"***The private market is very, very far*** from positioning itself on the subject within a few years".*

Architect, R16

Another barrier was expressed by the architect R07, who thinks that the investors will keep their economic vision to build fast and cheaper. They will be a real barrier to the SEOL approach. The respondent R10, on the other hand, raised the activity sector as a barrier. He noticed that some sectors are more or less up to date.

Chileshe et al. (2015) reported for RL adoption; barriers could be due to the nature of building and activities (Chileshe et al. 2015a). This was also raised by respondent R10, who has noticed that some sectors and type of projects are more or less in advance. He explained that depending on the project type, the expectations are different in terms of deconstruction or dismantling. The reasons behind a material selection could be, for example, a political driver or a risk control driver. He supported the argument by giving the example of the use of LED or not. Therefore, the sector of activity will be determinant on the approach. The nuclear sector has already "a head start" because of today; they cannot

> *"...imagine* ***designing a nuclear power plant without thinking about its deconstruction*** *and the use of the materials that will be used during the construction phase".*

> *"**Retails is going to be favourable to LEDs, even if we do not know what to do with it when the asset is deconstructed** while the nuclear sector or the industrial sector will have a different approach. They will investigate whether the investment in LED will not generate taxes when they become waste. How can we recycle and reduce this share of waste, so will have the notion of risk?"*

Digital Project Manager, R10

5.7.3 Teamwork, multidisciplinary-and management

A. Current project management not adapted

Adopting a new approach, whatever it is, leads to changes. This was identified in many studies addressing CL, deconstruction or 3Rs approaches (Gorgolewski 2008, Jaillon and Poon 2014, Nisbet et al. 2012, Sassi 2008). In line with the literature, R14 said that the main impacts would be on the actor's themselves. They need to learn to work differently. Checking steps should be done throughout the work to be able to certify that the materials used are the one which was prescribed. The architect R09 who has more than 30 years of experiences reported that during an unexpected visit on the construction site, he discovered that the workers were planning to install materials that weren't allowed in the specification. He also stressed that the architect role is secondary and they don't check the construction on-site. He said

> *"…I discovered that they were just about to install things on the roof, which **was not allowed in the specification**. So, you **must get control of the building and spoke with them**. And the architect, for some reason, had two weeks off. So, no one had noticed if I hadn't gone that day, this stuff would have gone into the building. It's **very unusual for architects to have that level of control of a project**. There are so many projects now. **The architects are secondary in that process**".*

Architect, R09

Several respondents equivalently reported that the checking process should be rigorously set up right at the beginning of a project, whether for the on-site work or the design work. R10 added that one of the major obstacles is to be able to identify properly the quantities but also the materials used in the asset during the construction phase but also the operating and maintenance phases. **No-follow-up exists** between the construction phase and the maintenance phase. Specifications should continue to be observed during the in-use phase if we want to avoid to have an asset that was handed over "deconstructible", but that became un-deconstructible later on the in-use stage.

B. Multidisciplinary Team

The need for systematic cooperation and a multidisciplinary approach was stressed in several studies (Häkkinen and Belloni 2011, Jaillon and Poon 2014). Therefore, to be able to set up efficiently a project taking into account the SEOL, the team must be defined and involved right in the beginning. This is not what currently happened in the project, as explained by R09 and reported by Hosseini et al. (2015) for RL approach (Hosseini et al. 2015). He stressed that usually, you have several levels of contractors, the main contractor and the subcontractor, and so on. And usually, the contractor, when the project starts does not know who the subcontractor would be. Having all the different parties involved in the process, when the project starts, around the table is quite challenging, according to R09. He said

> *"… You* ***can't get all these people together in conference*** *and say: "Right now we have to explain to you that in 20 years' time, this building must be dismantled. So, you must do this and this". And they will say oh no! The reality is that the* ***main contractor will work out who the subcontractors will be when he starts on-site****".*
>
> *"The main contractor has a Contracts manager, a Site Manager, an estimator, a quantity surveyor and a BIM person, who struggles to work out what the drawing supposed to be.* ***Anybody is physically doing anything on the site****. It is the subcontractor. And* ***the subcontractors have their own subcontractors****".*

Architect, R09

He also added that the main contractor is not dealing with the on-site work. The contractor team is usually quite restricted. He gave the example of a huge contractor who was employing only six people. They complete their team by sub-contracting to other sub-contractor who also had his sub-contractors. So finally, the project team structure is a real barrier that should be overcome to be able to work collaboratively and consider the asset lifecycle holistically.

He took another example of a public sector project showing the drawbacks of having an unstructured team. He was visiting the on-site construction as a consultant and discovered that the workers were working without observing the required health & safety recommendations. They also use the insulation that they were supposed to put in the wrong way. He said:

> *"If I were the architect, I would go straight to the contractor. But that happens all the time. "****So, it's about having a team people****. When we talk about,* ***we must involve everybody right at the beginning when you start a project****".*

CE Specialist - Architect, R18

This argument was also supported by the R18, the circular economy specialist who stressed the importance of working in a multidisciplinary team, right when you start the project. Because he worked in multiples European countries, he was able to compare and experience the approaches that varied from France, the UK and Belgium and see their bad sides. He said that in France, the project process is organised in such a way that when we talk with the builders, everything is already sketched, the construction permit has been issued. He said "it's too late" to see how it will work. The tendency observed in France is to consider that the responsibility will go to the company. He encountered the same willingness to break down the supply chain and refuse to work in a multidisciplinary team. He gave an example of a huge renovation project that he was leading in Belgium, and he said:

> *"...everything was impossible because I was not allowed to work from the beginning, with engineers, with design offices, with landscape architects. I was told no, it's your responsibility. First, do the project, and then we'll see what happens".*
>
> *"...**always work in a multidisciplinary team from the beginning**. That is what I have always done and what I have always demanded. I worked for 11 years in London with some of the world's leading architectural firms and engineers. **Anything was always possible when you sit around the table at first**".*

CE Specialist - Architect, R18

R18 added that you need to have everybody around the table, even the suppliers. Prices should be defined with them if you want to avoid material quality issues. Because they want to win the tender, they will do anything to be the cheapest. So, the lack of multidisciplinary work and requirements in specifications around the quality, recovery of materials, and quality for health are crucial barriers when you want to deliver a building with a SEOL. It will help to avoid the substitution of materials during the construction phase. Indeed, the discussion around material replacement is a common issue in every project, highlighted by several respondents and discussed in the sub-section 544-D. Working with a multidisciplinary team raises the importance to define and respect the collaboration boundaries and avoid the plethora of communication issues that will be discussed in the following section.

5.7.4 Communication issues

A. <u>Define and respect collaboration boundaries</u>

One of the challenges highlighted by several respondents is the clear definition of collaboration boundaries. When you are working with different approaches, whether BIM or/and SEOL, stakeholders roles and responsibilities change. This will be discussed later in section 6.3. R13 described the collaborations issues that he faced in a big project in France constructed with BIM, and that will be maintained with BIM as well. He said:

> *"Although we had actors who were very committed and motivated to participate in the process, **during the construction phase, we had meetings that went on and on**. These meetings were to determine what information was needed to ensure optimal maintenance and upkeep of the hospital in the future".*

Manufacturer – BIM project Manager, R13

Also, R16 boosted the previous argument by saying that the difficulty is to know how to say "stop". Indeed one of their approach to project management is to assist the client closely and to support him. The use of BIM exacerbates the collaboration boundaries issues because they go beyond the handover phase. They assist the client also for the preparation of Operation & Maintenance with BIM. Likewise, he added that for their modular and flexible building approach, they should maintain a good relationship with the client and be flexible in terms of time. He said:

> *"...when we enter into a very open dynamic of collaboration, the client is* ***always asking for a little more and little more****..."*
>
> *"Otherwise, we enter into a relationship where it no longer works with the client, and we have difficulty doing something really flexible".*

Architect – BIM Manager, R16

The traditional approach is to develop the project and have several contractually limited exchanges with the client for validations. But this is done when the project is already well advanced and nearly finished. But finally, the client said, "Oh no, that's not what I want at all"! That happens very often as R18 had also pointed it out. This represents a real barrier for the project management that will be exacerbated by the SEOL approach due to the global vision that is needed. To avoid to redo the project from scratch, the collaborative multidisciplinary approach is recommended. On the other hand, one of the dangers of the approach and the tools to implement it is the limits. He gave the example of the use of a platform for their project to which they give access to the client. The lack of "control access" management leads to some excesses, as mentioned by R16:

> *"...We don't have access control management or some people see some things and others don't. As a result,* ***everything is visible****..." "...the client has the impression that every day we make deliverables for him.* ***They keep pointing out every mistake he has seen****..."*

Architect – BIM Manager, R16

B. <u>**Limited and late communication**</u>

R09 highlighted in the sub-section 573, the lack of well-defined and structured team. These barriers lead obviously to limited and late communication. He explained that usually, the contractors sort out who will be the sub-contractor very late. R15 stressed the late designation of the contractor team. He worked in an off-site construction manufacture group that also has a higher division. He explained that they already design, construct and use modules. And then, they deconstruct them, take them back to the factory and store them to be able to reuse them for another client who will need temporary building. He added that the crucial barrier is that the contractor arrives very late in the construction process. They usually pop in the technical stage 4 (of the RIBA). They are not involved in the design phase, which is a crucial step when you are dealing with modular projects or with projects that should have a SEOL. Therefore, in agreement with R09, he said that the key element is

> *"...**early communication between both the designers and the** contractors because most of the time, the contractors arrive very early at these stages. Therefore, they might arrive at the **technical design stage 4**, so they might **not get involved in the early stages, which is very bad**. Therefore, if they were involved early, their early involvement will be key to the success of this process".*

BIM Manager, R15

For innovative projects and for new approaches adoption, R20 insists on the importance of discussion between the client and the project's stakeholders. Discussion is also required for additional costs associated with a new approach. He said

> *"…**we discuss with them to validate** these additional costs. It is easier to validate the surcharges if the project management takes part in investing in these new methods". "...it necessary to **spend a lot of time with them to discuss, to reassure them sometimes**. To rework what is important and what is less important... And the challenge is to manage to hang the companies, without frightening them."*

Owner – Engineer, R20

Regarding the prefabrication approach, Jaillon and Poon (2010) highlighted the importance of an early collaboration between architects, contractors and manufacturers. Liao et al. (2017) reported that the lack of early collaboration with contractors and facility managers did not enable them to contribute their knowledge (Yuan et al. 2018). The lack of communication and effective cooperation between projects' stakeholders was identified by many authors, as a critical barrier (Chileshe et al. 2015b, Häkkinen and Belloni 2011, Chileshe et al. 2015a, Knecht 2004).

C. Lack of common classification

The communication issues are also linked with the classification used in the construction industry. If different classifications are used it will create inconsistency and ambiguity when we communicate around a project. The lack of a common classification was pointed out, as a barrier by (Häkkinen and Belloni 2011). In consonance with the previous statement, Knopp-Trendafilova et al. (2009) reported that the use of BIM and a common classification simplifies plan modification (Knopp-Trendafilova et al. 2009). However, Gelder (2011) stressed that even within one classification system (OmniClass or Uniclass, for example) tables do not align (Gelder 2011).

R12 compare the French classification system with Switzerland. According to him, around 80 to 90% of the description is taken from a library of elements' description. The lack of a homogeneous description base is a barrier for good communication. Currently, for every project, everyone reinvents the prescription from scratch. He said

> *"…if we were based on a nomenclature that is uniform for everyone…**it would simplify things**. This would solve the problem of compatibility between different software, and it would also **solve the problem of trust since we would all have a reference base that is uniform**"...*
>
> Architect, R12

R13 worked in different countries, and he was involved in the recent study made by BuildingSmart, on classification subject. He also led a working group at TC442 BIM CEN level, where the classification was a subject. The conclusion was that there are more than a hundred classifications. He said that the problem is:

> *"…not classification but the identifier. We all dream of one day **being able to share the same one**, but it may remain a dream".*
>
> Manufacturer – BIM project Manager, R13

He took the example of an important project in France where the models were required in native format and IFC. As a manufacturer, he was asked to be able to provide their products with the three well-known classifications: Omniclass (UK), Uniclass, and Uniformat (US).

5.7.5 Several levels of Responsibilities and traceability

When the SEOL is incorporated into the asset lifecycle, as a new approach to move from the linear to the circular economy, one jostle the construction phases and the construction supply chain. The role of each stakeholder will be affected, and the responsibilities might change. In the following session, the points raised by the 20 interviewees will be discussed, in terms of responsibilities that were classified in three types, the territorial level, the individual level and the stakeholder's level.

A. Territorial Level and Individual Responsibilities

Regarding the territorial responsibility, R10 said that there is a lack of responsibilities at that level. And he said that the territory should be responsible for its choices. He reported

> *"…**A territory is responsible for having established initial specifications** to have an industrial or service building in a place that is environmentally friendly and can minimise its impact on the territory".*
>
> Digital Project Manager, R10

He added that one organizational barrier at the territorial level is the lack of the traceability and readability of the responsibilities. Today they are making choices at their level, but they are not responsible for the impact that their choices will have in 20 or 30 years. With the SEOL approach, we are asking them to be responsible for the impact that their today choices will have. The readability and traceability of the impact don't exist yet. This is something that should be put in place to support the SEOL approach. Without that, we will continue to face some territorial aberrations having a crucial impact on the population. Decisions and follow-ups should be tackled by using taxation as leverage. He believed that for example, buildings that have a big impact should be taxed for that and building having adopted a SEOL approach should be rewarded.

> *"…It would seem normal to me that high-impact buildings are taxed more than those that will have a low impact,* ***both for the territory and for the use of the raw resources*** *of our planet.* ***There could be financial and fiscal "bonus-malus" systems applied to the building****".*

Digital Project Manager, R10

B. Stakeholders Level of Responsibilities

Three respondents expressed that the change of the approach will have an impact on stakeholders' responsibilities (R10, R13 and R18). R18 added that having a common vision is everyone's responsibility. To obtain that is not easy. To increase the success of whatever the CE approach or the SEOL approach, the investor responsibility is to express a sufficiently high level and to give the budget for that. This means that from the outset, the programming phase and studies should be well done. To illustrate his idea, he said word-for-word:

> *"The investor* ***should give the budget for that****…You don't build an Audi for the price of a 2CV".*

CE Specialist - Architect, R18

Given the fact that there are numerous stakeholders involved in a project, whether new or refurbishment, the responsibilities are shared between all of them. The degree of responsibility will depend on the tasks attributed to each stakeholder. In the case of a SEOL project, the management and involvement of each stakeholder will change, and their responsibilities of each will also be affected.

Company or architect's responsibilities**:** The responsibilities will also vary depending on the country and are closely linked with insurance issues (discussed in section 5.3.2). For instance, R18 reported that the tendency in France is to put the consider companies as responsible. However, in England and Belgium, the architect is in the front line. According to his point of view, the architect should have a key role, especially when working in a circular economy or SEOL approach were working in a multidisciplinary team is fundamental. He added that:

> *"…unfortunately, the architect's role is increasingly being taken on by others…except maybe still in England. But in France, the architect is seen as an artist".*

CE Specialist - Architect, R18

R12 highlighted the case of materials reuse and the responsibility that is no longer shared with the supplier of the material. He said that in the case of reclaimed material, the responsibility should be taken fully by the company. And due to that, companies are not fond of reusing them and prefer not to take the risk.

Owner or Manufacturers' responsibilities**:** R13, a manufacturer was questioning who will bear the recycling burden, the owner of the building or those who provided the products to build it? Another barrier is that if we consider the fabricant as responsible, what will happen if he doesn't exist anymore 30 years after the use of the product? R13 thinks that it is up to the client to make sure for the recyclability of the product that he will choose to use in his building.

According to R20, the adoption of new approaches does not generate major changes but a transfer of responsibilities and contracts' changes. For instance, the **Facility Manager** intervenes very early in the project instead of when the asset is delivered. For the use of reclaimed materials, he reported that they take some risk related to innovation, that they measure, weigh and accept.

> *"...Before he was **never consulted**. So that means we're going to have a little **change in responsibilities**. The **operator** who will be there, right from the design phase, **will be a little more responsible** for what he has to manage afterwards, compared to today..." "This is experimental, particularly on buildings with high energy performance, where we want to monitor the operation in accordance with what was indicated in the design stage. This is to thwart a little the projects that we saw as very successful on paper and much less so in reality".*

Owner – Engineer, R20

Everyone responsibility**:** According to R10, there is a lack of traceability for the work. Traceability of both the decision and the follow-up must be set up to overcome that. All the stakeholders involved throughout the asset lifecycle will be responsible, at different levels, for the traceability of the work and must keep it updated.

> *"…Today, the major obstacle is to be able to identify not only the quantity but also the nature of the materials used in the design and construction phase but also the operating phase of the building. Today, **there is no follow-up with finesse, of a replacement element**. We can initially have a material that is very easily deconstructible with screw systems but was transformed with elements that are welded during its execution phase, and that becomes no more deconstructible at all".*

Digital Project Manager, R10

R13, as a manufacturer, expressed his concern about the role that the manufacturers could play in the SEOL approach. He said that we should start with the project requirements, the design and the specifications. Implementing the SEOL approach will oblige the manufacturers to make available products capable of being recycled or reused. The main barrier that he can see is that strong pressure will be put on manufacturers. They must be able to guarantee a recycling process for all their products, and this must be mentioned clearly in the specifications.

> *"...Companies are told not only to provide solutions that provide the expected performance (acoustic, thermal, mechanical with additional building management requirements), but also that these* ***solutions must be recyclable****".*

Manufacturer – BIM project Manager, R13

R12 raised the power of manufacturers in the construction industry. They will find a trick to decline their responsibility and will say that the implementation was not done properly and doesn't fully comply with their specifications. This argument stresses the importance of product specifications.

5.7.6 Key players & new roles

In traditional projects, all the stakeholders haven't the same importance in the project. In the following section, the author will discuss the barriers related to the stakeholders involved in an asset, from its inception to its SEOL management.

A. Architects role

In total, nine respondents agreed to say that the architect role is fundamental. R09 stressed one important barrier in the current process, which will be exacerbated in a SEOL approach. He said that usually, architects don't have a high level of control of their projects. This is mainly due to the number of projects that they are working on. So slowly, the role of architects is changing to become secondary in the project process. This was also pointed out by R18, who said that the architect's role is increasingly being taken by others. Usually, in France, architects are considered as "artist" and the stereotype still stuck to the profession.

For the implementation of the new approach, this is a barrier. Indeed, according to R14, at the design level, the most challenging is that the design team must understand the issues raised by the SEOL approach and find operational solutions for its implementation. This was supported by R12, who reported that, due to the major changes that the design stage will have, the architect is in the core of the approach. R15's comments, below, summarize the preceding arguments:

> *"The design of the assets. I think this is the main aspect that should change…but the design is the key aspect that you need to be changed…The* ***key stakeholders are designers,*** *I think. Because* ***if they got the design right then, it would be helpful for the construction*** *from the people on the construction site to* ***build it correctly****. It will help the people in use to expand later on or change it or repurpose it. And it will help the deconstruction phase".*

BIM Manager – Facility Manager, R15

The role of the architect is to be a moderator in the approach. Architects should be open-minded, but the key actors are the owner and manufacturers. To support R16, R18 said that the architect in a SEOL approach would be a conductor. For him, the key phases in a circular economy approach are design and especially programming. The inventory that should be done, at the beginning of the project will represent a huge barrier due to the lack of information we have about the site or the building that we plan to refurbish or deconstruct. He said, “we need to know what we have, what we are starting from”. Otherwise, the project will not be inserted properly on the site. For him, when a site is not a greenfield site, the circular economy should start, from what was done in the past and have an overall assessment of the history of the site. This will be a barrier because it is not at all the current practice. And as, said previously, the lack of data will deter the implementation of this approach.

> *“…this is really very, very important. You need to have a very, very* ***complete inventory of the conditions under which you start****. And if there is construction on site, what do we do with it? Do we keep it, do we demolish it? If we demolish (because often it has not been built to be disassembled, we have to demolish), what do we do with the materials?” "…You have* ***to look at the building in time****, not only now and up to the construction (which is done in general) and its use, and its end of life or its transformation and successive transformations". But I also* ***like to go back upstream, back in time if there is a way****”.*

CE Specialist - Architect, R18

The argument was evenly assumed by R07, who said that it’s actually something feasible. For him, every stakeholder is important, but the architect and the builder will be a bit more important. His multidisciplinary approach, based on his experience in India enables him to have a holistic view. He works closely with masons. His multidisciplinary team is composed of engineers, researchers and knowledgeable and real builders. All the project stakeholders are involved in the design and construction phases. The main barrier for him is to implement his SEOL approach in France. He said

> *“…In India, when* ***we study a detail, we build it with our builders****. It's seamless. The carpenters make the models, and it is the same carpenters who build the houses”. “…We're not going to build everything by ourselves, like in India…” “…In our team,* ***we have knowledgeable and real builders****. We have multidisciplinary teams and thanks to all that, we have the same spirit as in India. We have people who know about construction and who will be able to drive the companies…* ***all project stakeholders are involved in the design and construction phases”.*** *"…We have many projects that take time to emerge in Europe because it is complicated to adapt this method elsewhere. It is a highly effective method, but it must be adapted to the companies that want to work differently”.*

Architect, R07

To reinforce the idea of multidisciplinary and the requirement of all the stakeholders in the design phase, R19 explained the approach of an ongoing project using the earth material as a structural wall for a public building in France. He added that the stakeholders are all involved in the design phase, and there is a permanent discussion between the builders, the laboratories, researchers and the design office. In comparison with traditional methods, the roles were intertwined. For him, the barrier is that

> *"…I would say that we were much* ***more involved than in a normal construction site****. …classically,* ***the roles are much more divided****. There can be almost the design office that will make execution plans and freeze everything before the construction even begins".*

Structural Engineer, R19

In the literature, the architect was identified as a key role for the 3Rs approach, especially for the reuse of materials in buildings. Indeed, as discussed in sub-section 551-E, the reuse of reclaimed materials may lead to adapt the initial design or change the design and construction processes (Gorgolewski 2008).

B. <u>The client</u>

Several interviewees shared the point that the client will have a key role. According to R01, the client will play a key role in the SEOL approach, and he should be familiar with the approach to be able to promote it. For R09, if the client is not going to ask for the SEOL approach, no one else will claim it.

> *"In the sense is the client really who oversees commissioning the building. If the client says,* ***we want to make sure this building can be decommissioned or deconstructed*** *or whatever in the future.* ***That's a key part****. If they don't say that, then no one else is going to say that".*

Architect, R09

R16 believes that the project owner will have a key role alongside manufacturers. The project owner must be the initiator and give the means to achieve the SEOL goal by limiting the financial constraints. He will have the power to make the project successful or not. According to R16, it will be impossible to adopt a SEOL approach with a reduced budget. Another architect, the respondent R18, supported this argument and pushed the reflexion further by believing that the programming phase and the inventory related to it are very important.

In the literature, the client role, as a barrier was also discussed in several studies. Indeed, Gorgolewski (2008) has identified the owner as a barrier especially for the initial investment that must be done for purchasing materials early in the project process while the contractor is not appointed yet (Gorgolewski 2008). In the line of the project-stage investments, Kifokeris and

Xenidis (2017) have listed thirteen barriers related to the owner in the context of the constructability approach. Among them, “the lack of concept awareness, false evaluation concerning the impact from the implementation of a constructability program on the project, reluctance for additional early project-stage investments…” (Kifokeris and Xenidis 2017).

C. <u>**Key players – manufacturers**</u>

As it was discussed above, the manufacturers will also play a crucial role in the SEOL approach because the choice of the materials used for the building will be determinant in its recyclability. The main barriers will be to provide the market with sustainable materials that could be recycled (R10). R16 evenly stressed that it would be difficult to get to uptake the SEOL approach if major Manufacturers wouldn't adapt their products. R16 believes that manufacturers have a huge role alongside the project owner. The increase of the implementation of the SEOL approach should be done progressively. According to R14 and to support the previous respondent’s argument, he said industrialists would be key players alongside manufacturers that should simplify their products. They will have no interest to change the way they design their products and go back to simpler practices.

> *He said "... potentially, this can be a brake unless manufacturers manage to make constructive systems that are also deconstructive systems".*
>
> BIM Manager, R14

The lack of manufacturers’ involvement was stressed by many authors (EPA 2008)(Chini 2005)(Nakajima and Russell 2014)(Milani 2005)(Häkkinen and Belloni 2011, Jaillon and Poon 2010). Milani (2005: 278) identified the Extended Producer Responsibility (EPR) as the single or regulatory realm in which the state can make its biggest contribution. The EPR concept was introduced in 1990 by the Swedish Ministry of Environment. In 1991, the German Packaging Ordinance, an early EPRs application by Germany, focussed on “take back” requirements for packaging (Milani 2005). Later, in 2005, the CIB report indicates that Design for Disassembly has been used in Europe in response to the EPR laws (Chini 2005). In 2014, the possibility of applying the EPR to building products had been discussed. Many countries have recommended the development of an EPR program in which manufacturers are responsible for recycling their products at demolition. The EPR program requires manufacturers to “take back” their material waste. Solutions were discussed, such as leasing rather than buying, especially for interior fit-out elements and services installations, kitchen and bathroom equipment. (Nakajima and Russell 2014).

D. <u>**The key role of the control officers**</u>

In France, the control officer role is to assist the design team with all the regulatory aspects. The designer and the economist prescribe materials used for the project, but it should be validated.The control officer holds the power to say "yes, you have the right to use that”. R10 added

> *"…even if the architect and the economist were volunteers, but* ***the control officer does not agree at all*** *and wishes to respect the regulatory aspects line by line, he* ***would refuse****".*

Digital Project Manager, R10

According to R19, the role of control officers is "...is to say whether or not there is a standard and whether we are in compliance with the standard". Nowadays, it's quite difficult in France to find control officers that use their common sense. It will also depend on the goodwill of control officers. Currently, the trend is:

> *"...to find more control officers that will say "no" to processes, than there are controllers who will ask themselves questions that they have never asked before...It's just a real approach: "we cover ourselves, we just do our mission, and we don't take responsibility."*

Structural Engineer, R19

Control officers also play a key role when it is planned to use reclaimed materials in the building. They are real barriers for that because there are no regulations.

E. Facility Managers

According to R20, Facility Managers are also playing a critical role in the reuse of equipment or materials. He said that the decision to use reclaimed materials is taken during the design phase. A barrier that appears on some projects is the maintenance provider who does not agree to reuse due to the lack of guarantee for the reclaimed materials. He said

> *"...they do it themselves in troubleshooting. A heating company, for instance, that has 30 boiler rooms to manage on a site. The company can decide to dismantle a pump that is still in good condition, keep the pump for a year or two and use it as a* ***troubleshooting pump until it orders a new pump*** *on a site. After that,* ***the company is in charge of management.*** *As a client, for us,* ***it is not a problem****. In any case, we see what we can do with our providers and what risks we take and do if we accept it or not".*

Owner – Engineer, R20

R10 and R14 have also raised the facility managers as a critical role because they will have to maintain the building according to the original specifications and requirements expressed by the owner. In the case of SEOL expectations, the building must be delivered deconstructible and must be maintained with these expectations. Every replacement has to be compliant with the specifications. This is a barrier because as R14 stressed, facility managers are not used to following prescriptions. Therefore, they will need to change their habits and record every change made in the asset.

F. <u>Lack of some profession</u>

Several respondents reported that, with the adoption of the SEOL approach, there is a lack of some professions. R11 thinks knowledge is missing in the area of SEOL approach, and new roles are emerging. He said it could be a mission that Environmental specialists can hold under an extra mission. He added that it reinforces the roles of the environmental quality engineer and the economist who will prescribe the materials. This is an additional area of expertise that should be created, and stakeholders should be trained on it. R18, who is doing consultancy in a circular economy approach, is already having expertise in the CE area, under which the SEOL is. He is under the responsibility of the architect, engineers, etc. and he actually works alongside the client. This is a new role, and he reported that it is very difficult to get paid to do it. Another new role is working with companies dealing with reclaimed materials (R20).

5.7.7 Lack of skills and education for skills improvement

The incompetence of the construction industry was highlighted by seven respondents. It was expressed like a crucial barrier for the implementation of the SEOL. These can be split into several sections. First, the lack of skills will be discussed, then the lack of looking for competencies elsewhere and lastly, we will expose the training issues.

A. <u>Lack of competences – skills</u>

a. Building industry incompetence

Construction industry incompetence: Several examples were given by R09, who has more than thirty years of experiences as an architect. He also stressed the waste generated during the construction due to the incompetence of the building industry. He said:

> *"A lot of these companies have a lot of surplus materials windows that have gone to site. And there is some problem. They must get the right size and very often they just throw them on the scape. They are new windows, but they are salvage**. Because the building industry here is so incompetent** that a lot of material arrives on-site in a new project and ends up being throwing away".*

Architect, R09

b. Architect's incompetence

R06 stressed that architects haven't a good knowledge of the different components used for the building. This invalidates them later to be able to say if they can reuse the materials or not. In agreement with the previous respondent, R09 mentioned that nowadays, architects, in general, are not well-informed because he said that they know nothing about building construction. This is the case for the young generation for architects but also for the oldest. He gave the example of a well-known architecture practice that had built a modular building. R09 thought the module unit is also dismantled, but surprisingly, when he questioned architects about the materials used, they had no idea. He said that there is a lack of knowledge about the composition of the building, they have drawn the façade, but that's it. Another example supporting the architect's lack of knowledge, he insisted and said

> *"…I discovered, recently an* ***architect that didn't know the difference between Polyurethane insulation and Mineral wool****. I said "what insulation did you use to the building? He said I used insulation. I don't know; it's just insulation. What's got to do with us? We're just the architects he says".*
>
> *"…****Architects see buildings as CAD images****. They don't see as the real material. So, therefore, they're only interested in what the building looks like.* ***They don't understand or know anything about what it's made from****". "…very often* ***people don't even know what material was used in the building****".*

Architect, R09

c. Construction workers incompetence

R09 also raised the construction workers incompetence. He explained that during an on-site visit, he noticed that the workers were putting the insulation in the wrong way. He said

> *"…they were bashing the wood fibre stuff in such a way that it would never be recovered".*

Architect, R09

R19 pop up the difficulty to find knowledgeable workers for non-conventional materials. He said, based on his experience that for example, to find masons who build in stone or earth is not easy. They are not many. Depending on what he said, there is a lack of workers in that area in comparison with the demand (even if it is a niche).

R19 stressed a lack of competences for reclaimed materials, for example, for the wood. He said that there are not many people that know how to assess the strength grade of a piece of reclaimed timber. This is also a barrier because due to the lack of skills, the wood is not reused. Or it can be reused with a high-security marge to make sure that it will work, they downgrade it.

The lack of competences was also brought to the table by R18. Even if nowadays, in the food industry and medical sectors, we know exactly the products' composition, that is not yet the case in construction or furniture sectors. He gave an example of furniture composition ignorance and the impact that can have on the market. Vendors may have arguments to sell better their products, but their ignorance stops them from using it. He asked the vendor

> *"..." what is the material of the chair?" "It's plastic." "What the hell is plastic?" Finally, it turned out to be polypropylene and so on. There is no problem. I told him "You have a fabulous selling point, you have a product that is healthy". When you say it's plastic, people say it's a petroleum product, it's disgusting"..." I told him, "No, your*

material is good. Besides, it comes from Sweden, and that's why it's good because they've been careful. ***But you don't even know it****".*

CE Specialist - Architect, R18

He explained that in France, they want to move to the use of timber, but they still mix a little steel, a little concrete. He thinks that the reason for that is because they still don't know how to do it very well. When you plan to move from an approach to another or from concrete to timber, we need to do it gradually. According to him, the mistake usually observed is due to the lack of training, which is a real barrier for moving to new approaches.

d. Blue and White Collars

Two respondents have considered, based on their sustainable architectural approach that builders become key player during the construction process. Indeed, because the structural wall is not hidden anymore with plasterboard, the wall must be finished perfectly. This is usually not the case in current approaches. The previous argument was also supported by R12 who expressed that in his day to day practice, the hierarchy of interlocutors and companies have changed, even some interlocutors are reduced or even deleted. The classical price breakdown of a conventional building is: the sub-trade lots represent about 40 to 60% of the final price. But he noticed that in his project, the finishing works represent only 15-20%. He said:

"…the necessary skills, requirements and contacts are no longer the same…" "…So, we move the place where we're going to put money". He added "…I think we need to decolonize the industrialism that is in the minds of the usual building craftsmen. But for that to happen, ***it is necessary to give them back their skills and know-how****".*

Architect, R12

They need to be more confident about their know-how and that they don't need "mother industry" to know if they are allowed to use the materials. So the barrier is that the current construction workers are not well-trained. Tackling the training issue will lead to having "white-collar" workers must be a little "blue-collar" and "blue-collar" workers a little "white-collar". Their mutual qualification levels will be raised. R12 worked during years in Switzerland, and he said

"…If we compare with Switzerland, for example, "…the vocational training centres for apprentices, the ***apprenticeship system*** *and therefore* ***the skill level of construction workers is much highe****r".*

Architect, R12

B. Competences improvement

a. Look for expertise elsewhere

In the previous section, we have seen the area where the incompetence's were identified by interviewees. The reason for that lack of skills is the result of several things. First, R18 highlighted another issue that people, generally don't have the reflex to go and seek for the expertise, wherever it is, even if abroad. They think, nationally. Every country development is at a different level. He said that we should see what exist and use it and not start from scratch, as he observed in France. This is a crucial barrier because without knowing what happens elsewhere, it will not work. We will lose time to reinvent the wheel.

b. Lack of Education

The incompetence could also due to a lack of available training or lack of cultural training. The lack of education was pointed out by nine respondents. R19 raised the lack of earth building qualified labour. He pursued by saying that he doesn't think that there is in France many schools offering the earth building training. R04 related the skills issued faced in one of his project where non-conventional materials were used. He said the implementation barriers and the skills to do it properly had been overcome through training, upgrading people's skills. R06 and R11 said to be able to uptake the SEOL approach, we should be able to train on that area, and architectural schools will play key roles. R06, based on his teaching experiences, he said that

> *"…it must be* ***a module in its own that talks about green building****. So here, we* ***must teach them that it is good to recover an old beam*** *that is used in structure".*
> *"…As an architect, I usually say that the beam is good and that it must resist to that much, and I ask the structural engineer to calculate it. From the outset,* ***architects must be trained to be able to take this kind of decision during the design phase****".*

Architect, R06

R12 and R14 highlighted that architects should stop to stick to a reflection focussing exclusively on space, ambiences, etc. They are far from real constructive questions that are fundamental for a sustainable approach and specifically for a SEOL approach. Therefore training on constructive issues and the holistic approach of the asset lifecycle are important. R18 also raised the quality of training, based on its own experience on BIM training. After their training, they weren't able to use it properly. Anecdotally, R18 gave an example based on his teaching experience. Students are well trained in their field, able to do smart calculations, but they finish by losing their common sense. He said:

> *"…Sometimes you have to* ***teach engineers who are in 4th year that hot air rises****. This is not a joke.* ***Some people don't realize it****".*

CE Specialist - Architect, R18

Training a team is a long process (R18) that should be done throughout the entire supply chain. R18 gave an example of one of several projects, where he has used a probiotics system. He explains that the aim is to treat the building with bacteria instead of chemicals during the cleaning process. The building is completely healthy and in bacterial balance (much like we have in our bodies) from the beginning. To be able to set up this in his project, he has involved all the stakeholders at the beginning of the project, including the operation & maintenance contractor and even the cleaning company. He said

> *"…at that point, you have to include* ***the cleaning companies*** *that are to be part of the team. Maybe not in terms of design, but at least when the building is delivered. It is necessary to prepare the specifications of cleaning companies already and possibly educate and train them".*
>
> CE Specialist - Architect, R18

The lack of training was stressed by Couto and Couto (2010) for deconstruction approach. Authors considered that specific training is needed for asbestos and lead-based paints removal (Couto, J. and Couto, A. 2010). Training needs were also identified as critical barriers for the adoption of the RL approach (Osmani et al. 2008, Park and Tucker, R. 2016, Leal Filho et al. 2016, Ravi and Shankar 2005).

5.7.8 Urban planning

R20 is working for the French leader of social housing, the company uses BIM and manages more than 250 000 social dwellings in France. They build more than 7000 new dwellings every year. According to him, the end of life of buildings planned for demolition or deconstruction is not due to their state of dilapidation. Reasons for a premature EOL can be political, social, functional or urban reasons. For the urban reason, the configuration of the city does not satisfy the decision-makers.

> *He said "...between 80-95% of the demolitions carried out today, for the last fifteen years, have been* ***demolitions linked to urban redevelopment, redevelopment of neighbourhoods where streets must be identified, to make the neighbourhood a little denser, to have buildings of lower height and then on a human scale****. But very little of the demolitions are related to the obsolescence of buildings that are physically coming to the end of their life.* ***It's not a technical EOL,*** *but it is the end of urban life, the end of neighbourhood life, the end of social life or changes in function".*
>
> Owner – Engineer, R20

5.7.9 Summary

Participants have identified twenty-two organizational barriers for the incorporation of a SEOL into the asset lifecycle that are not cited in the literature, listed in Table 39. Table 40, a summary of the findings reveals that the barriers the most reported by the respondents are related to key players and new roles, lack of skills and education for skills improvement and the level of responsibilities of the stakeholders. The most frequent words used by the interviewees are “buildings”, “architect”, “design”, “project” and “materials” as depicted in Figure 36.

Table39: Organizational barriers identified by the interviewees and not found in the literature (Source: Author)

	ORGANIZATIONAL BARRIERS
1	Issues associated with the quality of the architecture
2	Architects do the design but don't take care of the construction phase
3	Issues associated with archtect's profession
4	All the supply chain involved in a SEOL approach are not familiar with specifications
5	Difficulty to get insurance for non-conventional materials
6	Type of projects: public / private as a barrier
7	Lack of follow-up between the construction and the operation phases
8	Project team structure is a real barrier
9	Define and respect collaboration boundaries
10	Territorial Level and Individual of Responsibilities
11	Stakeholders Level of Responsibilities
12	Company or architect’s responsibilities
13	Owner or Manufacturers’ responsibilities
14	Facility Manager's responsibilities
15	Everyone responsibility: traceability of the work during the entire asset lifecycle
16	Lack of some profession (Assistant to the Contracting Authority) for SEOL and CE
17	Building industry incompetence
18	Architect’s incompetence
19	Construction workers incompetence
20	Blue and White collars
21	Competences improvement: look for expertise elsewhere
22	Urban planification

Figure36: The word cloud frequency for organizational barriers (Source: Author)

Table40: The summary of the results for organisational barriers (Source: Author)

ORGANIZATIONAL BARRIERS																				
BIM Users / BIM Manager																				
Roles	Designers						FM			Owners			TE	E	QS	M	SE	CO	D	R&D
Respondents	R06	R07	R09	R12	R16	R18	R02	R15	R14	R04	R20	R01	R10	R03	R11	R13	R19	R08	R17	R05
571-Working methods & approaches																				
A-Issues associated with the current approach						x			x		x		x							
B-Issues associated with the quality of the architecture						x					x									x
C-Issues associated with the project management				x																
D-Issues associated with professions					x				x											
E-New approaches issues		x				x			x		x						x			x
572-Activity sector - public/private type		x			x								x				x	x		
573-Team work, multidisciplinarity and management																				
A-Current project management not adapted			x						x		x		x							
B-Multidisciplinary Team			x			x					x									
574-Communication issues																				
A-Define & respect collaboration boundaries - know When to say stop					x						x					x				
B-Late communication between designer-contractor			x		x			x												
C-Lack of common classification				x					x							x				
575-Several levels of Responsibilities and traceability																				
A-Territorial Level and Individual of Responsibilities											x		x							
B-Stakeholders Level of Responsibilities				x		x					x		x			x				
576-Key players & New roles																				
A-Architects role	x	x	x	x	x	x		x	x		x		x				x			
B-Key players – manufacturers					x				x				x			x				
C-Owner			x		x	x						x	x							
D-The key role of the control offices													x				x			
E- Facility Managers									x		x		x							
F-Lack of profession						x					x				x					
577-Lack of skills and education for skills improvement																				
A-Lack of competences - skills	x	x	x	x		x				x	x						x			
B-Competences improvement	x			x	x	x		x	x	x					x		x			
578-Urban planification											x									

(FM) Facility Managers, (TE) Thermal Engineer, (QS) Quantity Surveyor, (CO) Control Officer, (DE) Deconstruction Engineer, (SE) Structural Engineer

5.8 Chapter Summary

In this chapter, the six categories of barriers were analysed and discussed: economic, political, sociological, technical, environmental, and organizational barriers. Most of the barriers cited by the interviewees are also spotted in the literature. However, approximately 80 barriers were not found in the literature but cited by the interviewees.

(1) The economic context where profitability is the most important driver, leading actors to have a very short term vision instead of having an overall and holistic view of a building is an obstacle to SEOL. The higher cost of managing the assets' EOL sustainably, the current waste and business conditions are more favourable to demolition rather than deconstruction. Indeed, the lack of clients' will for using a SEOL approach and the cost of adopting the SEOL approach are significant barriers stressed by the interviewees and many previous studies. The market issue was also reported by both interviewees and literature review findings: the lack of a structured second-hand materials market, the lack of coordination between demand and supply and the lack of facilities. SEOL management will generate a huge amount of materials that must be absorbed by the development of reuse and recycling facilities. The creation of a centralised database for reclaimed material would help to balance the demand and supply.

(2) The barriers related to the lack of policies and their weaknesses are the most recurring. From the political point of view, the recovered material must be re-characterised, re-certificate to be compliant with regulatory. This will help with overcoming the insurance barrier raised by several respondents and authors. The willingness to get around the law was not found in the literature but cited by the interviewees.

(3) The barriers the most reported by the respondents in the technological category are related to materials, buildings and data: the data unavailability, exchange and accuracy.

(4) The most reported barriers by the respondents in environment is the quantity of polluted waste, especially asbestos and lead. All the environmental barriers identified by the respondents are similar to the environmental barriers found in the literature.

(5) Participants have identified nineteen organizational barriers for the incorporation of a SEOL into the asset lifecycle not found in the literature. Most barriers reported by the respondents are related to key players and new roles, lack of skills and education for skills improvement and the level of responsibilities of the stakeholders.

(6) The most reported sociological barriers are resistance to change, followed by cultural beliefs and the lack of concern for the asset EOL. The most frequent words used by the interviewees are “people”, “change” and “working”.

6 CHAPTER 6: Framework improvement – Analysis and Discussion

6.1 Introduction

Figure 37 displays the process of the development and achievement of the framework through the thesis. A theoretical BIM-based Framework for SEOL integration was developed based on the literature review (Chapter 2, section 2.4.1). This Framework was sent to the interviewees with the set of questions, a few days before the interview. The Interviewees were asked to assess its suitability, and provide recommendations to improve it where possible. The results of the

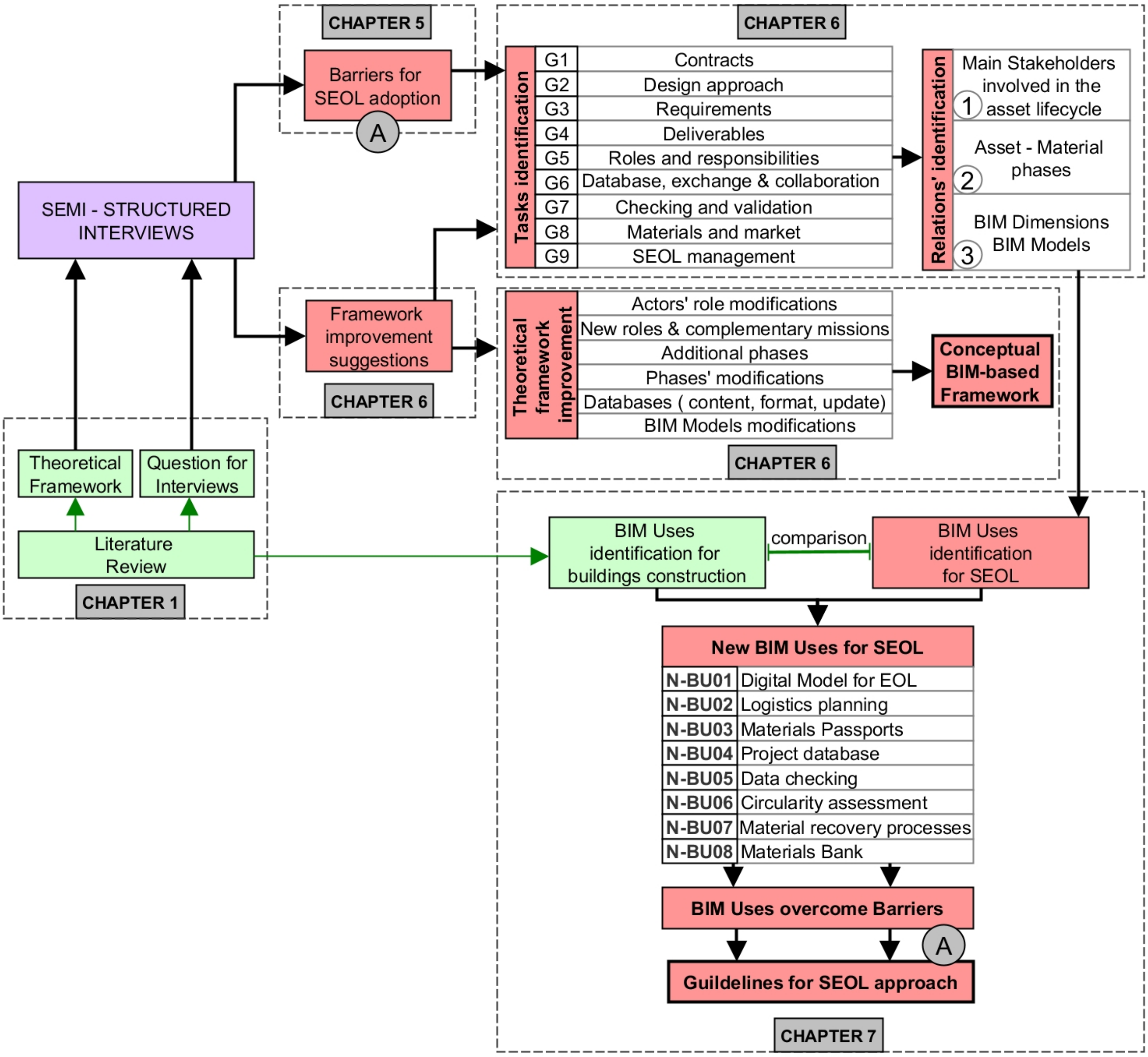


Figure37: Process of achievement of the BIM-Based Conceptual Framework (Source: Author)

interviews were classified into five sections (i) Contract type (section 6.2), (ii) Actors modifications (section 6.3), (iii) Phases changes (section 6.4), (iv) Data (section 6.5) and, (v) Models changes (section 6.6). Then section 6.7 will detail how all those feedbacks are integrated into the theoretical framework to improve it and become a conceptual framework. Even if it is discussed since the beginning of the chapter, the drawing of the conceptual framework is eventually given in section 6.8. Lastly, section 6.9 concludes the chapter.

6.2 General improvement and Contract type

R15 a British BIM Manager recommended structuring the Framework based on the RIBA stages and use the ISO 19650 “Organization and digitization of information about buildings and civil engineering works, including building information modelling. R15 mentioned that the End-of-Life of the building is not taken into account in the RIBA plan of work (Subsection 4.3). R15 said:

> *“…**there is no deconstruction phase** or other things. Which I think, if you put one here, **this is absolutely great**”.*
> *“… I think it's a really good process. It just **needs to be tied up with the RIBA plan of** works just because everybody is using it so when you are talking to people from the industry; it will be much easier for them to understand and to be helpful for you to present your research findings to them in a format that they understand really. Maybe you can even like, **present your findings in this way as well (DFMA)**. And put the overlay between the existing stages and what is going to add the deconstruction. You are like the design for the manufacturing phase, and they add some points here maybe you can put it like that”.*

BIM Manager – Facility Management, R15

Following the respondent R13, the clients should find out what information they need, what are the specifications and, what are the objectives he is looking for. All these requirements should be clearly expressed by the client and be reported into the BIM protocol. Two types of data will be given to the client, structured and unstructured information.

> *“…**the level of information** that is expected should be **included in the protocol**”.*
> *“…all performance is **structured data**. These are properties that will be automatically integrated into a database. These properties will also be found in an **unstructured format** in a data sheet. A datasheet, a DoP (Declaration of Performance) contains information that is unstructured; **it is text**. It will appear as a link, for example, in a database property”.*

Manufacturer – BIM project Manager, R13

According to R14, the main changes will be the contract and specifications that it must include. R09 also supported this argument. He said that the client needs to express very clearly his expectations in his conventional contract. But he specified that very often, they do a Design and Build contract which places the architect as secondary, in terms of design control. Therefore, the contractor should be completely committed to the SEOL approach and will take it on board. He added:

> *"…it's all about **writing a form of contract, a specification** that makes it clear that you must do that (a sustainable End-of-Life, deconstruction or disassembly). And that's critical. And the Quantity Surveyor must be involved in that process as well. There are **many different forms of procurements now**". "…much of this is about, **contract law, Procurement Methods and how actually procure buildings**".*
>
> Architect, R09

In conclusion, the framework was modified accordingly by the addition of the RIBA plan of work on Figures 48-49.

6.3 Organization of the new approach

For the implementation of a SEOL, several respondents evoked the necessity to adapt certain roles, to create new roles, and they also identified the key roles, among the stakeholders involved during the entire asset lifecycle. These areas will be discussed below.

6.3.1 Key actors

The key actors identified by the respondents are reported in Table 41. In total, ten respondents gave information about the key actors in the SEOL approach. Over the twenty interviewees, twelve of them considered that architects would play a key role in the SEOL approach. The SEOL approach will impact all the stakeholders' roles to greater or lesser degrees of importance. This will be discussed in the following section.

> *"…**the architect will have an important role**, almost as important as the manufacturer. It's not just him. For me, he is really a moderator".*
>
> Architect and BIM Manager, R16

> *"The **key stakeholders are designers,** I think. Because if they got the design right then, it would be helpful for the construction from the people on the construction site to build it correctly. It will help the people in use to expand later on or change it or repurpose it. And it will help the deconstruction phase".*
>
> BIM Manager – Facility Management, R15

6.3.2 Actors modification - Key roles

In the context of the addition of the SEOL as a phase into the asset lifecycle, the interviewees were asked to discuss what the impact on the stakeholders are and who the key roles are. Clients, design team, control office, the contractors' team, and facility managers are affected and this is discussed in the following sub-section.

Table.41: The key actors according to the interviewees

Key Roles	Respondents roles						N/R
	C	A	QS	E	M	BIM	
Achitect	x	xxxxxx		x		xxxx	**12**
QSs		x	x			x	**3**
Client	x	xxx		x		x	**6**
Contractor/Builder		x				xx	**3**
Manufacturers		x	x		x	x	**4**
Control Office						xx	**2**
Environmental Engineers			x				**1**
MEP Engineers		x					**1**
Structural Engineers	x						**1**
Thermal Engineers	x						**1**
Facility Manager	x			x		xx	**4**

(N/R) *Number of Respondent,* ***(N/Q)*** *Number of Quotation*
(C) *Client,* ***(A)*** *Architects,* ***(QS)*** *Quantity Surveyor,* ***(E)*** *Engineers,*
(M) *Manufacturer,* ***(BIM)*** *BIM Managers*

A. The client and design teams

R01 made a summary of the main stakeholders that should be involved in a SEOL project. His statements are summarized in Table 42, completed by statements given by others participants (R10, R12, R14 and R20, among others). First, according to R01, a SEOL specialist should be integrated into the team, in the Client-side and upstream of the project, during the programming phase. R20, an engineer working in the client-side confirm that innovative projects are discussed upstream when the project starts. Secondly, the client has to define clearly his requirements and objectives and spend time with the project management team, especially when they are working on an innovative project and solutions, leading to changes in traditional approaches and work methods.

> *"…There are all these issues of change that make it necessary to spend a lot of time with them to discuss, to reassure them sometimes. To rework* ***what is important and what is less important.*** *(...) So the changes are a lot in the exchange to measure where the project management teams stand".*
>
> Owner – Engineer, R20

Several validation steps and deliverables will occur, seeking to check if the project is developed according to the client needs, in compliance with standards and for the respect of programs. Client's specifications must be written, as well as the use cases to be identified. The client should be involved during the entire asset lifecycle. According to R20, on innovative projects dealing with reuse and recycling materials, they are supported by specialists. These specialists identify materials that can be reused or recycled on-site, list the materials and put them on their virtual platform to find potential, buyers. The platform is not offering storage possibilities. They anticipate and support the client for storage planning during the construction phase.

Table 42: Stakeholders, according tasks and BIM Dimensions, reported by the interviewees (Source: Author)

Phase	Stakeholders	BIM Dimension	Tasks
Programming	Client		Write specifications. Identify use cases.
	Buyer		Seek quotes on prices and availability of materials from a variety of suppliers.
	Assistance to Client -Circular Economy		Support the client for the SEOL or CE approach. Identify components that can be reused or recycled. Seek opportunities to reuse/recycle on-site
Design	Client		Validate project.
	Assistance to Client -Circular Economy	nD	Support the client for the SEOL or CE approach. Create listing (photo, desctiption, price) of the component that can be reused/recycled and make it available on the exchange platform. Help the client to anticipate stockage issues for on-site reuse/recycling CE assessment, simulations.
	Architect	3D	Design according to client requirements and regulations.
	Control Office	x	Check conformity with regulations of the design.
	Facility Manager	x	Enrich and validate design regarding his tasks Validate the reuse of components/equipments
	QSs	5D	Materials prescription. Cost estimation.
Construction	Client		Control that things are done properly in compliance with the programme. Check If the construction is done as prescribed.
	Assistance to Client -Circular Economy	nD	Support the client for the SEOL or CE approach. Check that construction meet the CE approach requirements.
	Project Manager	3D	Has the ultimate responsibility for all aspects of the build.
	Site Manager	4D	Make sure that construction project is completed on time and within budget.
	Control Office	x	Check conformity with regulations of the construction and standards
	Architect	3D	Check quality and compliance with plans.
	Lean Engineer	6D	What do we do with this waste? What is the traceability circuit for all this waste? What can be recycled?
	Contractors	3D	Build according to plans.
In Use	Client	3D 7D	As-Built Digital Record Compare the performance of the buildig and lessons learn Check the AIM update according to building changes
	Facility Manager	7D	Mangement of the building Monitor the operation in accordance with what was mentioned during the design phase Keep the AIM updated according to building changes
	End users	3D	Acess to some data (energy consumption, maintenance planing…)

The checking tasks will be crucial and performed by the architect and the client's team, including the assistant for reuse and recycle components issues. During the project asset lifetime, several models will be made and multiple BIM dimensions, in addition to the third, will be used to assess the cost, time, sustainability and even the circularity of the asset. The argument was also reported by R09.

> *"…the **4D/5D is very important in the construction phase** because we will manage everything, the arrival of the material, the evacuation of waste etc."*
>
> BIM Manager, R01

> *"…If the client says, **we want to make sure this building can be decommissioned or deconstructed** or whatever in the future. That's a **key part**. If they don't say that, then no **one else is going to say that**".*
>
> Architect, R09

As mentioned by R04, Quantity Surveyors (QSs) are part of the design team. This team is composed of technical partners including the **Structural Engineer** (reported by R04), the MEP Engineers (reported by R01), the **thermal design office** that gives requirements for insulation thickness to be compliant with thermal regulations and **acousticians** assisting the design team (reported by R12). As a prescriber, the QS will play an important role in a SEOL approach and he must be involved in the approach and should have technical sheets explaining how to recover materials for example (R06 and R09).

Lastly, as pointed out by R20, facility managers will also play a crucial role. In their project, facility managers are now involved upstream during the design phase. In the context of reuse of equipment or materials, they have to give their approval. Even if the Digital As-Built Record is not well developed yet, he believes that it will be a crucial part of the project. Indeed, traditionally, as a client, they struggle to get As-Built Record on time and complete. And they usually realise the incompleteness when they are looking for a part of it during the operation phase. Therefore, according to him, the digitalisation of the As-Built Record will help the client and the facility manager. He extrapolates thinking that the Digital As-Built Record could be collaborative and shared between several parties, like the client, the facility manager and even the end-users.

B. The Control officer

Based on his experience as a BIM Manager, R01 reported that the Control office role, in France has changed. With the digital model, they carry out checking directly on the construction site saving time spent with the traditional approach to getting the information. Nowadays, they can use new technologies, such as scanning on-site make a comparison between the scan and the virtual model. As seen in Table 42, In France, the control office is selected by the client, and he is working with him and the architect to make sure that the building will be in compliance with regulations during the design and the construction phase until the asset is handed over. This statement came over the interviews of French architects and owner (R01, R08, R19 and R20). R10 said that even if the prescribers are the architect and Quantity Surveyor, the control office has the power to accept or not. This is crucial in a new approach implicating the use of non-conventional materials or the reuse of reclaimed materials. The control office will be an obstacle because he will be reticent to give a positive opinion, on safety elements either of persons, or of fire, or of the safety of the building structure. According to him, that is where these elements of reuse will be confined to developments where there are no such notions of risk. Therefore, this reduces the scope for reuse, in buildings where the control office operates.

The decision for the use of reclaimed materials will be taken during the design phase. Facility managers and maintenance providers will have to give their approval if they agree to manage elements that are not new. Maintenance companies are reticent for reusing salvaged materials.

R09, who has worked in both Ireland and the UK, explained that the control officer role doesn't exist in the UK.

> *So, if you're using reclaimed material, sometimes there could be a blockage because the building control officer says you can't use it because we don't know if it is safe. In the UK, it is the architect that is responsible for the control. It's a funny situation in the UK. In Ireland, it sounds more, like the French system. Somebody who's appointed as they must be responsible for everything, the compliance the regulations.* ***You have to pay special insurance to have played that role.*** *You must sign off everything. That's not the situation in the UK …That can be the architect; it could be an engineer or whatever. Somebody must register with the local authority that they're the certified person, and they are responsible for checking".*
>
> Architect R09

C. The Contractor Team

In France, the contractor cannot be involved at the beginning of the project because he is not yet selected. He usually intervenes after the Technical Design. He will estimate the work based on the file that is given to him during the consultation phase (R12). R07 reported that in India, the architectural team is made up of architects, carpenters and masons. The seamless of the approach is that when, for instance, they have to study a detail, they build it with their builders. He explained the advantage of having architects and builders in the same office. R07 added that he tries to keep the same spirit in projects that he is developing in France. In their team, they have knowledgeable and real builders, engineers, researchers, laboratories…). He said:

> *"…first, the client has only one person opposite who does the whole project, second,* ***we don't have a "battle"*** *like in France looking for companies, and third,* ***the people who build are the companies and not the architects****".*

*"…The carpenters make the models, and it is the **same carpenters who build houses**".*
*"…we have people who **know about construction** and who will be able to **drive the companies**. We're still going to put out a **call for tenders**. Because of the insurance problems, etc., we cannot do exactly as in India, but we will keep the spirit and the methods. All project **stakeholders are involved in the design and construction phases**".*
*"…Adding a SEOL approach will reconnect builders. They will become **full players in the construction world**, which is a good thing".*

Architect, R07

6.3.3 New roles and complementary missions

The need to add several new roles to a project in order to achieve SEOL was pointed out by many respondents. They raised the point that, for the framework to be suitable, it must contain certain new roles and complementary missions. Organisation for assessing the approach and a certification process should be created. This will be discussed below.

A. New roles

Two new roles were identified from the respondents' answers. First, the assistant to the Contracting Authority for the new SEOL approach or the Circular Economy approach. These roles started to appear for some projects, but they are still at their infancy. R14 said an Assistant to the Contracting Authority needs to be created. Based on what happened with the BIM process in France and HQE label, upstream research, training, good practices, dissemination and certification should support the SEOL uptake by the construction industry. The role of the Assistant to the Contracting Authority in CE will be to advise the client on the SEOL approach and widely the CE approach.

To support the previous argument, R11 talked about "specialist in Circular Economy". R18 revealed that he is actually playing already this role for projects that are developed with the Circular Economy approach. He said:

*"…I do **consulting in the implementation of the Circular Economy**. It is a **new role** and therefore it is very difficult to get paid to do it, because we are **under the responsibility of the architect, engineers**, etc. and we actually **work alongside the client, alongside the contracting authority**".*

CE Specialist and Architect, R18

For the SEOL or the CE approaches, as discussed in the previous section, the area should be organized. For instance, R01 said that it might be interesting to have a design office specialised in the CE approach, in the same way as we have today environmental specialists. R11 gave further consideration to the subject and proposed to create a professional organisation that will organize the approach, in the same way, Building Smart is doing it for BIM.

In addition, R11 explicitly said that for the SEOL approach, we would need someone who is able to update the Asset Information Model (AIM) during the lifecycle of the asset. A complementary role will emerge responsible for creating the DIR (EOL Information Requirements) in the same way that the AIR (Asset Information Requirements) is managed today.

> *He said "…in the same way as today, find people who are able to describe Asset Information Requirements (AIR): what data should be included in the AIM at the beginning of a project? We will* ***need someone who can express what data will be needed in the deconstruction models****: the carbon footprint of each object, a volume density, a demolition method..."*

Quantity Surveyor and BIM Manager, R11

R20 reported that, on innovative projects dealing with reuse and recycling materials, they have in their team specialist to support them for the reuse and recycling part. They help them for identifying materials that can be reclaimed, stored on-site waiting to be reused for the new project or waiting for potentials' buyers. The company providing this kind of services is also advertising and commercialising the reclaimed materials.

B. Complementary mission

Four respondents said that the SEOL approach would lead to some arrangements on existing roles with the creation of a specific mission. There is no consensus on which role will have an added mission. This will affect several trades. For instance, R14 explained the role of a new project preceded by a deconstruction phase, for which BIM methods will be used. The role is to help to define the analysis criteria, the client deliverables, BIM protocols and digital models. A specific section was added to its mission for the deconstruction phase. The modifications highlighted by the interviewees are summarized in Table 43.

In the previous section, the roles modifications that should appear in the context of a SEOL approach have been discussed. But a general re-organisation of the project team must be made. Indeed, as highlighted by R18, it is also crucial to re-organize the project team. He worked in several European countries and reported the difficulties faced in Belgium to work in the same way as in the UK. He expressed the importance to always work in a multidisciplinary team from the beginning. This is what he always do on his projects and always demand to be set up right from the beginning of the project. He said:

> *"…I worked for 11 years in London with some of the world's leading architectural firms and engineers.* ***Anything was always possible*** *when you sit around the table at first. I came to Belgium to renovate the European Commission headquarters…,*

everything was impossible because I was not allowed to work ***from the beginning, with engineers, with design offices, with landscape architects*** *etc.”*

CE specialist and Architect, R18

As seen in the previous sub-section, actors are affected by the SEOL approach implementation, but the phases will also be impacted by the move towards the CE. This will be discussed in the following section.

Table 43: Roles modifications raised by interviewees (Source: Author)

Mission added to existing roles	Suggested by	Quotations
Quantity Surveyor	R11	"For me, this reinforces the roles of the **environmental quality engineer and the economist** who will prescribe the materials".
Environmental Engineer	R11	"...Afterwards, he needs to be made aware of all this by people who have **data on building life cycle analysis**. There are also the **HQE and environmental BETs** that will have feedback".
Architect	R05	"…that it is those who are involved in **life cycle analysis**. **The thermal engineer and the architect**".
Thermal Engineer	R05	"…logic would have it that it is those who are involved in life cycle analysis. The thermal engineer and the architect".
LCA	R11	"...Afterwards, he needs to be made aware of all this by **people who have data on building life cycle analysis"**.
Demolisher / Deconstruction	R11	"I think there will have to be a **committee of demolition experts** who can say what is important or not. So both **demolition workers** and also environmental specialists, carbon footprint specialists and specialists in the circular economy. **New roles are emerging**.
	R04	"...You bring the demolisher into the team to help you bring elements to a project he won't see. He will explain how with today's means he will demolish the building. In 100 years the means will have evolved and secondly, he will not be paid for this work...**He must have a mission to be able to do it**"
	R18	"**Demolition workers** are the new actors involved in the project".
Assistance to the Contracting Authority	R14	"Then there will be the **creation of Assistance to the Contracting Authority** to advise on this area".
Reuse and Recycling start up	R20	"...Cycle up acts as an **assistant to the project owner**. They help us to **define what we can recycle**..." "...will take care of **the communication, the photos' lexicon**, **the quantifications and put it on the platform**". "...It's a startup, **a new profession**".

6.4 Phases changes: Additional and modifications

The interviewees suggested modifying the overall aspect of the conceptual framework’s phases. Some of them want to add phases that are missing in the process. Others suggested modifying the existing phases by, for instance, adding some arrows.

6.4.1 Additional phases

A. Before the design phase

The programming phase was asked by 3 interviewees. R01 said that during the programming phase, the actors are identified and integrate this SEOL phase upstream, among the objectives of the client. The client must also write his specifications, and as in the BIM, the use cases must be identified during the programming phase. R10 added that in the programming phase, the client specifies all his requirements; for instance, he specifies that he wants a building certified LEED Platinum. In our case, he will ask for a building that can be deconstructible or dismantle by the end of its lifespan.

> *"…the phase that would really have the greatest impact on the integration of the SEOL logic over the entire life cycle is the design phase and upstream,* ***the design programming****". "…on the programming design phase that I do not see appearing in the Framework and which* ***has a direct impact on deconstruction, it is a fact of seeking environmental or other certifications****".*
>
> Digital Project Manager, R10

R18 also stressed that the design phase and especially programming are crucial. Based on the projects that he realised with the Circular Economy approach, he said we should prepare the market. He said, if for the project you have specific requirements regarding materials you plan to use, you should assess the market and prepare it. Indeed, R18's strategy was to put competitors around the table and announce to them what the CE specialist was looking for. He took the example of the minimum fibre size that he would allow in all products containing fibres (insulation). When he asked evidence about the size of the fibres, manufacturers were not able to answer and gave evidence on the non-toxicity of their products. Therefore, R18 went through a very time-consuming process to know what the minimum fibres' size would be toxic. For example, taken, the preparation of the market was composed of several steps. (1) Requirement: Looking for products containing non-toxic fibres (2) What are the minimum fibre size that is acceptable by the body? It doesn't exist. (3) Ask medical professions and invent a minimum fibre size criteria that should be specified by manufacturers. (4) Group all the competitors around the table and specify them what you are looking for: Materials containing that size of the fibre, as maximum? (5) They will have the duration of the project to modify their products, to be able to give evidence of the fibres' size and participate in the project. He said:

> *"…It is important to know that a project, between the time it is designed and the time when materials are needed on-site, often three to four years ago". "…We were called crazy. But today, if you look at most materials, catalogues etc.…" "…****Thanks to this, today they indicate the minimum fibre size in their products****".*
>
> Circular Economy specialist and Architect, R18

B. Tendering phase

R10 has put on the table the impact on the prescription and the tendering phases because the objectives of the projects must be known very early. R09 insisted on the importance of writing a form of contract with the specifications that make it clear that you must do that. And that's critical. The procurement methods are not adapted to the SEOL approach. The client and architect might have a set of ideas about how they want to do buildings, for instance, to make the building deconstructible. Then when the contractor is selected, he might say:

> *"…no we don't do that. This is how we build, and this is how we're going to build".*
>
> Architect, R09

R12 supported the previous statement and assumed that the contractor intervenes in the French project process, after the Technical Design stage, which is too late. The tender documents are sent to him for estimation and the requirements for SEOL (e.g. disassembly) must be defined clearly and should be taken. Manufacturers must know very early what the clients' objectives are to be able to make available during the tender phase the FDES, DoPs documents that are usually requested. R13, a plasterboard manufacturer said:

> *"...if the customer wants demountable (and also reusable) partitions, this will have a significant impact on the **prescription phase of the solutions proposed in the call for tenders**".*
>
> Manufacturer – BIM project Manager, R13

In consonance with the manufacturer, the interviewee R13, R10 also stressed the impact that the SEOL will have on manufacturers. As it started to be done in several types of products, manufacturers must re-think their process to integrate the recycling, reusing approach.

C. DFMA phase

In a SEOL approach, prefabrication phase should be part of the BIM-based Framework as requested by R01. One of the possible use cases is that the BIM model can be used for linking the process of prefabrication to the other phases. According to R15, the SEOL needs to be thought during the design. We can add a stage for the modularization of the design. To be able to disassemble, you need to know first how to assemble. He added that:

> *"...maybe after the "concept design" or "development design", maybe before the "technical design", we can **add a stage (3.5), a "design for assembly"**, that can help in the later stage which is the design for construction".*
>
> BIM Manager – Facility Management, R15

This 3.5 stage (in the RIBA plan of work) will refer to the modularization of the design. This stage doesn't officially exist yet, but when R15 was working in an off-site construction company, they have invented this stage. She recommended the researcher to add the RIBA plan of works stages in the Framework to help people from the industry to locate. He suggested using the RIBA for

DFMA as a model to present the finding. He added that for the off-site construction manufacture already have this lifecycle process. In fact, he took the example of his previous company.

> *"…the off-site construction manufacture and their hire division…**they design, they construct, they use it, but then they reconstruct, and they take it back to the factory and store it.** They have stores. Then, they reuse it when another client as a temporary building".*

BIM Manager – Facility Management, R15

D. Rehabilitation phase and Diagnostic phase

R02 suggested adding the rehabilitation phase into the process. It goes back to the design phase and then construction. R01 and R05 put forward the fact that a propitious framework should be done for existing buildings that need to be refurbished with a partial deconstruction and for those that need to be completely deconstructed. R01 said that in the case of the SEOL for a building that has not been designed purposely to be easily deconstructed,

> *"…will scan the existing. There will be **a diagnostic phase**, identify all the elements that make up the building, including the materials that make up these elements. Then with the digital model, we will be able to **simulate its SEOL, regarding time, cost and anticipate all the logistics**. … We will have **3D, 4D, 5D and SEOL** management".*

BIM Manager, R01

R17, as a Deconstruction Engineer said that the information needed imperatively for conducting the deconstruction tasks are the structural diagnostics and the network plans. He added that the network plans are usually difficult to obtain. The modification of the phases already drawn in the theoretical BIM-based Framework will be discussed deeply in the following section.

E. Add waste materials processes: Construction and "In Use" phases

In total, six respondents asked to add an arrow from some phases to materials waste flow. Four phases were mentioned, the construction, In Use, Manufacturers and product recovery phase. First of all, R09 reported that materials could be considered as waste, even if they are new. A lot of materials arrive by mistake on-site and are thrown away, due to the size, quantities or something else. Some suppliers recover this kind of materials and make them available for purchase at a reduced price. Thereof, they can be reused. So, an arrow should also be added in the Framework from the construction phase to the supplier. R10 reported that various kind of materials waste appears during the construction site, such as pallets, plastic, sheath cutting, paint cans etc.

R01 and R13 highlighted that manufacturers have already started to organise their waste production during the construction phase, as said previously. In the same way, during the "In Use" phase, in which refurbishment activities could appear or replacements, will also generate some waste (R10). According to R19, the Framework is clear but should give more information about the Materials Bank. In that place, everything that could be recyclable will be listed in the database, from which one can extract quantities, materials data etc. Therefore, the phase of product recovery should be more developed. Indeed, he said:

> *"...**the phase of product recovery, of storage in these "resource bank" or in these materials bank**, there will be a real challenge that these materials be well **characterized, identified** and that they can, perhaps in the **storage area, receive again a marking, a labelling to meet the standards**".*

Structural Engineer, R19

This means that the BIM-based Framework can be improved by detailing the recovered material flow and the principal steps toward the re-prescription for a new project.

6.4.2 Modification phases

A. Design phase

The modification that should be added according to R01 should indicate clearly the three sub-phases in the design phase and the deliverables given to the client, between sub-phases (3 sub-phases added in the framework in the design in Figure 49, actually labelled "phase" not sub-phase). For the move to the next stage, the client should validate the deliverable he has got. The client team has to check if the architect's project has met the client requirements. Needs for later exploitation should be part of the client's requirements. In a SEOL approach, transparency about materials composition and their traceability are crucial, as discussed in section 6.2.4. To encourage the SEOL approach to be adopted, R01 proposed that:

> *"…a **tax system** must be done as early as possible in the life cycle of the building, **at the time of the building permit**".*

BIM Manager, R01

The role of the control office in France (it doesn't exist in the UK) is to give observations on the project according to regulations compliance. In a BIM environment, the observation is given on the collaborative platform. Upstream, charters defined by the client, help to frame the exchanges.

> *"…So finally **change the design and manufacturing processes** and encourage a distribution network. **Recover materials and keep them in stock**... But these materials have to be re-detachable element by element to be recovered".*

Control Office, R08

R09 gave the example of a house for which an extension was made using reclaimed materials. This had an impact on the design phase that cannot be completed until they knew the windows' size. Some companies have a lot of surplus materials or building components that have gone to the site but faced a problem and cannot be used anymore. It happens that the suppliers take back these materials from the site and sell them as reclaimed materials. But usually, this kind of materials are just thrown away. They are new but salvaged. So in the process, this should appear in the BIM-based Framework.

The design phase should also be modified, according to R10, who said, based on his experience on nuclear power plants. The "technical part" will be more important and rigorous regarding material selection. These are sectors of activity where the deconstruction phase becomes central and unavoidable, right from the design phase. He took the example of industrial building waste that is regulated in France. Indeed, waste is classified according to their hazardousness and environmental impact in several classes. He pursuits by saying that in the nuclear sector, there are materials contaminated with radiation that must have special treatments. Therefore, the cost of treating this waste has a major impact right from the building design decision phase.

> *"…today, we cannot imagine designing a nuclear power plant* ***without thinking about its deconstruction*** *and the use of the materials that will be used during the construction phase".*

Digital Project Manager, R10

According to R12, the design phase should be split into 3 or 4 stages. The QSs comes at the same time as the design phase and not after it. During the first step, the designer settles the constructive, thermal and architectural issues. Then, the cost estimation is done by the QSs team. If the cost is too high, the design should be re-worked to fit into the budget. He insisted on the fact that in France, in a public contract, the contractor cannot intervene during the design phase. R14 pointed out the importance of the architectural charters provided by the client that must be respected by the design team and the QS. He added that:

> *"… You should* ***involve the deconstruction contractor*** *in the design phase. It's like everything in BIM. You have to put* ***everyone around the table beforehand****".*

BIM Manager, R14

> *"Between a sketch and a detailed preliminary design and a project, there are at least 3 or 4 steps. Now you don't really feel them. We do not solve the same issues at the same time".*

Architect, R12

B. Construction phase

Modifications that should be applied to the construction phase will be discussed below. According to R01, the client must be added to the BIM-based Framework in the construction phase because he plays an important role, just like the project manager, site manager and the control office. The client will validate or not decisions that are taken during the construction. The various BIM dimension will be very useful during the construction because he said:

> *"…the* ***4D/5D is very important in the construction phase*** *because we will manage everything (the* ***arrival of the material, the evacuation of waste****). We must adjust* ***Lean construction processes*** *during the construction phase, for waste concern and what we are doing with this waste? What is the traceability circuit for all this waste? What can be recycled?"*

BIM Manager, R01

R01 stressed the importance of the execution phase. During this stage, companies' proposal should be checked rigorously to make sure that they are compliant with what was initially imagined and budgeted. As reported by R05, a huge amount of waste are generated during the construction phase. Therefore, an arrow must be added in the BIM-based Framework and join the flow of reclaimed materials. He explained that their work is based on this missing arrow (see Figures 42-43 where the new arrow was added). He said:

> *"…We work on* ***this arrow, and we try to make it go towards the bank of materials*** *represented in the process. In France, what comes out during construction represents a huge amount of waste. If we count the public works, we are at the hundred million tons / year while for demolition we are on the ten million tons".*

Research and Development, R05

R09 highlighted the waste generated during the construction of the project. He said that some materials have gone to the site, but for some reasons, they are not used and thence, re-sent to the suppliers. They are considered as waste, but they are new. Therefore, an arrow is also missing in the Framework coming from the construction phase to the supplier. He said doubtfully that Gypsum board companies claim that they take back any waste generated during the construction phase and recycle it. Among the interviewees, a plasterboard manufacturer (R13) confirm that their product is 100% recyclable and that they take back to the site production any waste from the construction site.

C. Maintenance phase

R15 reported that usually, at RIBA stage 6, when the building is handed over, the COBie is developed and is part of the deliverables. As mentioned by R13, during the "in use" phase could occur the extension of the building, partial demolition and refurbishment. R10 added that an arrow should be appended for waste coming from "in use" phase. R14 stressed that during the "in use" phase, Facility Managers have to keep in mind the initial specifications of the SEOL approach, requested by the project owner. He said:

"...once delivered, respect the operating specifications. I think that it is especially in terms of ***exploitation that there will be much higher expectations****".*

BIM Manager, R14

D. The Sustainable End-of-Life (SEOL) phase

R07 brought out that the reconsideration of the asset lifecycle with the incorporation of the SEOL will reconnect the asset's EOL with the construction world. Therefore, builders will re-take a key role in the construction process. He stressed two types of deconstruction, natural or man-made. According to him, ruins are a natural form of deconstruction. He took as an example of an ongoing project, for which excavation earth is used for structural walls. He said:

"…there is nothing to do; the earth used for the construction will ***gradually erode and return to the earth.*** *There are, therefore, none of these three actions, landfill, reuse and recycling. There are many scenarios. The earth will remain like a ruin, will slowly erode and return into the earth,* ***like a sandcastle****".*

Architect, R07

R14 emphasized that to implement the SEOL, the building should be considered as systems with materials. He said that, as one can make a plumbing system, one has to make a deconstruction or dismantling systems. Then, it must indicate the materials included in the building. According to him, the deconstruction process is simply the reverse logic of construction. We will have the same logic for planning and costing with a difference for revenues generated by the reclaimed materials sale.

According to nine respondents, the SEOL phase should be modified with particular attention put on the diagnostic stage. R13, the plasterboard manufacturer said that materials coming from deconstruction should be sorted on-site, and directed to different channels.

Based on the feedback of respondent R17, a deconstruction Engineer, the SEOL process can be improved. He explained the various stages for a deconstruction project. First of all, during the pre-work stage, a SOGED (The Waste Organisation and Management Scheme) should be done. During this step, the idea is to recover materials, as much as possible. The SOGED is a diagram that gives information about materials that will be deconstructed, what can be reused and where the materials will be sent. Then a waste diagnosis is made by visiting the building to evaluate the quantities and types of waste. With that document, the company know the tonnages, their potential revalorisation and the nearest sectors where they can be sent to. The objective for each deconstruction project is to send the recovered materials to the nearest recycling subsidiaries. But he added that they often faced a space shortage issue that increases the project's carbon footprint. They work directly with the recycling subsidiaries with which they exchange information by using simple Excel spreadsheets. Materials must be treated separately and sent to specific channels. So one of the major steps is to identify the polluted materials and send them to the adequate process.

> *"…we do a **core sampling and analyse** it to find out what's in it. What we are looking for above all is to see if there is any pollution. For example, we will look to see if the concrete slab is polluted. If it's polluted, **it goes into a specific channel**. And if it's not polluted, it can be revalorized". "…we can have **polluted waste that we can no longer recycle**. It all depends on the activity of the building or site. For example, if you have a slab that contains hydrocarbons, that slab cannot be recovered. This type of waste **goes into different channels** and is much more expensive".*

Deconstruction Engineer, R17

For some demolition/deconstruction project, recycling processes can be set up onsite. For instance, for a concrete building, it may be asked that the company in charge of the demolition must be required to have a crusher that they will use on-site. He said that the deconstruction project follows the reverse system of construction. A deconstruction project is organised around several stages.

First, there is the diagnostic stage where it is looked if there are polluted materials, such as asbestos, lead etc. Usually, the diagnostic stage includes a structural diagnosis and samples or cores on concrete may be taken to know the thickness of the concrete or slab. In complement, the network plans are imperatively needed. This information will help to estimate the amount of waste. A preliminary phase is the "cleaning phase" aiming to revalue materials. After the preliminary project, all the constraints of the project are identified, such as the cost and the planning and storage issues. Then there is the technical phase to launch the tenders. Then, the company that will be responsible for the deconstruction is chosen. A deconstruction project also has a "carrying out work" phase. And when the deconstruction is finished, the deconstruction project is handed over. All the reclaimed materials are identified, quantified and sent to their specific recycling circuit for valorisation.

R01 gave the example of existing buildings that need to be deconstructed. He said that the existing building would be scanned and modelled in 3 dimensions. A diagnostic phase will enable to identify the building components. The digital model enriched with the data provided by the diagnostic will enable to do different SEOL simulations, regarding time, budget and logistics. He said:

> *"…doing it in BIM is interesting. We will have **3D, 4D and 5D and facility management data** because some elements can be reused".*

BIM Manager, R01

R08 added that one of the first things to do is to identify the date of construction of the existing building. In France, the demolition is controlled by some regulatory obligations. Indeed, statutorily, a building of more than 1 000 sq. meters must have a waste diagnosis done. This is an inventory of materials composing the building and their quantities. He said that, as a control officer, his concern is more about workers safety and not checking if materials are recovered or not.

6.4.3 Stakeholders involvement and Exchanges between them

In a SEOL or CE approaches, the early participation of the parties involved in the project is crucial. This is true for the main stakeholders mentioned in the theoretical BIM-based framework, but also for added actors as requested by several respondents. For instance, for the assessment of reclaimed material, R06 stressed the importance of exchanges between the structural engineer and the designer. Technical solutions prescription and material selection are also characterized by important exchanges between the architect and the Quantity Surveyor. R12 reported that for instance, for a timber structure, the architect usually has a lot of exchanges with the MEP engineers and the carpenter. The exchanges will also be important between the architect and the QS. He said:

> *"…what is missing is between Quantity Surveyor and specialist architect,* ***technical design offices****. There's a lot of going back and forth with them… Considering our choices to* ***work a lot on construction systems*** *etc., we have a lot of interface with* ***structural engineers, especially in wood****."*

Architect, R12

He suggested adding a "box" in the BIM-based Framework, the Technical Engineer box, between QSs and designer. Indeed, there are a lot of exchanges between these three entities: the architect's design, then there are technical partners, including the QSs. The requirements are sometimes defined by them and not necessarily the contractor or the user. He illustrated his argument by giving the example of thermal regulations for which the thermal design office gives the requirements for insulation thickness. And these, requirements are adjusted with the acoustician requirements. R12 approach is to avoid finishing works and focus on the structural walls. Therefore, he has a lot of interfaces with the structural Engineers. These exchanges happen between the design and design improvement stages (RIBA stages 3 and 4).

6.5 Database: content, format and update

6.5.1 Data requirements process

At the beginning of a project, the first step is to define clearly the Organisational Information Requirements (OIR), which is the requirement of the organization. The OIR includes data and information which are required to achieve the organisation's objectives. Then the stakeholders of the project must be identified. He said that the process to get the data for the SEOL is like

> *"…You make a **kind of tunnel**, if it was a deconstruction, things to see: at what level, from what department will it have an impact? And once you see all this**, you turn it into data**. And you say, **I need such data in my AIM**".*

BIM Manager, R14

All the information coming from the equipment installed in the building and the materials used (external information) should be added to the data. According to R14, one of the requirements for the SEOL approach could be "limit the environmental impact at the time of deconstruction", "recycle 80% of the materials". First, the requirements of the organization should be identified by doing the OIR. Then, one need to define what kind of information is needed for the AIR (Asset Information Requirements). This will come from the objectives specified in the OIR. The project information requirements will enable BIM specifications. The project information models provided by different entities will enrich the AIM (Asset Information Model). All this is detailed in chapter 4, section 4.3.4 and section 7.4

6.5.1 Database creation and content

Several respondents have listed the data that might be required for the SEOL management in BIM. This was summarized in Table 44 that is inserted in the conceptual framework as a box called "A" (on the left in Figures 48-49). For the EOL phase, there is cross data coming from the design, construction and "in use" phases. Data will also come from Manufacturers by means of FDES Sheets in France and technical sheets in general. R10 said that the data coming from the exploitation phase is considerable. R10 classified the data into two categories: the visible and invisible data. The visible data is the volume, weight, volume…etc.

> *"…there is a need in relation to what is **called invisible data**…we will also need the induced data: What is the shear strength of a beam, what is its bearing point. How was it used? So, his whole history. What is the permissible load? What is the moisture level of a wood beam used?*

Digital Project Manager, R10

R13, as a manufacturer, explained that all the components used in their products must comply with the recycling process that has been put in place. Therefore, among the data provided in the digital model, they have a property named "disclaim" where they mention that their responsibilities are not engaged if the specifications are not respected. The data for reclaimed materials and the difficulty to get them was discussed in section 6.5.3. According to R15, A BIM Manager working in the UK, the database can be called a Common Data Exchange (CDE). Each project has its proper CDE and contains all the data generated throughout the entire project life cycle, including the "in use" and EOL phases. He proposed that the Material Bank can be linked to the project CDE. According to him, the Material Bank can come from CDE CAFM system. BMS and any other system is containing data about the asset. COBie can be used as an exchange format. He suggested what the CDE can contain and expressed the need for having material bank databases for new materials and reclaimed materials.

> *"…all those processes, even detailed information about how design happens, how construction happen, how it was managed in the CDE and also information for deconstruction. So the* ***CDE can be that bank****". "…So this main bank maybe you should integrate with all of those CDEs to get the data that is necessary. Or it can* ***link to the CAFM or BMS system*** *(building management system)". "...there is a COBie that will be shipped with that file that is going to be reused. So, there* ***should be a data bank****. The database is needed for both* ***new and old materials****. All the processes can feed into it".*
>
> BIM Manager – Facility Management, R15

Table 44 Data required for SEOL management (Box "A" in the Conceptual Framework (Source: Author)

Sources	Data	Data	Sources
	Physical Data	**Geometrical Data**	
LR	Waste material description	Volume measurement characteristics	R10
R19 R11 R10	Density	Surface	R10
R10	Fire resistant	Quantities	R19 R20
R01	Material toxicity	Recycling/Reuse quantities	R01 R20
R02	Ageing coefficient	Superstructure depth	R17
R10	What is the moisture level?	Network plan	R17
R10	Weight	As-built drawing	R09
R17 R09 R02	Material expertise/probes	**Recoverability Data**	
	Mechanical Data	Cost of recycling /kg	R01
R10	Shear strengh	Cost in supply installation	R01
R10	Bearing point	Cost of elements prefabrication	R01
R10	What is the permissible load?	Cost of deconstruction	R01
R17	Structural plan	Initial price	R10
	Environmental Data	History, how was it used?	R10
LR	Embodied energy: Cradle to Cradle	Who is the manufacturer?	R10 R20
LR	Embodied energy: Cradle to Gate	**Waste management route**	
R11 R01	Carbon footprint	Landfill	LR
R10	Ton of carbon equivalent (tce)	Reuse on-site/off-site	R20 LR
R10	Ton of oil equivalent (toe)	Recycle onsite/off-site	R01 R20 LR
R17 R10	Location	Type of recycling (burn, melt, etc.)	R01
R14	Building performance data (BREAM, LEED, HQE, etc.)	Material recyclability	R01 R02
		Material reusability	R01 R02
	Data format	Demountability data sheet	R17
R15 R14 R13	Data classification	Deconstruction method	R20
R10	Data form (data sheet, DoP, etc.)	Containers needed (size/number)	LR
R17	Material technical sheets	Availability date	LR
R15 R13	Format (PDF, IFC, COBie, etc.)	**Waste classification**	
	The source of the waste	Hazardous/non-hazardous	LR
LR	Construction	Inert/non-inert	LR
LR	Excavation	**Other**	
LR	End-of-Life	Disclaim	R13

(LR): Literature Review
Respondents

6.5.2 Data Format

During the entire asset lifecycle, the data generated will be provided in various formats. Based on an ongoing project in France, R13 explained that, as required by the client, the models were provided in 2 formats, IFC and native format. He added that the format should be defined at the beginning of the project and contractually agreed. Furthermore, data classification must also be specified. In the case of R13 projects, he reported that they use the IFC classifications, but they also provided their information in several classifications:

*"...all our solutions are attached known classifications, **Omniclass** (UK), **Uniclass, Uniformat** (American)".*

BIM Manager, R14

The deliverables formats must be clearly specified when the project starts. R15, an estate BIM manager working in the UK, reported that the deliverables that they usually get are in IFC and in COBie. To be able to use the data, they have to copy it to a different format: a PEET import for Planon. The PEET Import is just an excel spreadsheet that doesn't have tabs like a COBie Lite, and is used to import information directly to our CAF System Planon. He specified that sometimes they don't need to copy to another format. He said,

*"...we did get recently a handover that is straight into the PEET import that we wanted not the standard COBie format which was **good for us, but not really standard**".*

BIM Manager – Facility Management, R15

So, to be able to use the data coming from the construction phase, the format is very important and must be contractually defined. For the SEOL, the same process should be followed. But the transition between the "as maintained" phase to the SEOL management phase raised a lot of arguments among the interviewees. This will be discussed later, in section 7.5.

6.5.3 Data update

The "as maintained" phase and the update issue was highlighted by four respondents (R10, R13, R15 and R16). The update process must be specified in the BIM-based Framework. Indeed, R13 distinguished two types of information: passive and active. For instance, the technical sheets contain information about products or systems that might, in the future, not be available anymore. Processes for update should be put in place with facility managers who will be in charge of the asset operation and maintenance. Identify clearly data that must be kept updated within specifications for the facility managers and the client. What must figure into the BIM-based Framework is the update between the AIM and the DIM. R10 reinforced the previous argument by giving the UK COBie approach, as being a very interesting example. They said

*"...you must be able to provide the information, the technical data sheet, of the solution implemented on the building". "…it is absolutely essential that manufacturers are prepared to guarantee that the information requested by their clients is correct because they will then handle it. It is important, it is vital…there are **processes to be put in place to ensure that the data is up to date**". "...if the information is updated in the "in use" model, it **must also change the deconstruction model**".*

Manufacturer and BIM Manager, R13

"…COBie, these data centralization spreadsheets make it possible to be on more reliable, simple and more accessible formats to everyone. It is essential to be able

*to **push the operators until the integration of the update**. One of the big issues is updating".*

Digital Project Manager, R10

During their entire lifespan, buildings are destined to be, more or less slightly, modified. There will be several operators, who will follow one another and who will have kept the update more or less well. Therefore, the mistakes will accumulate throughout the entire asset lifecycle. To make the data last, requirements must be stipulated right at the beginning of the project and for each stakeholder involved in the asset lifecycle. He said,

*"the data may not last, because it is passed from hand to hand, because there are changes that have not been updated in the model, **because people are not empowered, or people are not competent or do not give a damn**".*

Architect and BIM Manager, R16

As discussed in this section, databases should be added to the theoretical BIM-based Framework. Exchange formats, data classification and data required, among others, must be clearly defined when the project starts. In parallel to these modifications, respondents pointed out changes for the three models drawn in the Theoretical Framework. These changes will be discussed in the following session.

6.6 Models changes

The BIM-based theoretical Framework was shown to the respondents and questions were asked about the three models developed during the asset lifecycle: the PIM (Project Information Model), the AIM (Asset Information Model) and the DIM (Deconstruction/Dismantling/Decommissioning Information Model). One of the most important standards used to frame the Conceptual Framework is the ancient PAS1192 which recently became ISO 19650. The last model, the DIM, was proposed by the researcher to the interviewees. As highlighted in the literature, there is no model yet for managing the asset EOL activities (Akinade 2017). R15, based on the RIBA Plan of Work, stressed that there is no deconstruction stage. Therefore, for the research, the "stage 8" was added to the RIBA Plan of work and in Figure 2 of the PAS 1192 (British Standards Institution 2013), replaced recently by the ISO 19650 standards (British Standards Institution 2019). The RIBA Plan of Work and French system were discussed in chapter 4.

6.6.1 Collaborative platform and Model View Definition (MVD)

In the scenario of managing data in BIM throughout the entire lifecycle, a collaborative platform is required. According to respondent R02, all the data generated is placed in a collaborative platform and will continue to live during the asset lifecycle. R14 pointed out that there is two concerns and visions about the asset's data centralization: the "central facility repository" or the "building operational system". In fact, a huge amount of information will be collected from the design phase to the SEOL phase.

The data can be classified according to the business view that will require the Model View Definition (MVD). We will have a decentralized view of the data, and thereof, we will be able to extract, as many MVD, as possible. He considers that deconstruction or the SEOL, in general, is a business view: The Sustainable End-of-Life's "business view". If we want to have this view, a filter must be applied. The data that will be required and generated during the asset lifecycle must be stored in a collaborative platform. Scrupulous attention should be paid for all the data on the platform: their actual existence, their reliability and their updated state. He said:

> *"...we will retrieve all the design and execution data, we will **add them to an environment** that knows how to deconstruct these data and especially organize them". "Among the data, we are going to have, regulations, the data of the connected objects, we will have building performance data, BREAM, LEED... All this will come together but **not in a model**".*
> *"It's a bit like the logic of a COBie. We are on **a Model View Definition** (MVD) that will be a **deconstruction MVD** or a **SEOL MVD**". "...I make sure that in the AIM, I **have all the data** that will be used **on this business view**, for example, deconstruction".*
> *"…So this means that the BIM vision is almost served by the 3D model… **we could make the Building Information Model without a model. That's what Americans do with COBie**."*

BIM Manager, R14

After having set up the environment where the data will be stored and exchanged, attention is called for the data required, when the project start. In a BIM environment, as discussed in section 4.3.4, the OIR (Organisational Information Requirements) describes the information required by an organisation for asset management systems and other organisational functions. The importance of the OIR was raised up by R14, who is a BIM manager that is very knowledgeable on data management and BIM in France and the UK. He was involved in the "Plan de transition numerique", the French strategy for BIM implementation.

In Chapter 4, related to the background of the research, the asset lifecycle, according to the RIBA Plan of Work and the various documents required throughout the project lifecycle were deeply discussed. The RIBA Plan of Work and the French system were also compared to help the reader to understand both systems. The RIBA Plan of Work and the ISO 9650 were selected as the systems used for the figures and the Framework. In the following sections, we will discuss the various changes suggested by the interviewees for the models generated during the asset lifecycle in BIM.

6.6.2 Design and construction phases-PIM

Concern was raised by R13 about the requirements that must be known very early in the project. He said that the SEOL needs must be indicated upstream, at the time of specifications. Project requirements from each stakeholder must be included in the BIM protocol. Needs will also concern the level of Details (LODs) the quantity and quality of data required etc. As a manufacturer, he needs to know the requirements for the SEOL upstream to make an appropriate offer taking into account the difficulty of this particular approach. It is also essential for planning.

The arguments of this respondent refer to the documents (EIR, BEP and MIDP) mentioned in Figure "Information Delivery Cycle" of the ISO standard, detailed in section 4.5. Regarding the requirements, R15 said that the AIR (Asset Information Requirements) is not used during the design phase, whatever he is involved in the design phase or not. It is not needed at the early stage because the content of the AIR is, among others, products information that isn't known yet. Indeed, the supply chain comes usually at the very end of the construction. These should be added in the Framework. Throughout the asset lifecycle, R13 agreed that 3 models would be developed. He said:

> *"...potentially we'll have* ***three models****. For the execution model (Exe),* ***I need to provide information containing the requirements of the project management to on-site workers****".*

Manufacturer and BIM Manager, R13

During the design phase, the Project Information Model (PIM) is developed by the design team. The model is enriched with data coming from the stakeholders involved in the design, such as technical engineers, the Quantity Surveyor. According to R10**,** one of the advantages of designing by using the BIM process is that all the choices are kept into the model. The PIM will be used for the construction phase.

6.6.3 The handover phase: 2 models (The Digital As-Built Record and the AIM)

At the end of the construction, the "As-Built" model will embed all the data used for the conception and construction of the asset. Even though the will is to strive for having a Digital As-Built Record, it is not yet commonly used. According to R01, in BIM, the As-Built Record handed over the construction of a project. Another model will be prepared for the Operation and Maintenance phase and will be used during the lifecycle of the building. The Asset Information Model content will be discussed in the next subsection. R11 reported that for some activities, the model is used for construction, such as synthesis and execution phase. He added that for some projects, the will is to push the use of BIM towards the Digital As-Built Record and operation and Maintenance. He said

> *"…for me the As-Built Record is what we built, the "**As-Built"**…we integrate **technical data sheets**, **technical opinions, exact implementation dates**. It is necessary to integrate **all the information related to the construction**".*

Quantity Surveyor and BIM Manager, R11

The As-Built Record is given to all the parties, and it will be kept in archives in case of a disorder happened. Respondent R11 suggested adding the Digital As-Built Record into the Framework. He added that the SEOL part could also be a set integrated into the Digital As-Built Record, among the final deliverables.

According to R20, the Digital As-Built Record is still in its infancy. He added that today they are not necessarily able to use it, as provided in BIM. In his company, the Digital As-Built Record is a topic under active research aiming to improve it. They also try to find out if tools exist to manage, share, store and secure the Digital As-Built Record. He said,

> *"...currently, the As-Built Record is **the most challenging stage** for them. This is the "pet peeve", to have the right and complete documents. Often, when they are given to us, we cannot see that they are incomplete. We **realise their incompleteness when we need them during the "in use" phase**". "…the Digital As-Built Record will help to smooth this challenging stage by **identified easily the missing data, identifying which data was checked or not, identify the data reliable** etc."*

Owner – Engineer, R20

R16, based on his projects conducted with BIM, gave some precisions that must figure into the Framework. He said that two models are required from companies: Digital As-Built Record model and an Operation and Maintenance model. The Digital As-Built Record model, as said previously, will be archived. The Digital As-Built Record is completely exhaustive and represents the building "as it is built". To be able to use it for the EOL phase, the As-Built Record model must be updated accordingly to the asset evolution. This should be added to the Framework and specified in the requirements, at the beginning of the project.

Regarding the second model for Operation and Maintenance, the content will be adapted to the activities. It will lose some 3D graphical data and gain non-graphical. It cannot be the same as the Digital As-Built Record. He concluded that for SEOL management, both models would be used.

> *"...to deconstruct, we will use the **As-Built Record model and the exploitation model**".*

Architect and BIM Manager, R16

> *"…when I'm involved, the architects have already created the model, the construction guys already put some information in the model. But I give them our AIR and EIR the Asset information Requirements and has a lot of requirements that*

*need to be in the model that they're not there in the design that is **not really useful in design**. So we **enrich the model**, not simplify it with more data that would be useful for asset management".*

BIM Manager – Facility Management, R15

Based on an important project done with BIM from design to Operation and Maintenance, and to support the previous argument, R13 reported that the model used for the construction phase is not the same model used for the "In Use" phase. He added that the model used for the SEOL management should be the "As construct" and on the "As maintained". R02 has the same opinion. He thinks that after the handover phase, the data go to two different directions (Digital As-Built Record and the AIM). Therefore, for managing the asset EOL, more information is need than for the "In Use" phase.

*"…and I also confirm, even if I have never done one, that **the model for deconstruction will necessarily be different because the deconstruction objective is not an "in use" objective**".*

Manufacturer and BIM Manager, R13

6.6.4 In use phase: Asset Information Model (AIM)

R02 took the example of existing buildings and explained the process they usually follow. Walls and partitions are not managed in CAFM software. Asset management is based today only on rooms and equipment included in the room. Even if some information is lost in the CAFM software, it continues to leave and to be accessible somewhere on the collaborative platform.

*"…we usually scan it so we can manage it. We're not going to model it the same way. We'll put in **the information we're interested in**".*

BIM Manager - Facility Management, R02

R13 explained that Asset Information Model would be much higher in detail than the PIM. Some information will disappear in favour of others that will arrive. For the "In Use" phase, we will have the data required by Facility Managers who are interested only in space's management and the data inherent to them. R15 reinforced the previous argument by saying that for the "In Use" phase, the model will contain more data. He explained that today, as a BIM Manager, when he is involved in the project, the architects have already their PIM model enriched with the data coming from the construction stakeholders. He pursues by insisting on the importance of updating the AIM model during the entire asset lifecycle to be able to have an "As maintained" compliant with the real state of the art of the asset.

R16, a French architect using BIM until the Facility Management phase, was in agreement with the previous respondent, a British BIM manager working as a Facility Manager on the Operation and Maintenance phase. He added that the AIM model is geometrically degraded. It has been emptied of its "heavy" information, such as 3D geometry but it is richer in term of intelligent data.

For example, all the HVAC components, electrical installations, etc. all things that will evolve with the building are targeted. He emphasized the importance of updating the AIM and the As-Built Record model, accordingly to the building evolution. According to him, in the Framework, requirements about the update activities should appear. Who will be responsible for that? He said:

> *"…It is necessary to set up the appropriate charter which is set up to say: every year I make the As-Built Record model evolve according to the evolution of the operation/maintenance model".*
>
> Architect and BIM Manager, R16

The update of both the As-Built Record model and the AIM, are crucial when one considers the management of the EOL with the BIM process. Both models will aliment the SEOL Model. This will be discussed below.

6.6.5 EOL phase: Deconstruction Information Model (DIM)

Several respondents agreed to change the BIM-based theoretical Framework by connecting the DIM model with the As-Built Record model and the AIM "As maintained". The quotations related to this point are provided in Table 45.

Based on the respondent statements, the DIM will be a combination between the Digital As-Built Record and the AIM "As Maintained". The model will contain data related to the Sustainable End-of-Life activities, whether deconstruction, dismantling or decommissioning. Each component of the asset will contain information needed by End-of-Life managers to enable them to conduct, for instance, the deconstruction appropriately and efficiently. The data will include details about the components, their history, such as when they were installed, replaced, the necessary precaution to adopt during the deconstruction, and how to recycle, reuse them. All the respondent agreed that the data embedded into the AIM and the PIM must be updated according to the asset's evolution.

Table 45: The respondent and their argument for the DIM (Source: Author)

R	Quotations
R02	"...this model used during Facility Management **will not go on SEOL**. For me, SEOL will be managed **during the design phase**. Then t**he model will be used for SEOL will be the PIM and not the AIM**".
R11	"...the model that will be used for construction will be also used for deconstruction. There is a logical sequence between the PIM design model and PIM construction. And then we'd have the model or AIM or DIM. That is to say, I would not start from the AIM model to do the DIM, **I would take from the PIM model**... the **DIM model is part of the AIM** model. It is included in it.
R13	"...so I confirm that the model of the "Exe. " (PIM) is not the same as the model for "in use" (AIM). And I also confirm, even if I have never done one, that t**he model for deconstruction will necessarily be different** because the deconstruction objective is not an "in use" objective". "…in fact, it is absolutely **necessary to link the model to AIM**, which will be **updated by the building manager**, it must be l**inked to the deconstruction model…"** "...if the **information is updated in the "in use" model, it must also change the deconstruction model**. Finally, if I summarize, it must be **based on the "as construct" and based on the "as maintained."** "…in many cases, it will be t**hree different models"**
R14	"I think the problem is **the vision of the AIM.** Very often, it is carried by people who are only in the operating phase". "...**the information from the PIM should not be removed**. In practice, you should not think of a model. **We have to think of "data"**. "...an **AIM is a big database**. **It's not a model.** Typically, all the technical data sheets, if they are put in the model, it will be a disaster. The model will never run". "...If you need a **Business view** that is linked to regulations, the business that is linked to specific maintenance or deconstruction, I make sure that i**n the AIM, I have all the data that will be used on this business view**, for example, deconstruction".
R15	"...the **AIM has more information than the PIM**. I think the "**as maintained" model is an update of the AIM a**nd it can have the component qualification, it can have quantities extraction. I do not know about deconstruction model can contain, but we can perform **scenarios analysis and waste sorting plan**, based on the model that is **an upgrade of the AIM**. So it would be **the AIM** (Asset Information Model) and we can also have maybe **information that is taken from the PIM.**
(PIM) *Project Information Model,* ***(AIM)*** *Asset Information Model,* ***(DIM)*** *Deconstruction / Dismantling / Decomissionning Information Model,* ***(R)*** *Respondents*	

6.7 Improved framework

The BIM-Based theoretical Framework is improved based on the respondents' feedbacks. First, the research deduced tasks from the respondents' discussion on the Framework and the barriers, discussed in chapter 5. Then, the goal was to identify potentials BIM Uses for the SEOL approach. As shown in Tables 46, 47 and 48, a list of 80 tasks was identified based on the interviewee's feedback. The 80 tasks were organised, according to their characteristics, into three categories: 32 organizational-related tasks, 30 policies and procedures related tasks and 18 technological related tasks.

6.7.1 Tasks classified into three categories

An organizational task includes the requirements expressed by the stakeholders, the requirements related to the data, including the updating. It also includes the project team organisation and their roles and responsibilities. It integrates the organization of the SEOL activities, including processes set up, SEOL activities planning and their execution. Part of the organizational tasks, are the database creation and management and the activities related to exchange and collaboration between the stakeholders. From the twenty interviewees' feedback, thirty-eight related organizational tasks were identified by the researcher.

According to Succar (2009), Policies and Guidelines are rules and principles written for guiding decision-making (Succar 2009). Contracts, rules and Guidelines include contractual agreements, tendering, and procurement launched for projects. The identification and specification of the requirement of the client, the builders, facility managers, end-users, regarding the data, classification and updating expectations are included in the policies and guidelines category. All the deliverables, their validation process are identified, framed and contractually agreed (Table 6.7).

Similarly, the collaboration and exchange rules are defined and agreed upon by all stakeholders. The various BIM models' contents are also expressed at the beginning of the project. All the required data are specified, and the checking process also addresses data validity and compliance. Projects' stakeholders are all more or less involved in the Contracts, rules and Guidelines writing. The owner, the designer and the CE or SEOL specialists are pivotal roles in the contractual document redaction and in the clear expression of the project expectations in terms of sustainable EOL and requirements to achieve for the project. There are twenty contracts, rules and guidelines related tasks identified from the interviewees' opinion (Table 47).

Table 46: Organizational related tasks (Source: Author)

Organizational related tasks	Group (*)	Interviewees
Approach to avoid finishing works	**G2**	R12
Avoid use of complex components	**G2**	R09, R12, R13, R18, R20
Consider buildings as systems - Deconstruction system	**G2**	R14
Consider having reversible active roofs (An occupation, either of meetings or gardening or of solar elements)	**G2**	R20
Design modularization/DFMA	**G2**	R01, R15, R20
Design with reclaimed components	**G2**	R09, R10, R06, R12, R18, R20
Keep as much as possible from the existing building	**G2**	R07, R12, R20
Start Circular Economy by taking into account the site history	**G2**	R18, R07
Consider a zero-waste strategy during the entire asset life phase.	**G2**	R20
Use of DFMA, hire division with demoundtable modules and storages	**G2**	R15, R20
Devote specific budget for the approach	**G2**	R18, R20
Design improvement, EOL anticipation (modularity, rversibility, flexibility, urbanism and social issues)	**G2**	R10, R12, R16, R18, R20
Create a new and reclaimed material databases (listing)	**G6**	R15, R19, R20
Set up & manage the collaborative platforms for data	**G6**	R01, R14, R15, R20
Express Product requirement: Market preparation	**G8**	R18, R20
Product preparation: Give evidence of the products' recyclability	**G8**	R13, R18, R20
Rigorous material selection	**G8**	R10, R20
Advertise and sale reclaimed materials	**G8**	R06, R15, R19, R20
Identify reusable and recyclable materials	**G8**	R07, R12, R16, R18, R20
EOL management: Constraint identification (storage, channels for recycling…)	**G9**	R17, R20
Storage of reclaimed material for on-site utilisation or waiting for buyers.	**G9**	R05, R07, R20
Waste Diagnostic stage for SEOL (structural diagnostic, Look for network plans, Identify the materials for recycling, public domain use Authorisation)	**G9**	R17, R13, R01, R08, R10, R05, R03, R19, R09, R07, R20
Set up waste mangement scheme	**G9**	R17
Planning activities for SEOL, Site installation and skips'positionning	**G9**	R14
Cost estimation for SEOL	**G9**	R14, R03
Onsite recycling process/crusher	**G9**	R17, R06, R20
Existing Building without BIM models scanning existing building/3D model for SEOL management	**G9**	R01, R20
Cleaning phase: First manual deconstruction	**G9**	R17
Set up recycling processes waste before in use phase: Manufacturers responsibility	**G9**	R13, R09, R10, R05
Set up recycling processes waste after asset use (polluted material sorting…)	**G9**	R13, R19, R06, R17
Labelling the recovered materials to meet standards	**G9**	R19, R20
Storing recovered materials	**G9**	R19, R20
New budget division (Builders, control office and designers are key roles)	**G5**	R01, R04, R05, R06, R07, R08, R09, R10, R11, R12, R13, R18,
New role creation	**G5**	R01, R04, R05, R07, R11, R12,
Give the approval for use reclaimed material (control office, FM, client …)	**G5**	R10, R20
Architect involvement during the construction phase	**G5**	R12, R09
Look for required skills (assistant for reclaimed materials, SEOL or CE) and give support to your workforce, if necessary	**G5**	R1, R04, R06, R07, R09, R11, R12, R14, R15, R16, R18, R19,
Stakeholders involvement, everybody, multidisciplinary team (cleaning company part of the team)	**G5**	R06, R12, R14, R01, R18, R20

(*) ***(G2)*** *Design approach,* ***(G5)*** *Stakeholders roles,* ***(G6)*** *Database,* ***(G7)*** *Cheking & Validation,* ***(G9)*** *SEOL activities*

The Technology related tasks, associated with people and machines, are practical tasks conducted using the application of scientific knowledge (Naughton 1994). These tasks include technical material information, the building components and their composition, construction systems and requirements for deconstruction or disassemble the asset components. The update of the data technologically is a technology-related task that will be contractually required. There are fourteen technologically related tasks identified by the 20 respondents (Table 48).

Table 47: Contracts, rules and guidelines (Source: Author)

Contracts, rules and Guidelines related tasks	Group (*)	Interviewees
Set up new certification program/cost	**G7**	R13, R14
Permit approval change: add tax system	**G7**	R01
Compliance with the SEOL requirements by contractor and the FM. Monitor the operation in accordance with the study expectations.	**G7**	R06, R09, R14, R20
Set up process for data trust improvement	**G7**	R12, R20
Set up SEOL deliverables validation steps	**G7**	R01, R20
Contract adaptation for including SEOL phase	**G1**	R14, RO9, R20
Tendering / Procurement changement	**G1**	R01, R09, R07, R10, R12, R18, R20
Selection of the contractor early during the process	**G1**	R09
Define the deliverables (digital models, number, exchange, format, content…)	**G4**	R01, R02, R10, R11, R13, R14, R15, R16, R20
EoL Dimension to assess the ciruclarity of the asset	**G4**	R01, R16, R11, R13
Handover phase: Digital "as built" record content, compliance and accuracy	**G4**	R16, R11, R09, R10, R13, R15, R16, R19, R20
BIM Execution Plan: stakeholders requirements, include LOD	**G3**	R12, R13, R20
OIR information required by the organisation	**G3**	R15, R14
Set up SEOL client requirement and objectives, EIR and MIDP documents (architectural charters, etc)	**G3**	R01, R10, R14, R11, R15, R20
Set up requirements for the DIR/DIM model content	**G3**	R09, R14, R15, R11, R01
Asset Classification System requirements (Omniclass, Uniclass, Uniformat)	**G3**	R13, R14, R10
Set up the AIR/AIM content	**G3**	R15, R14, R02, R13, R20
Set up processes & requirements to ensure reliability and update of the Data and models in the platform	**G3**	R14, R01,R02, R16, R10, R11, R13, R15, R20
Clear Specifications and responsibility (Disclaim property)	**G5**	R13, R12
Product content transparency	**G5**	R05, R01

*(*)**(G1)** Contracts, rules & guidelines, **(G3)** Requirements, **(G4)** Deliverables, **(G5)** Stakeholders roles, **(G7)** Cheking & Validation*

Table 48: Technologically related tasks (Source: Author)

Technology related tasks	Group (*)	Interviewees
Use technical sheet for decision making: how to recover materials?	**G7**	R06, R09, R20
Technology update to be able to access to the data	**G3**	R16, R13, R20
Identify the Buildings composition & recyclable/reuse components	**G8**	R17, R19, R14, R20
Prepare the market, time to make prototypes or find manyfacturers	**G8**	R18, R20
Specfications adaptation for SEOL (demountability, deconstructability)	**G8**	R06, R09, R10, R13, R14
Identify polluted materials	**G9**	R17
Diagnosis: classic geometer survey, destructive survey for tensile tests, core sampling and analysis	**G9**	R17, R19, R10
Data required for Deconstruction management	**G9**	R17
Whole story of the building	**G9**	R19, R10, R18
Collaborative platform (CDE) content	**G6**	R14, R15, R20
Collaboration boundaries definition	**G6**	R16
The use of Digital As-Built Record	**G6**	R01, R13, R20
Set up rules for data inputs, exchange and interoperability (between project stakeholders, including Material Banks and recovered materials' facilities)	**G6**	R02, R06, R09,R10, R11, R12, R13, R15, R17, R19, R20
Data availability, accessibility	**G6**	R10, R13, R15, R17, R19, R20

*(*) **(G3)** Requirements, **(G7)** Cheking & Validation, **(G6)** Database, **(G8)** Material selection & Market preparation, **(G9)** SEOL activities*

6.7.2 Tasks classification into nine groups

The research focuses on addressing the eighty tasks, highlighted by the 20 interviewees, and induced by the incorporation of the SEOL into the asset lifecycle. As shown previously, they are classified into three categories, according to their characteristics: (i) organisational, (ii) Contracts, rules and Guidelines and (iii) the technology-related tasks.

Then the tasks were categorized according to the asset lifecycle stage or activity they refer to nine groups that were used to order the tasks raised by the interviewees. (G1) Contracts, rules and guidelines, (G2) Design approach, (G3) Requirements, (G4) Deliverables, (G5) Roles and Responsibilities, (G6) Database, Exchange and collaboration, (G7) Checking and Validation, (G8) Material and Market, (G9) SEOL management (Table 49).

Table 49: The classification of the eighty tasks into nine groups (Source: Author)

Categories	Groups
Contracts	**G1**
Design approach	**G2**
Requirements	**G3**
Deliverables	**G4**
Roles & responsibilities	**G5**
Databases, exchange & collaboration	**G6**
Checking & validation	**G7**
Materials & market	**G8**
SEOL management	**G9**

After the categorisation of the eighty tasks into nine categories, they were considered in the BIM context. The aim was to evaluate each task and to identify its impact on the project stakeholders, phases and models. The nine groups of tasks are discussed in the following subsections.

A. **Contracts, rules and guidelines (G1)**

Two respondents pointed out the contract issue in the context of the incorporation of the SEOL phase into the asset lifecycle (R14, RO9). They believe that the standard contracts' forms, must be adapted and introduce that a comprehensive SEOL contractual terms requiring to meet new needs for the asset EOL management must be introduced. Similarly, for the BIM adoption, the BIM protocol was added as a contractual document. Indeed, for projects adopting BIM approach, an effective multidisciplinary collaboration must be embraced. This new collaborative approach required role changes for the clients, architects, and contractors. As reported by Sebastian (2011), a new contractual relationship is needed, and process reorganised (Sebastian 2011). In the same way, the BIM protocol must include sustainable EOL expectations for a project using BIM.

Regarding the tendering and procurement methods, adaptations should be made. As put on the table by several respondents, the traditional procurement could not be used anymore in a SEOL approach (R01, R09, and R10). In effect, the traditional procurement method allows knowing the contractor, very late, once the design and details specifications are fixed. In a SEOL approach, it is crucial to involve builders earlier during the design phase. For some interviewees, builders play a key role during the design phase, when decisions are taken for construction systems to adopt. The design and detailed specifications are chosen with builder's support (R07, R12, and R18). The selection of the contractor must be made earlier during the project process (R09). The involvement of contractors at an earlier stage of design was also reported by (Oyedele, Ajayi, and Kadiri 2014; Liu et al. 2015).

The use of Integrated Project Delivery (IPD) method and collaborative BIM environment can enable the early involvement of contractors (Ajayi et al. 2016). Indeed, in the last few years, several innovative procurement methods were developed, such as Cost Led Procurement (CLP), Integrated Project Insurance (IPI), Two-Stage Open Book, Integrated Project Delivery (IPD) and Project Alliancing (PA), among others (Ciribini, Ventura, and Bolpagni 2015). The British Government introduced in 2011, the CLP, IPI and Two Stage Open Book procurement methods. The British government states that new tendering technologies "*embrace early contractor involvement, higher levels of integration and transparency and the option of independent assurance*"(Her Majesty's Government 2013).

B. Design approach (G2)

In the context of a SEOL or a Circular Economy approach, the client must have a budget allocated to these approaches. He also has to have a global asset lifecycle view and be aware that he is making an investment. As reported by R18, a Circular Economy specialist.

> *"So, he has to **understand that this is an investment** he has to make in the first place. And if we don't make this investment in the first place, it will **cost** them a **lot later**. If we do not integrate, **from the design stage,** whether it is a new building or under renovation, these concepts and move the project forward (we obtain permits, etc.), we will not be able to integrate them".*
> *"The responsibility of the principal or investor is to demand a sufficiently high level and to have budgets that match. You don't build an Audi for the price of a 2CV".*
>
> CE Specialist and Architect, R18

As reported by several interviewees, the design must be different. Respondent R10 gave the example of the nuclear plants' projects and reported that they could not be designed without thinking about what they can do with materials at the end of life of the nuclear asset. This is a mandatory approach. The design for deconstruction, or disassembly or dismantling, are several approaches having in common the goal to design with the end in mind to be able to recover materials. As reported in many previous studies, to be able to recover materials, these approaches are required (Cruz Rios, Chong, and Grau 2015; Bradley and Scott 2002; Knecht 2004; Crowther 2002; Akanbi et al. 2019; Kibert 2003). The way designers are tackling their job must be modified (Tingley 2012; Oyedele, Ajayi, and Kadiri 2014; Crowther 2005).

To be able to make the buildings easily demountable, they must be designed purposefully for that fate. Consequently, the construction's systems must be revised. Indeed, interviewee R14 believes that building must be considered as systems in the same way as HVAC systems.

*"I have a **very IFC vision with two important things**, which have an impact. I would tend to talk about **reconstructive systems**. This means that to **simplify the deconstruction process**, it would be necessary to be able to **identify these deconstruction systems"**.*

BIM Manager, R14

Several authors raised the necessity to consider buildings as systems to be able to disassemble their components. For example, for deconstruction optimization, the use of an open building system with interchangeable parts is preconized (Kibert 2003). Flexibility is another approach aiming to use of demountable parts of the building to make it adaptable to an external and internal change (Ajayi et al. 2015). The deconstructability or demountability are approaches that consider the composition of buildings in several layers. The British Chartered Institution of Surveyor (BCIS) split building system into six groups: substructure, superstructure, finishes, fittings and furnishings, services and external works (BCIS 2006). Other authors supporting the Brand layers approach and group them in six categories: site, structure, skin, services, space plan and stuff (Brand 1994; Akinade et al. 2015).

In consonance with the previous arguments, the design approach adaption was pointed out as a crucial task by eight interviewees (R01, R06, R07, R09, R10, R12, R15 and R18). The first approach was reported by respondents R15 and R01. They put on the table the Prefabrication and Design for Manufacture and Assembly (DfMA) as a strategy to make the building demountable. Coming from the automobile and consumer products sectors, the DfMA approach aims to ease the manufacture and assembly. Many studies addressed the DfMA approach to tackle wastages during construction (Gbadamosi et al. 2019) and associated DfMA with the use of BIM (Machado, Underwood, and Fleming 2015).

Prefabrication or off-site construction are also strategies to improve the construction stage by manufacturing under factories conditions parts of buildings. They are then transported to the construction site and incorporated into buildings (Jaillon and Poon 2014). The association of prefabrication, modular design and standard components is an interesting approach for construction and design cost reduction and time-saving (Jaillon and Poon 2010). Prefabricated or modular buildings are made up with components manufactured off-site and assembled on site. This approach was reported by R15, who worked in a DfMA company. According to him, the modularization was done based on the designer project.

*"The modularization of the design usually happens within the design office and the contractor itself. That's how we did it when we had a design office. We used to **receive the work from the architect** and **modularize everything**. The architects give the layout, everything but it's not always modularized because they don't really think about it".*

BIM Manager – Facility Management, R15

The modules can be volumetric modules assembled onsite or, the modules can be flat packed and then assembled on site. DfMA contractors usually use demountable modules for hire. These modules are hired and then recovered, demounted, and they bring them back for storage, waiting for another hire. In his paper, Zhang et al. (2016), reviewed the history of the Chinese construction industry and focused on the association of BIM technology with the modular and industrialized construction approach. Chinese government considered the industrialization of the construction sector as a worthy approach for meeting sustainable requirements. For the Ministry of Housing and Urban-Rural Development (MHURD), over 50% of the housing project should be built by industrialized construction by 2020 (Zhang et al. 2016).

The second approach used by respondent R12 is the avoidance of the finishing works, based on the BCIS building system layers (BCIS 2006). The project is designed to avoid hiding structural walls or the HVAC systems with plasterboard. R12 said that they always find a way to get them to go where they want; they must fit in well with the structure. As reported by Nagapan et al. (2012), construction waste is produced throughout the entire asset lifecycle (Nagapan et al. 2012) categorised regarding their source, in two groups: structural waste and finishing waste (Skoyles and Skoyles 1987).

This kind of approach enables to reduce the quantity of construction waste. R12 usually associated this approach with the use of earth as a material for structural walls, rammed earth or CEB (Compressed earth blocs) (Morel et al. 2001). Several respondents have a sustainable EOL approach by using earth, especially excavation earth with the purpose threefold: reduce waste, reduce the CO2 by using local material and reducing the buildings' impact at the end of their lives (R09, R10, R06, R07, R12, and R18). Some authors add another type of reclaimed materials, such as wood, stone, among others. Their general motivation is reducing the global impact of their buildings. Designing with reclaimed materials is an approach addressed by many authors (Gorgolewski 2008; Addis 2006; Gorgolewski and Morettin 2009; Gorgolewski 2006). In the UK, the WRAP proposed a guide for a designer to support them for designing out waste (WRAP 2009). For instance, Akinade et al.(2018) assessed the stakeholders' expectations for the use of BIM for C&D waste management (Akinade et al. 2018).

The last approach used by two interviewees is the Circular Economy (R18, R07). Both are architects, and they aim to close the loop of materials. R18, a proven specialist in the Circular Economy, reported that the best way to fully perform the Circular Economy principles is to have an inventory of the site and start the Circular Economy, many years before.

> *"…when there are major renovations or buildings on site, is* ***to start the Circular Economy, thirty or forty years ago****… And it's not starting now, but it's starting from what was done at the time. So you can integrate into the overall assessment, not only what will be done but what has been done…"*

> "…You have to ***look at the building in time***, *not only now and up to the construction (which is made in general) and its use, and its end of life or its transformation and successive transformations. But I also* ***like to go back upstream, back in time if there is a way****".*
>
> CE Specialist and Architect, R18

The Circular Economy (CE) theory was launched by the Ellen Mac Arthur Foundation in 2011. CE aims to use materials more efficiently (MacArthur 2013). The CE theory is opposed to the current linear economy based on "take - make - dispose" approach. The main idea of the CE is increasing goods' lifespans and reducing wasteful resources by adopting a more efficient design approach. The Circular Economy "*is a simple, but convincing, strategy, which aims at reducing both inputs of virgin materials and output of wastes by closing economic and ecological loops of resource flows*" (Haas et al. 2015).

CE in the built environment: The theory was used for the first time in the built environment in the Netherlands (RAU architects - De Architect, 2013) (Bouwens et al. 2016; "RAU - Architects" 2013) Circular Economy or Cradle-to-Cradle concepts imply a radical change for the construction sector in the way buildings are designed, and the material selection is made. Cradle-to-Cradle® considered buildings as "Material banks". Geldermans (2016) defined the material banks as "temporary storage of materials that comprise the building assemblies" (Geldermans 2016). He believes that it is worthy to combine it with concepts such as design for adaptability to smooth the CE implementation. Global programmes for sustainability and Circular Economy agendas call for the minimization of the environmental impact of buildings. Akanbi et al. (2019), have developed an analytical system for the assessment of the EOL performance of a building at the design stage (Akanbi et al. 2019). After a literature review analysis on CE assessment, Elia et al.(2017), proposed a four-level framework to support the assessment phase of a CE strategy (Elia, Gnoni, and Tornese 2017). Authors also reviewed the existing methodologies for the environmental impact measure in the industry and services sectors. Their potential relevance for CE assessment is presented.

C. Requirements (G3)

Several tasks are related to requirements clearly defined for the project. In BIM, projects should follow the ISO 19650 series (see chapter 4). The original figure, given in the PAS 1192-2:2013 (updated in the ISO 19650), didn't include the End-of-Life of the asset. Several interviewees proposed to incorporate the SEOL phase and explore the requirements needed for its management. The supplier's information exchange points and employers decision points associated with the SEOL/Demolition phase are also added. The integration of the End-of-Life as a stage in the lifecycle of the building requires adding to the Digital Plan of Work the Deconstruction stage, as phase 8. It leads to a change in the Information Delivery Cycle by incorporating the EOL phase and the information exchanges related to it. In the new Asset

Lifecycle concept, three Models are used throughout the entire lifespan of a building. This was illustrated and discussed in chapter 7.

Respondent R15 suggested to add the SEOL into the figure and to develop a new model that will be used for the SEOL management. Mainly all the respondents agreed for the importance to have a clear view of the client requirements when the project starts. The aim of managing the EOL of the asset sustainably must be expressed by the client at the programming stage. Respondent R14 suggested that the client should provide the architectural charters to the project team. The Asset Information Model requirements must also be identified when the project starts and to be completed throughout the project development (reported by respondents R14, R02 and R13). The classification required for the data have to be identified and mentioned in the BIM Execution Plan (BEP) (R13, R12, R14, R10) (CIC 2011).

Respondent R13 gave the example of a complex project developed in France, and he said that the three main types of classification were required for the data: Omniclass, Uniclass, Uniformat. The content of the model used for the EOL must be defined (R09). What type of data is needed, when the data is required and who must give it? Where the data is stored and who is responsible for the reliability verification and the update? The reliability and update of the data were stressed by respondent R14, who suggested to agree of all these requirements when the project start contractually.

Indeed, precise processes for the updating must be set up, and responsible have to be designated (R13, R16). Based on an ongoing project, respondent R16 suggested, for example, that the AIM must be updated by the Facility Manager every year. Accordingly, the PIM and the Digital As-Built Record have to be updated by the design team. Several interviewees (R10, R13, R15, and R16) agreed to the importance of setting up processes for Models updating. Based on ongoing projects, respondent R15 explained the several documents that must be set up at the beginning of the project (EIR, MIDP, AIR etc.)

> *"…now for example, when I'm involved, the architects have already created the model, the construction guys already put some information in the model. But I give them our **AIR and EIR** the Asset information Requirements and has a lot of **requirements** that **need to be in the model** ..."*
>
> BIM Manager – Facility Management, R15

Based on review of fifteen BIM guideline, standard and protocol documents, Sacks and Gurevich proposed a qualitative content analysis that can be used as a basis for setting up the main topics for a BIM project: the interoperability, collaboration modes, BIM execution plan, simulation and analysis, BIM manager's role and operation and maintenance requirements (Sacks and Gurevich 2016).

The BIM Execution Plan (BEP) document allows the client and the design team to set clear goals for the use of BIM. It also mentioned the expected deliverables and the specific requirements for simulations (energy, analysis, LCA, LCC, etc.) (Sacks and Gurevich 2016). In a SEOL approach, the client will mention his expectation according to the EOL management, EOL simulations and the asset circularity goal. The BEP will play a crucial role in the working process regulation between the stakeholders involved in a project.

D. **Deliverables (G4)**

As mentioned previously, the deliverables will be indicated in the BEP. The format must be specified, in IFC, native format and COBie (R13, R15). The number of deliverables, their formats and the date is also agreed at the beginning of the project (R14, R01, R15, and R16).

For a SEOL approach, specific deliverables must be added, such as EOL simulations according to the cost, the environmental impact, the duration, the asset circularity etc. For instance, respondent R15 pointed out that COBie development is usually made during RIBA Stage 6 (Handover and Closeout) (Sinclair 2012; Gething 2011). The key point to specify is 'what are the deliverables and who is responsible for them?' Kassem et al. (2014), proposed protocols for BIM collaborative design to support the entire supply chain in their exchanges and deliverables. The goal is the improvement of flow and consistency for data and deliverables (Kassem et al. 2014).

Based on the EIR identified at the beginning of the project, the AIM's content must also be specified (British Standards Institution 2013)(Manning 2014). As discussed in the previous sub-section, the PAS 1192-2 provides a framework for the models' development. During the design and construction stages, the Project Information Model is developed. After the project handover, the Asset Information Model (AIM) will be delivered to the facility management team. According to Carbonari et al. (2015), "during the operational phase, analysed in the PAS 1192-3 (British Standards Institution 2014) the AIM will evolve accordingly to the events (e.g. major and minor works, breakdowns, transfer ownership) that occur while the building is in use" (Carbonari et al. 2015).

Several respondents highlighted the importance of specifying the AIM and the Digital As-Built Record contents by involving facility managers at the beginning of the project and throughout its evolution (R01, R02, R16, R10, R11, R13, and R15). According to five respondents, at the handover phase, the Digital As-Built Record will be delivered to each stakeholder and represent the digital "as –constructed" asset (R16, R11, R14, R13 and R15). For the End-of-Life management phase, the data collected throughout the entire asset lifecycle could be used for managing the EOL more efficiently and sustainably. Several respondents assumed that a model view definition could be created for the EOL activities. The model, DIM will be alimented by the PIM updated and the AIM also updated.

> *I think the **"as maintained" model** is an **update of the AIM** and it can have the component qualification, it can have quantities extraction. I do not know about deconstruction model can contain, but we can perform **scenarios analysis and waste sorting plan**, based on the model that is an upgrade of the AIM. So it would be the AIM (Asset Information Model), and we can also have may be information that is taken from the PIM.*
>
> BIM Manager – Facility Management, R15

The content of the DIM model would be composed by graphical and non-graphical data. The intelligent model will enable deconstruction engineers to plan and organise the deconstruction activities more efficiently and accurately (R02, R10, R11, R13, R14, R15, R16). Four respondents pushed the idea further and have raised the possibility of a new dimension. In line with several authors have identified a lack of dimension for the EOL activities (Charef, Alaka, and Emmitt 2018). It was also reported by Akinade (2017) that not BIM dimension exists for C&D waste management (Akinade 2017).

E. Team organisation and Stakeholders roles (G5)

The organisation of the project team and the role and responsibilities definition are also important tasks pointed out by several respondents (R01, R13, R12, R18 and R20). For a project conducted in BIM and a SEOL approach, identification of proper stakeholders is crucial. As discussed previously, the client engagement for the SEOL approach is fundamental, but he also must be surrounded by committed people. According to Lindblad (2018), the best way for a technology such as BIM to be accepted is by imposing it contractually, making it not negotiable (Lindblad 2018). The client plays a significant role in BIM adoption and also for CE approach adoption, as reported by (Adams et al. 2017). In parallel, stakeholders roles and responsibilities must be clearly defined, and boundaries set up contractually at the beginning of a BIM project (Sinclair 2012; Sebastian 2011). For the use of a SEOL approach, the same requirement has to be uptake (Bouwens et al. 2016).

Among the stakeholders, manufacturers have a crucial role in the SEOL and CE approach. Their responsibilities and obligations about the content of their products must be standardized. This concern was raised by respondents R05 and R01, in terms of transparency. Respondent, R13, a manufacturer, also expressed their responsibility on their products' recyclability. In a Circular Economy or SEOL approach, the boundaries of their responsibilities must be delimited. Indeed, he took the example of their 100 % recyclable products and explained that they lose their recyclability criteria due to the adding of material by the painter. According to R20, in the context of onsite materials reuse or recycling, the Assistant to the Contracting Authority will play a key role. The involvement of facility managers upstream is essential, especially when the building is planned to be managed with BIM and when reclaimed components or equipment are used instead of new materials.

F. Database (G6)

Based on R15 experience in the UK, he suggested the creation of a collaborative platform, or Common Data Exchange (CDE). The CDE must be set up for the project, and it will be alimented by each stakeholders. This was also suggested by the interviewee R14 who recommended to use the name of "central facility repository" or the "building operating system". He said that the focus should be on data and not on the model.

> *"**In** my opinion, the information from the PIM should not be removed. In practice, **you should not think of a model**. We must think **"data…"** "…**We only think about data**. The **models are put back into the database**. And some data will never have gone into the database. For me, an **AIM is a big database"**.*

BIM Manager, R14

Having a collaborative platform for data management is also reported by several studies. Porwal and Hewage (2013) reported that "BIM-Partnering helped the project team to manage client involvement by creating a coordination platform. It was aligned with the government procedures and rules" (Porwal and Hewage 2013). "*We believe that Cloud Computing platforms provide a more efficient and robust mechanism for individuals within the AEC industry to collaborate and share data. Cloud Computing capability would make the most sense when utilized alongside a BIM data representation, in particular, to support collaborative working between various participants involved in the lifecycle of a building*" (Beach et al. 2013). Some authors named tautologically "collaborative platform" as "BIM", such as Akinade and Oyedele (2019) reported "*Although a collaborative platform called Building Information Modelling (BIM) offers a means of supply chains integration, it has not been efficiently up-scaled for delivering waste efficient building designs*" p.863 (Akinade and Oyedele 2019). Chen (2015) distinguished "single database" and internal/external collaborative platform (Chen 2015). He defined the collaborative environment that enables all stakeholders to access the central database. He raised the requirement to set up a "well-controlled data management policy to guarantee the safety of data". The collaboration limitations were also stressed by the respondent R16 as crucial and must be defined clearly when the project starts. R16 uses for their project the Autodesk BIM 360 platform that is free for Autodesk software users. The platform provides a variety of functions enabling to work collaboratively (Autodesk). He reported that, unfortunately, this platform has some limitation.

> *"…since it is free, cheap and good; **they see everything**. **We don't have access control management,** or some people see some things and others don't. As a result, **everything is visible.** It is **totally transparent**. As they have complete transparency, they have the impression that every day we make deliverables for them".*

Architect and BIM Manager, R16

This was also highlighted by Alreshidi et al. (2018), who have listed several requirements for overcoming collaboration limitations " (i) protocol development, (ii) establishment of responsibilities among disciplines, (iii) sharing via a common model that can be stored centrally or hosted on distributed environments, and (iv) improved communication among disciplines (Alreshidi et al. 2018). Indeed, as believed respondents R13, R02 and R15, the data exchange and interoperability issues must be rigorously framed, in the BEP. Regarding the data exchange, Figure 38 illustrates the possibilities described by respondents R14 and R15. It is added into the framework in Figures 48-49 as the box "C". R15 said that it makes sense to link material bank with the project. Knowing the quantities and the location of the reclaimed materials will help to prescribe them in the design phase (R09). For the EOL engineer, the reclaimed materials bank can be alimented by the recycling and reuse plants (R17).

The databases illustrated in Figure 38 can be divided according to two levels: the project level and the national/regional level. The reclaimed materials bank and the new materials bank could be managed at the regional or national level. Since one of the environmental impact factors is the distance where materials are coming from. For the project level, the Central Facility Repository (CFR) will contain all the information about the asset from its inception to its EOL. This raised several issues, such as data updating, discussed in the sub-section 6.6.2.3. Another issue is the reliability of the data assessed by checking and secured by validation.

G. Checking and Validation (G7)

The data generated throughout the asset life cycle must be accurate and reliable. For that, at the beginning of the project, checking steps are agreed contractually between the stakeholders. If the CE or the SEOL is required by regulation or by the client, the compliance will be checked by the client, the architect and the SEOL/CE specialist. For instance, interviewees R13 and R14 have suggested to set up a new certification program for the SEOL or asset circularity.

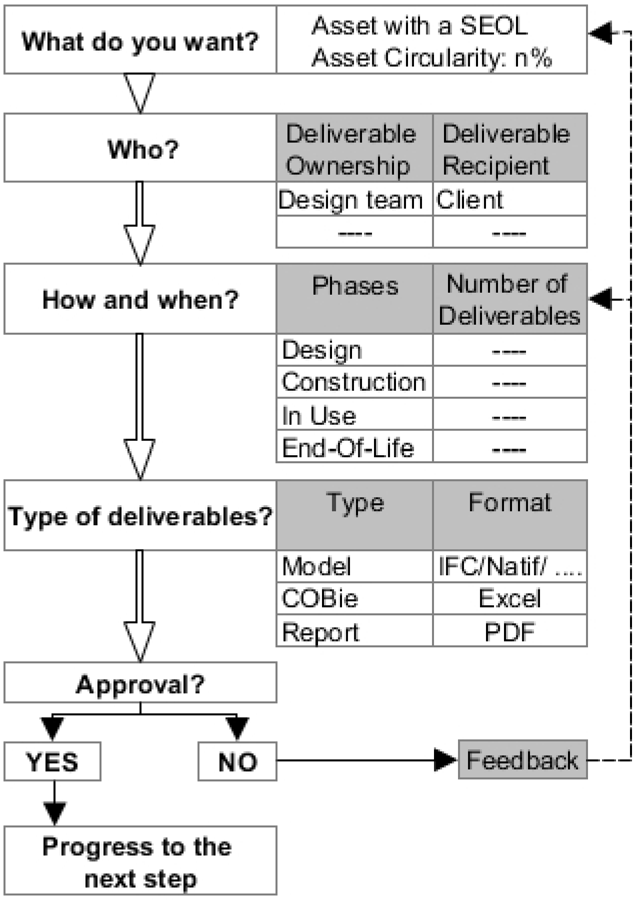
Several checking stages will have to be set up throughout the project design, construction, in use and SEOL phases. During the design stage, the client assisted by the "Assistant to the Contracting Authority" must check the design compliance with the CE requirements (R11, R13, R14 and R01). In the case of obligations, R01 suggested having a checking during the Permit approval by the Authorities responsibilities (Figure 39 that is defining the box "B" in the conceptual framework in Figures 48-49).

The interviewee R09 reported, based on several examples that very often, the contractor is substituting materials during the construction stage. Architects are not all the time very engaged in the construction phase. Therefore, a verification must be done during the on-site activities to make sure that the building is constructed "as-designed". Respondents R06, R09 and R14, pointed out the necessity to have checking during the "In Use" phase. Indeed, the respect of the

SEOL/CE must be observed during the operation and maintenance phase. This leads to having a specific contractual clause destined to responsible the Facility Managers.

In the BIM environment, the Central Facility Repository (CFR) is a collaborative platform where the asset Life cycle Data is stored and managed. The ISO 19650 contains several sub-section addressing the work in progress state; the check/review/approve transition until the archived state (British Standards Institution 2018).

Figure 38: Deliverables process and data check, as box "B" in the framework (Source: Author)



H. Material selection and Market preparation (G8)

Manufacturers should adapt their Material Technical Data Sheet to the SEOL and CE requirements. They need to be transparent on what their products contain to enable the client, the architect and QS to choose knowingly (R06, R09, R10, R13, and R14). Data must be given by manufacturers on how their product can be recycled or reused. Information about demountability and deconstructability should be included in the technical sheet. In France, the FDES (Environmental and Sanitary Declaration Sheets) are used by Manufacturers for reporting materials contents.

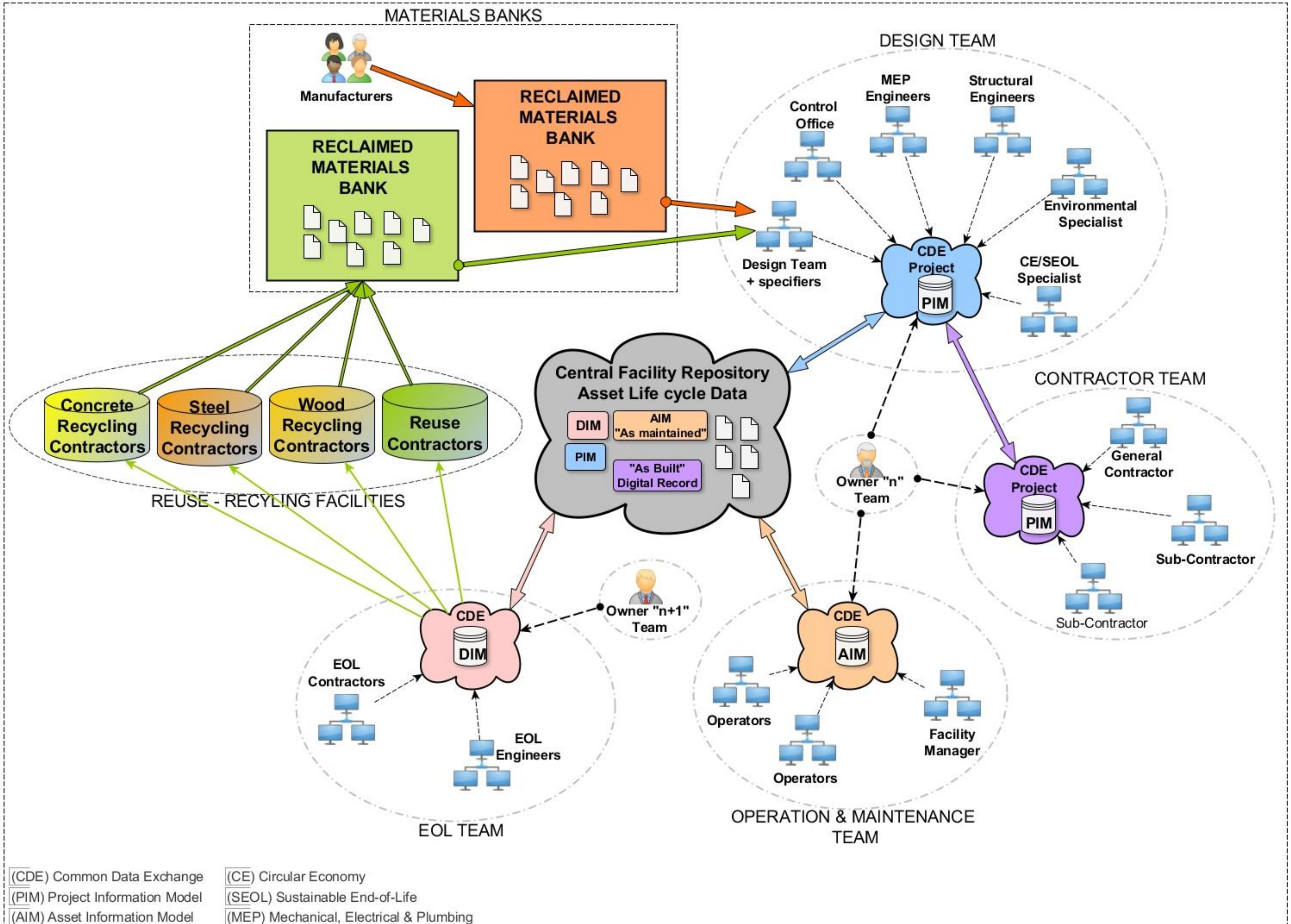


Figure 39: The databases, to be inserted as box “C” in the framework (Source: Author)

Materials are playing a key role to achieve sustainable buildings. Architects and specifiers have to know the products' composition and to understand the environmental impact of the choices they make. The Construction Specification Institute (CSI), the publisher of MasterFormat, has created a sustainable reporting data guide named GreenFormat© (Hooper 2007). For the GreenFormat's creation, the CSI objective was to stress the four Cs (Clear, Concise, Correct and Complete) and to offer transparency on construction product (Middleton 2013). GreenFormat is organizing to communicate the sustainability features of building products. Product's information is organized into nine categories: (1) Product General Information, (2) Product Details, (3) Product Lifecycle, (4) (5), and (6) reserved for future expansion. (7) Manufacturer Sustainability Policies, (8) Manufacturer Support Documentation, (9) Manufacturer's Certification.

The GreenFormat could be very helpful for buildings' composition identification of their recyclability and reusability capabilities, which are important data required for effective SEOL management, as reported by R17, R19 and R14. Architects, owners and specifiers can make informed decisions when selecting materials.

I. SEOL activities (G9)

The last group of tasks is related to SEOL activities. At the end of the buildings useful life, the owner can decide to demolish or deconstruct partially or completely the building.

Sustainable End-of-Life phase (Preparation)

Phase		
Initial Planning phase	**1 Waste Diagnostic**	
	BIM Models exist	BIM Models do not exist
	Use of "As-Built" Digital Record and "As-Maintained"	Existing building scanning
		BIM Model creation based on site visit, paper plans, core & sampling analysis, Network plans
	Identify polluted materials (cores & samples)	
	Identify existing redundant services	
	Quantities/type "waste" evaluation	
	"waste" potential revalorisation?	
	Identify the nearest sector where the "waste" can be sent for revalorisation?	
	Structural Diagnostic	
	Constraints identification: Cost, planning & storage	
	Simulations, cost, circularity, carbon footprint	
Tender	**2 Tender**	
	Invitation to tender	
	Company selection	

Figure 40: The Sustainable EOL preparation (Source: Author)

The SEOL activities are split into several phases. Interviewee R17, a deconstruction engineer reported that the deconstruction phase is organised in the same way as the construction but reversely. It was also supported by several authors (Tingley 2012; Diyamandoglu and Fortuna

2015; Zaman et al. 2018; Hosseini et al. 2015). Figure 40 and Figure 42 describe the SEOL process based on the literature review and interviewees feedback (R01, R11, R14 and R17).

> *"…it will* ***scan the existing****. There will be a* ***diagnostic phase****, identify all the elements that make up the building, including the materials that make up these elements. Then with* ***the digital model****, we will be able* ***to simulate its SEOL****, regarding* ***time, cost*** *and* ***anticipate all the logistics****.* ***Doing it in BIM is interesting****. We will have* ***3D, 4D and 5D and facility management because some elements can be reused".***
>
> BIM Manager, R01

The data-gathering phase can be done in two different manners, depending on if the existing building planned for deconstruction was managed with BIM or not. As shown in Figure 41, there are several scenarios, ranging from the use of BIM throughout the life of the building or only for its end-of-life management. Two scenarios are indicated in Figure 40: when the BIM model already exists and when it does not exist.

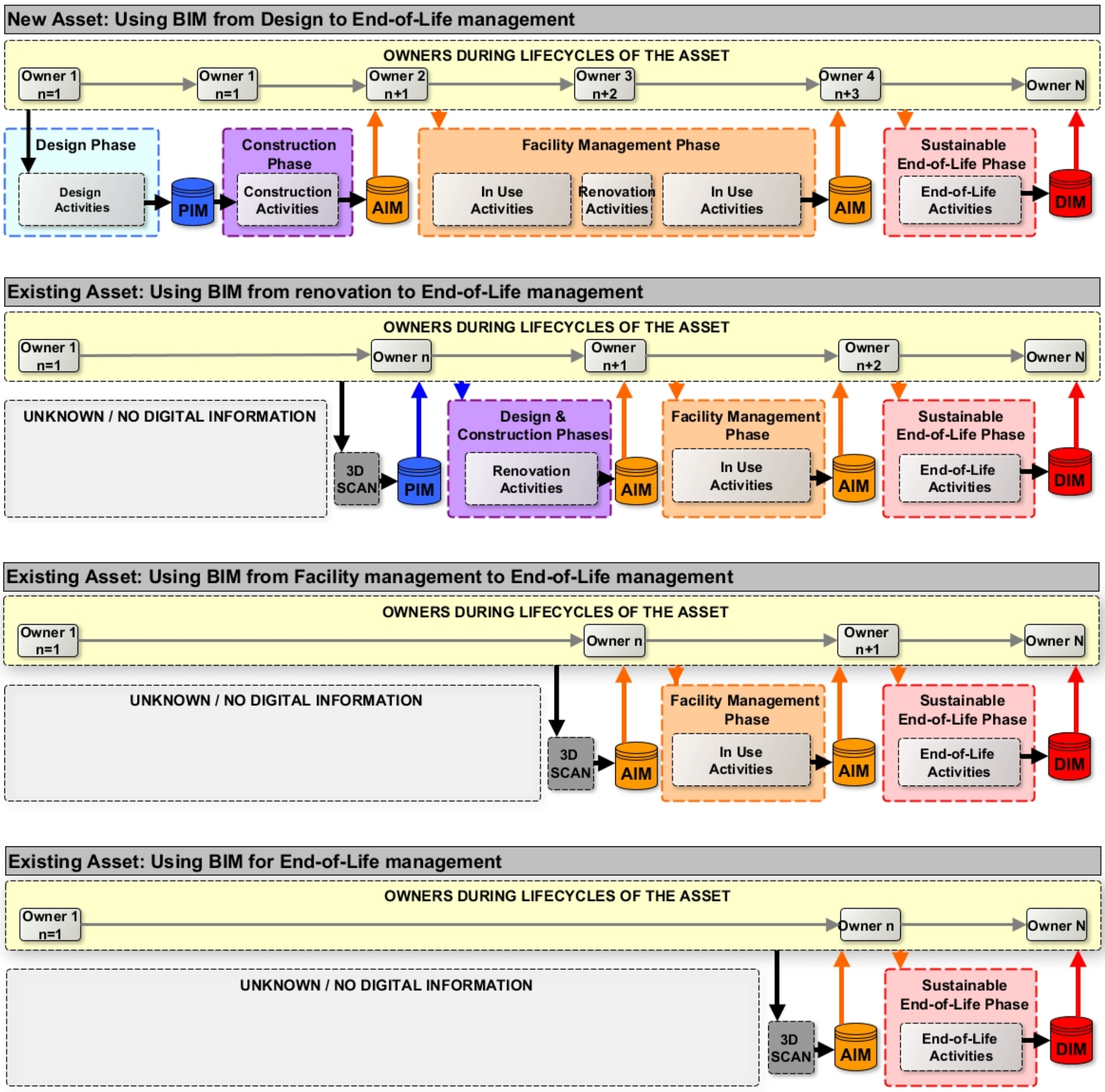


Figure 41: Several scenarios for the asset lifecycle in the BIM environment (Source: Author)

A review of the current Design for Deconstruction tools by Akinade et al.(2015), revealed that there are a lot of tools for assessing embodied energy, carbon footprint, whole life environmental impact assessment (GaBi 2016; Ifu Hamburg 2016) and optimisation of material selection (Wrap, n.d.; Tingley 2012; Akanbi et al. 2018; Akinade et al. 2015) There are few tools addressing the building constructability estimation (Akinade et al. 2015), lifecycle costing (Cheng and Ma 2013; NIST 2010) and material recovery assessment (Cheng and Ma 2013; BRE 2008; NIST 2010) . However, the study raised a lack of tools dedicated to deconstruction process simulation and plan generation (Akinade, Oyedele, Omoteso, et al. 2017).

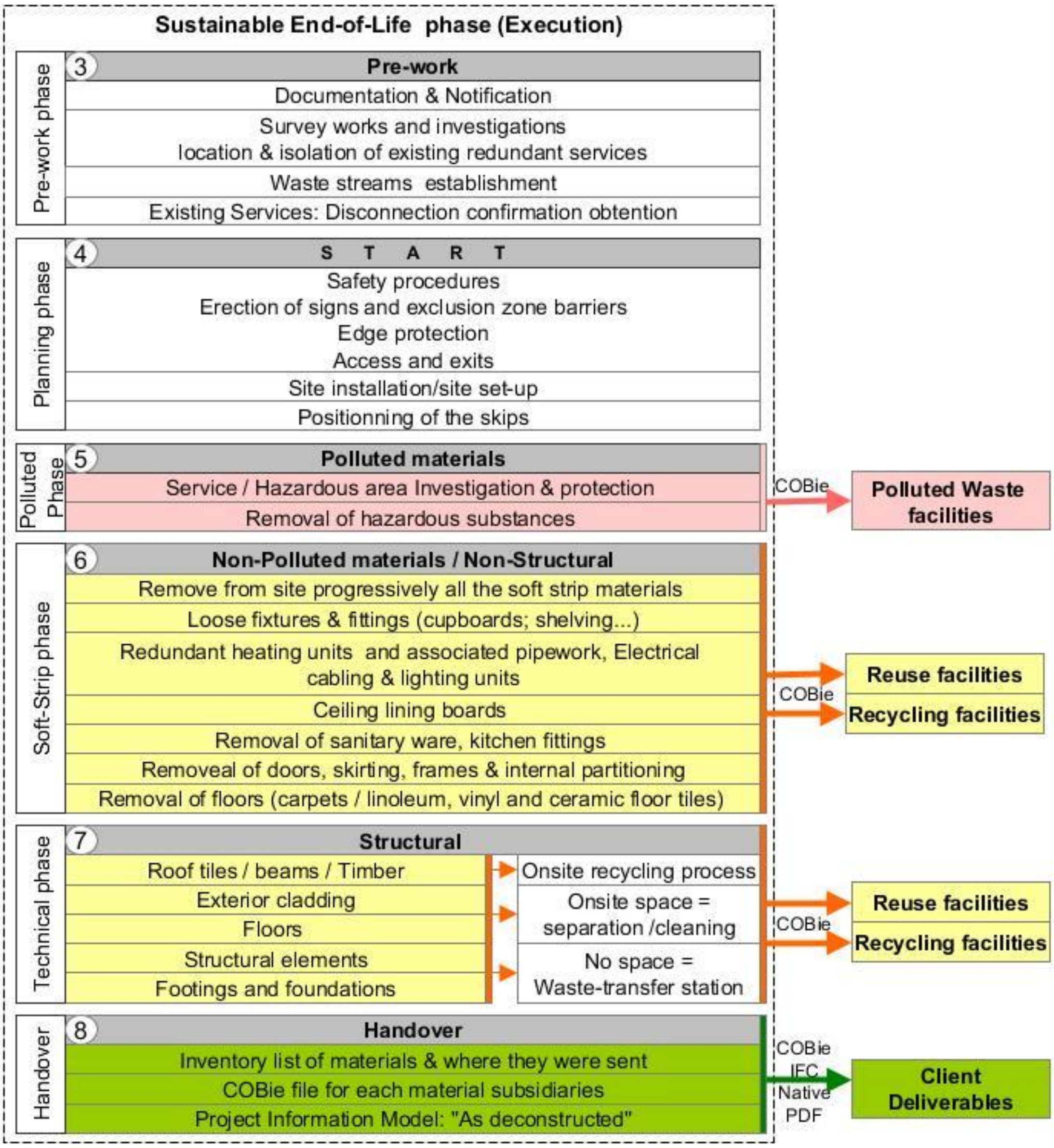


Figure 42: The Sustainable EOL execution inserted in the framework as box “E” (Source: Author)

For most of the existing building, the BIM model does not exist. In that case, the data needed by the SEOL management team will be collected through a 3D scan, 2D documents and on-site survey. Recently, Bortoluzzi et al. (2019), have developed an automated process to generate semantically-rich BIMs for facility operations and management (Bortoluzzi et al. 2019). The main benefits are to get a model rapidly and thus accelerating the use of BIM within the Facilities Management sector. Ge et al.(2017) have developed a reconstructed 3D model based on data collected by sensors such as images from a camera. The BIM model was dedicated to supporting demolishers in their tasks. It enabled to visualize where materials are, to have accurate quantities, and to plan the demolition (Ge et al. 2017). All the respondents agreed that BIM could be very useful for the management of the asset EOL. R17, the deconstruction engineers recognized the opportunity to use BIM to simplify their day-to-day practice. R14 said it is currently working on a project that contains a deconstruction phase before the construction phase. During the programming phase, it was agreed to do the deconstruction by using BIM.

J. SEOL Deconstruction process

Based mainly on respondent R17's explanation, Figure 43 was drawn to illustrate the process of the sustainable EOL phase, in the BIM environment. R10 stressed the difficulty to get invisible data that is required for the EOL management. In consonance with the previous argument, R17 and R19 reported that they usually must do destructive surveys for strength tests. As part of the Circular Economy approach, R18 and R07 are interested in the history of buildings and base their design on it. They believe that the new project is part of something that exists and must be considered. For respondent R15, COBie could be used as the main deliverables to be able to have an interface with the reuse, recycling and landfills facilities. The SEOL execution described in Figure 43 is inserted in the framework as box “D” in Figures 48-49.

The opportunity to use BIM technology and the data collected throughout the entire asset lifecycle was reported by several studies. The accumulated data from the planning phase to operations can be used for the management of the EOL of buildings (Eadie et al. 2013) (Akinade, Oyedele, Ajayi, et al. 2017). Many authors sought the potential of BIM in materials' recycling and re-use. Authors have developed frameworks for choosing, based on the BIM data, the EOL scenarios with the less environmental impact (Akbarnezhad, Ong, and Chandra 2014) (Ge et al. 2017).

Several SEOL management stages could be simplified by the use of BIM. For instance, in Figure 43 (that is inserted in the framework as box “D” in Figures 48-49), the Asset Data Centralization (in yellow) contains all the asset data generated during its entire lifecycle. So the SEOL engineers can start the pre-work stage by importing the data in the desired format (IFC, COBie, etc.). They will generate a Deconstruction Information Model (DIM) for the SEOL management (tasks in pink).

After the classification in nine groups of the eighty tasks collected from the interviews, their impacts on the phases of the project and on the stakeholders involved in a project were represented in Figures 44, 45 and 46.

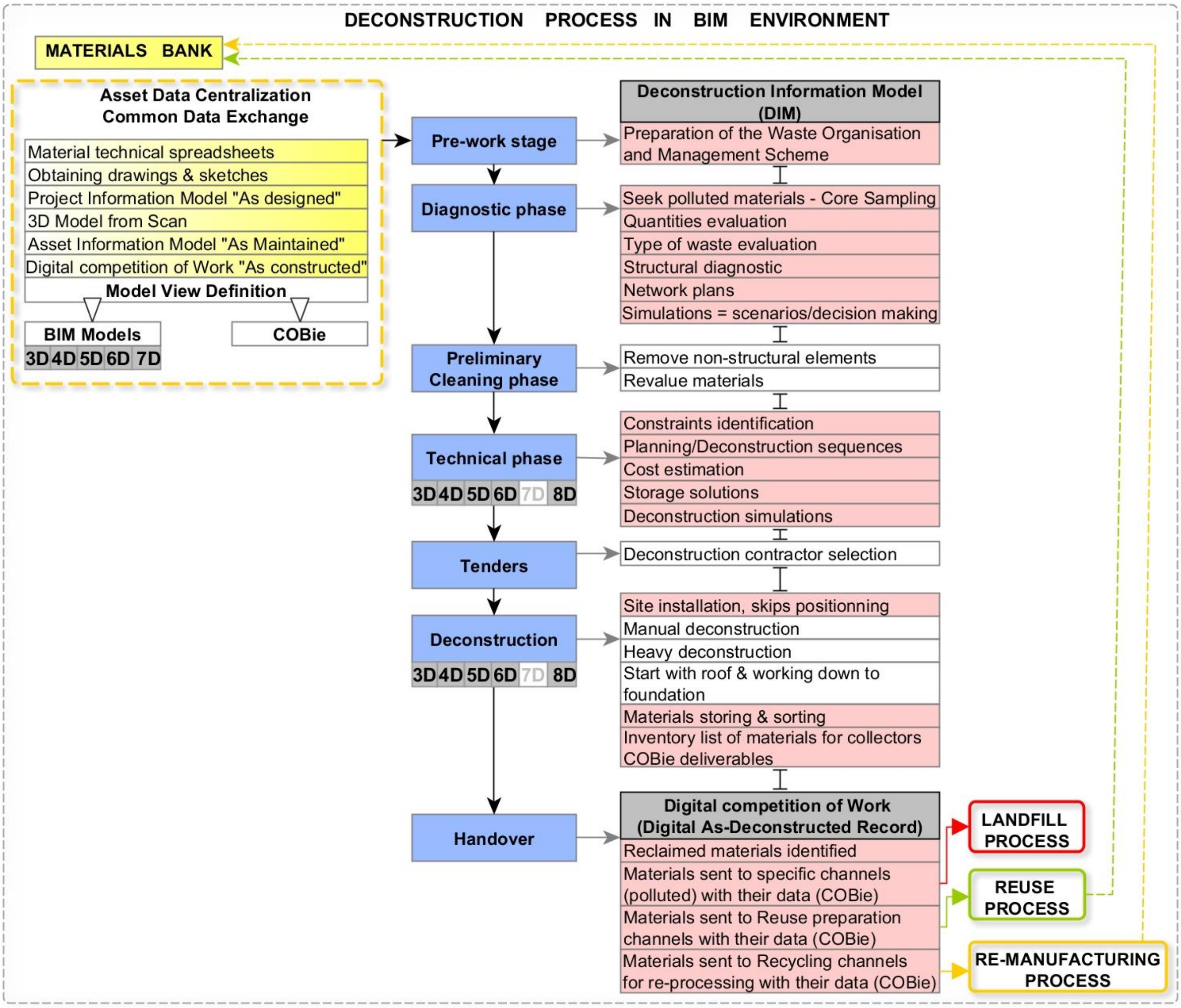


Figure 43: Deconstruction process in BIM environment (inserted as box "D" in the Framework) (Source: Author)

6.7.3 SEOL tasks' impacts on the project's phases and stakeholders

As a conclusion of section 6.6 and the last step before the drawing of the improved framework, three figures (43, 44, 45) were drawn based on tasks described in sections 6.6.1 and 6.6.2. Those tasks are extracted from the respondents' feedbacks. Then the links were drawn between the tasks and the stakeholders defined from the literature review (and from the feedbacks of the interviewees for the news stakeholders). The same approach is used for the links between the tasks and the asset phases and others (CDE, Material bank, BIM dimensions).

Figure 44, depicts the "Organizational related tasks", Figure 45 depicts the "Contracts, rules and guidelines related tasks" and Figure 46 represents the "Technical related tasks". Interactions between the tasks, the project phases and the stakeholders involved in a project with a SEOL approach are indicated with arrows. New links, based on respondent feedback, are shown in purple colour, while existing links, from the initial model, that require changing are shown in blue colour. The red links are the interaction between the phases and the BIM dimensions developed throughout the asset lifecycle, including the 8D specifically developed for the SEOL approach.

6.8 From theoretical Framework to a conceptual Framework

The next figures give the framework evolution from the theoretical drawing (Figure 47) to the conceptual (Figures 48 and 49). All the processes used to achieve the conceptual framework have been described in the previous sections of the chapter, notably all the boxes “A” to “E” are detailed in Table 44 and Figure 41. Figure 49 is a simplified drawing of the framework to enable a better reading.

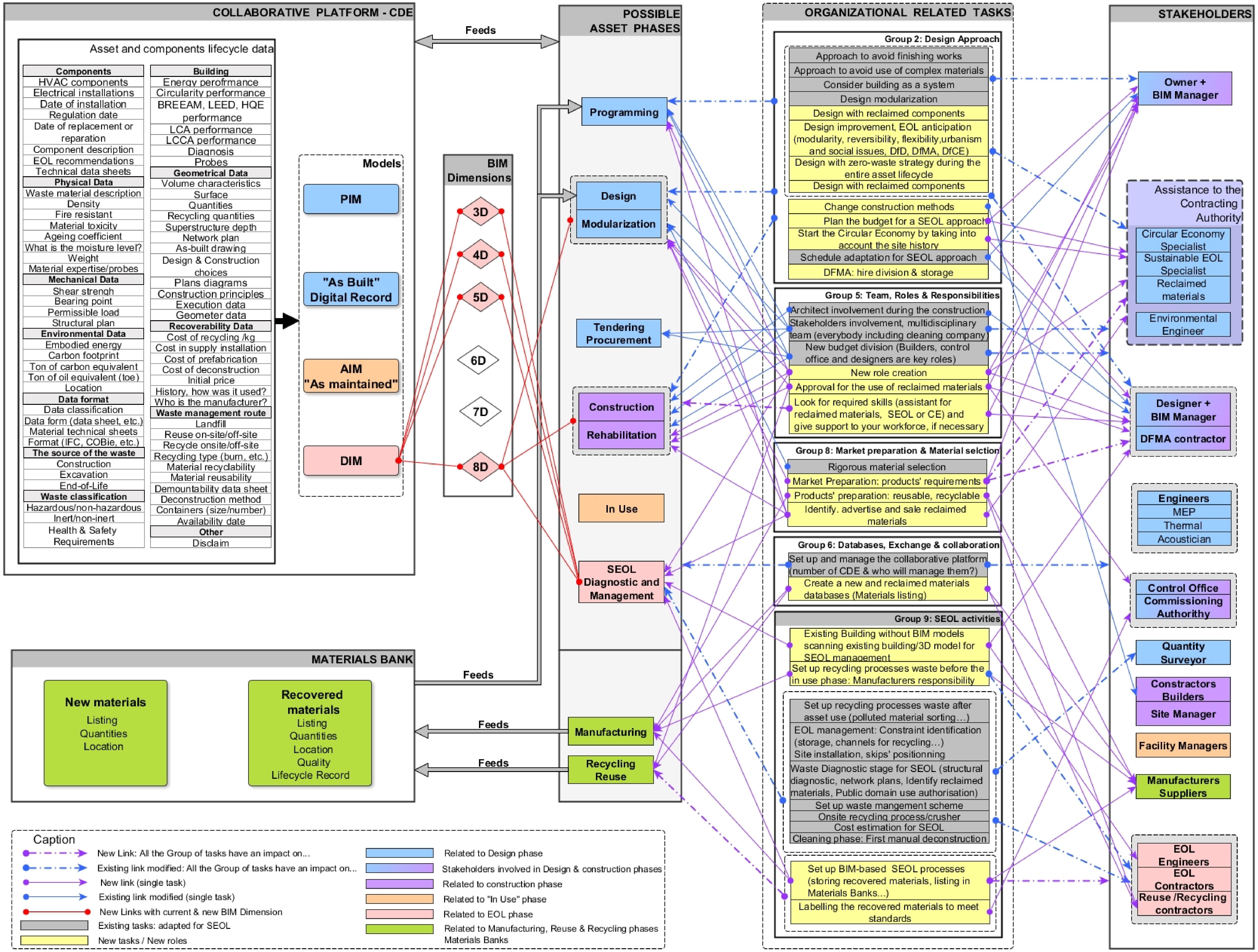


Figure 44: Organizational related tasks (Source: Author)

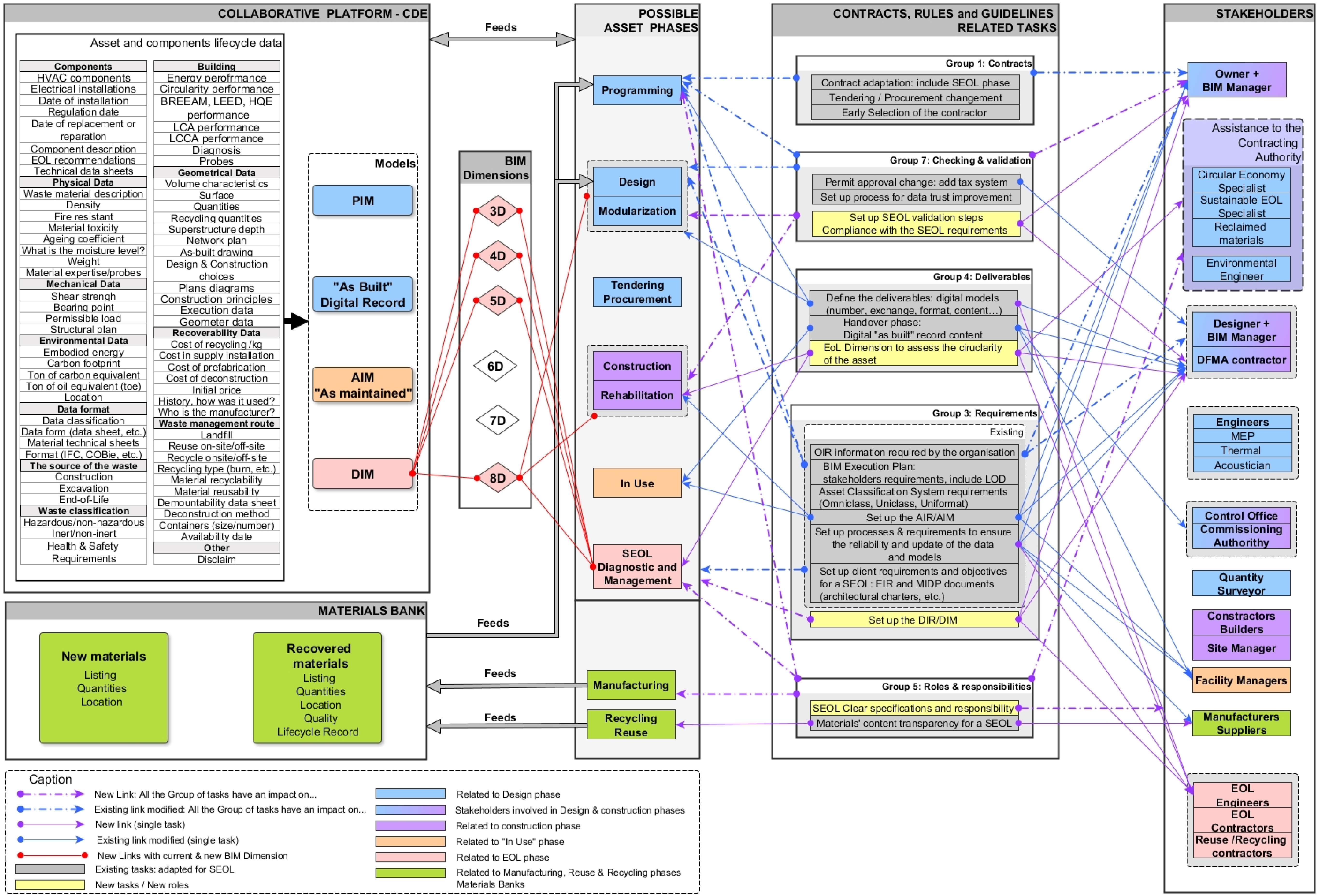


Figure 45: Contracts, rules and guidelines related tasks (Source: Author)

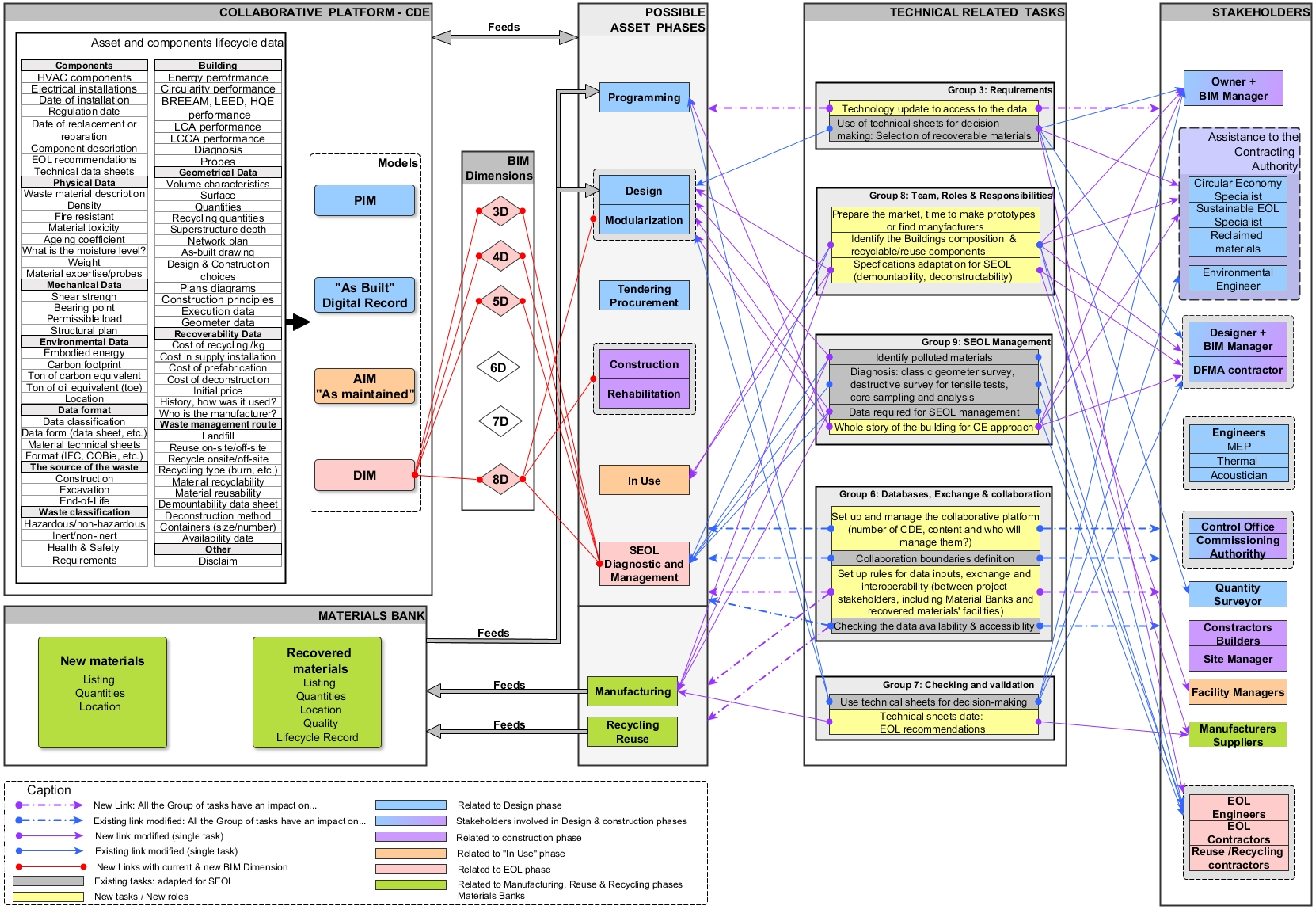


Figure 46: Technical related tasks (Source: Author)

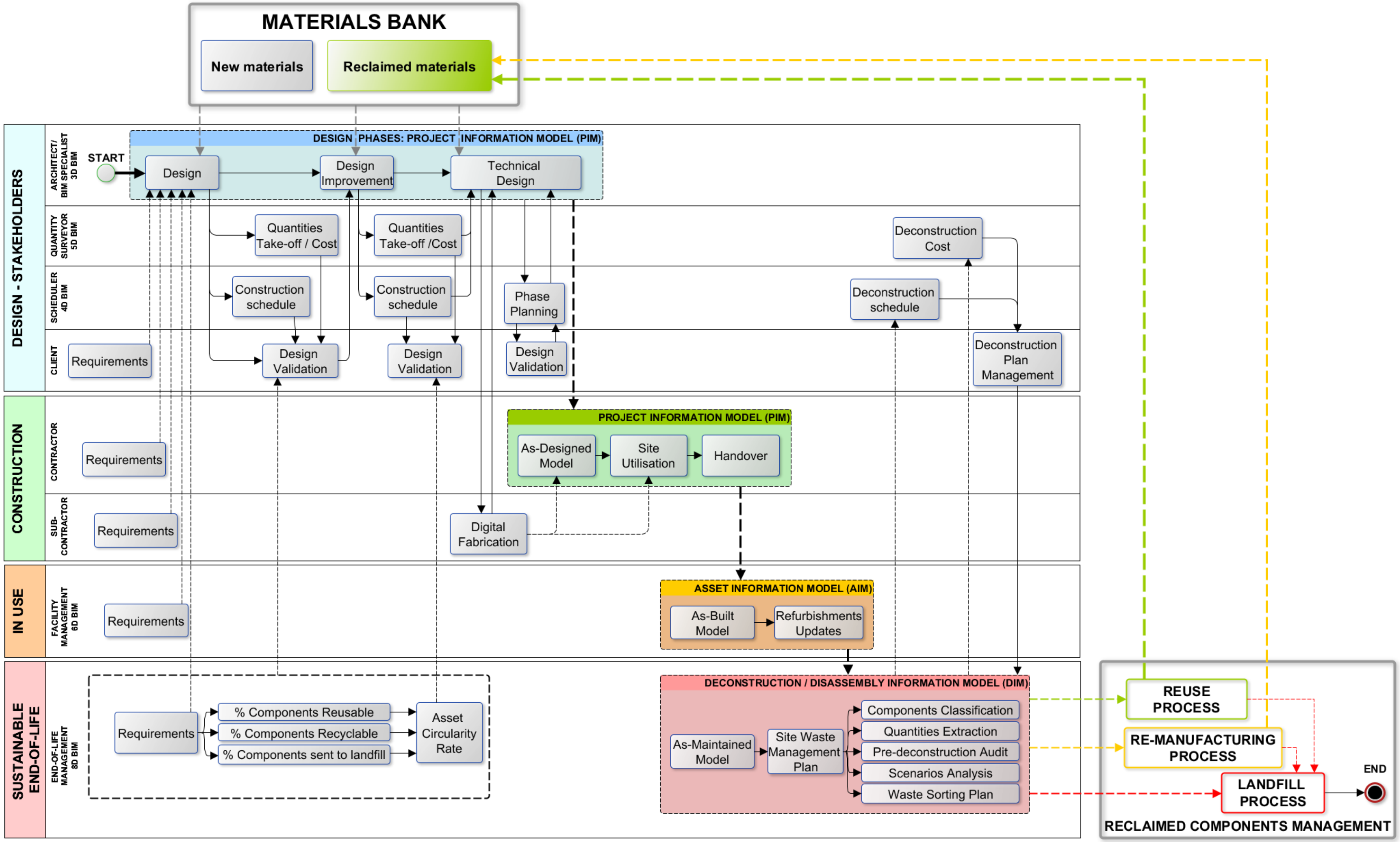


Figure 47: The Theoretical BIM-Based Framework (See Chapter 4 Section 4.1) (Source: Author)

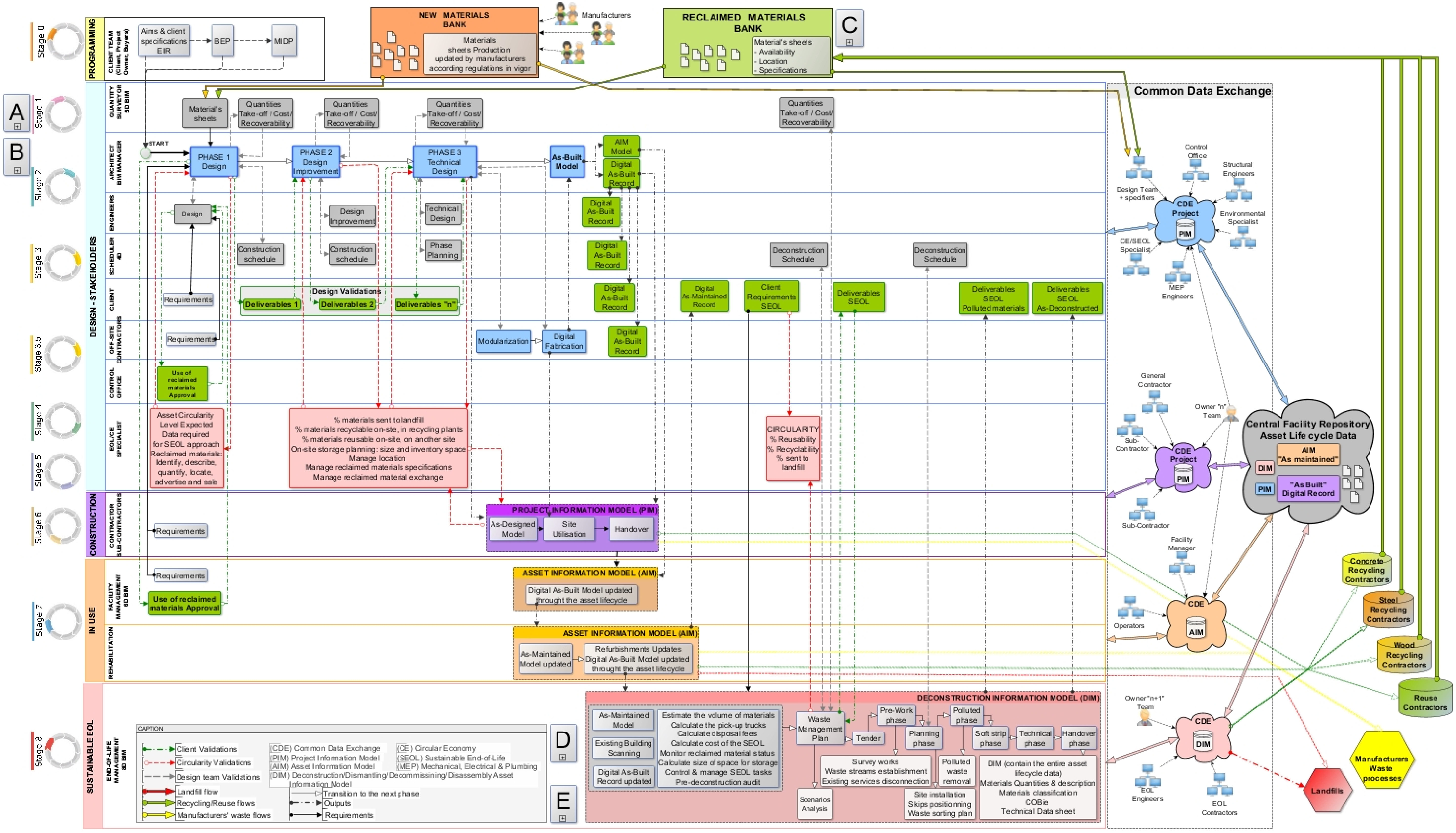


Figure 48: The Conceptual BIM-Based Framework for the SEOL approach (Source: Author)

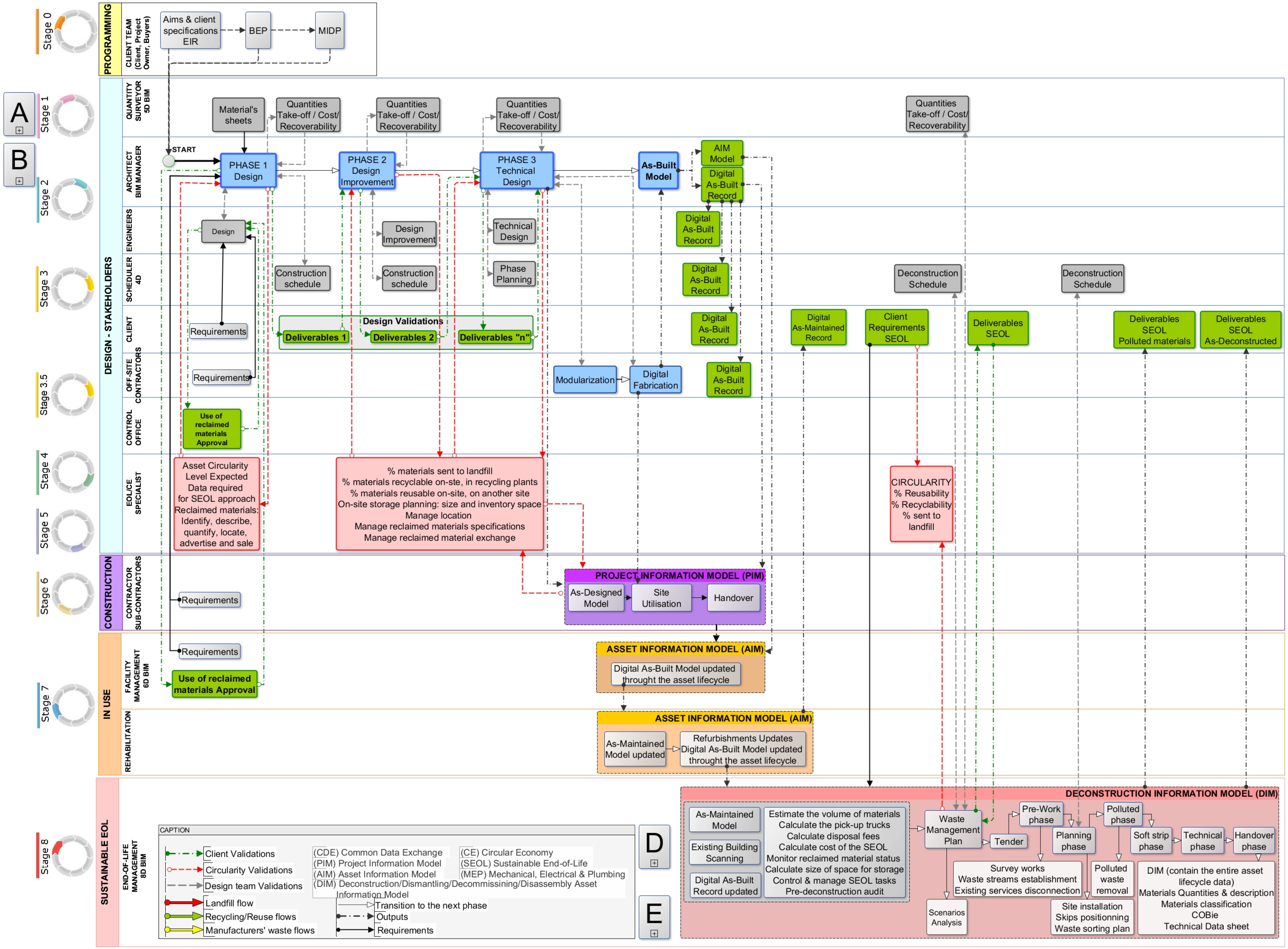


Figure 49: The Conceptual BIM-Based Framework for a SEOL approach (Zoom) (Source: Author)

6.9 Summary

The aim of the chapter was to improve and enrich the theoretical BIM-based framework for the SEOL integration in the asset life cycle in the Circular Economy context, by seeking the expert opinions through semi-structured interviews. In Chapter 2, section 2.4.1, was designed the theoretical framework based on the literature review. The Interviewees were asked to assess the framework suitability, and provide recommendations to improve it where possible. The results of the interviews logically enriched and completely changed the framework that became a "conceptual framework".

General modifications were requested by the interviewees: the general shape and the contract type (section 6.2). Therefore the framework is organised by following the RIBA stages (widely accepted). The second type of improvement deals with the modifications of the stakeholders' missions and the necessity to create new actors (section 6.3). Notably, an expert in the CE assessment is needed from the very beginning of the project. Thirdly, the changes in the asset phases are developed in section 6.4. Some phases were added, and some changed. Data management was also area of changes including data requirements, data creation, format and update (section 6.5).

Section 6.6 addressed the different models used throughout the asset lifecycle. Firstly, insights on how to create and manage the collaborative platform are given. The use of model view definitions (MVDs) for data classification was suggested (business views). Secondly, the Project Information Model (PIM) used during the design and construction phases is addressed. Thirdly the Digital As-Built Record and the Asset Information Model (AIM) used during the handover and "In Use" phases are described. Lastly, the Deconstruction – Disassembly – Demountable-Decommissioning Information Model (DIM) was explained.

In section 6.7 were developed complementary processes as "tasks" that should be integrated into the framework. Those tasks are extracted from the interviewees' feedback on the framework and from the barriers reported by the participants (Chapter 5). Those tasks are designed to overcome the barriers and facilitate the practical use of the conceptual framework. The tasks are structured into three categories ((i) organizational, (ii) Contracts, rules and guidelines, (iii) technical) and nine groups to ease their presentation and implementation. Those nine groups are (i) Contracts, rules and guidelines, (ii) Design approach, (iii) Requirements, (iv) Deliverables, (v) Team organisation and stakeholders' roles, (vi) Database, (vii) Checking and validation, (viii) Materials selection and market preparation, (ix) SEOL activities The SEOL activities include the definitions of its phases and the deconstruction process.

Section 6.8 offers the visualisation of the framework evolution from the theoretical drawing (based on the literature review) to the conceptual framework developed in the chapter.

7 CHAPTER 7: Guidelines for a SEOL approach in a BIM environment

7.1 Introduction

The holistic conceptual BIM-based framework was developed in Chapter six based on the analysis of the experts' interviews and the secondary data that found in the literature review. In chapter seven, supplementary analysis is developed to facilitate the implementation of the conceptual BIM-based framework. Firstly, potential BIM-uses related to the conceptual BIM-framework will be discussed and developed (section 7.2). Those BIM-uses are a guidance for implementing some aspects of the framework. Secondly, in section 7.3, the current and new BIM dimensions are investigated, then discussed how that can be useful to the conceptual BIM-framework implementation. Section 7.4 deals with the BIM models that used throughout the asset lifecycle and therefore, in the BIM-framework. Section 7.5 will give a summary of the guidelines in the format of the RIBA plan of work. Lastly, the conclusion will show in section 7.6.

7.2 Identification of the BIM uses

7.2.1 The current BIM Uses in the building industry

A BIM use can be defined as "A method of applying Building Information Modelling during a facility's lifecycle to achieve one or more specific objectives." (Kreider and Messner 2013). According to the New Zealand BIM Handbook, the BIM Use is "a unique task or procedure on a project which can benefit from the application and integration of BIM into that process" (NZIA et al. 2014). In the Penn State document, the BIM-uses are presented by identifying their purposes and objectives (Kreider and Messner 2013). The BIM Uses identification process is summarised in Figure 50, elaborated from the Penn State document.

In the literature review, several studies addressed the BIM Use topic. The BIM uses are based on the project and team goals. The "Penn State" documents have identified twenty-five BIM Uses divided into primary and secondary BIM Uses (CIC 2011). For instance, in the NZ Handbook, twenty-one BIM Uses have been identified. They are taken from the Penn State BIM Execution Planning Guide and adapted to the NZ context (NZIA et al. 2014). Twenty three BIM uses were identified in the BIM uses guide written by the Harvard University Construction Management Council (Harvard University 2012). Twelve BIM uses were identified by Kassem et al. (2014) (Kassem et al. 2014).To sort out a number of BIM Uses, Shou et al. (2015) comparatively reviewed the BIM Uses, for both the building and the infrastructure industries (Shou et al. 2015). Identified case studies, and main BIM Uses in academic publications and in industrial reports.

The aim of identifying the BIM Uses is to help for understanding the “BIM functions in different stages and the level of maturity in current practices”. Authors reported that the most common BIM Uses are 3D architecture, MEP, structure model and detail analysis. They considered the use of 4D schedule application and 5D cost planning as the next step. In parallel, they explored the BIM guidelines and standards worldwide and came with the fact that BIM is widely adopted by 10 countries. Due to the early US BIM adoption, more than half of the BIM guidelines and standards are from the United States. They have extracted from these 42 guidelines and standards, 34 BIM Uses.

Regarding to the Construction and Demolition Waste Management and Minimisation, Won and Cheng (2017) have identified the potential opportunities of BIM for C&D waste management and minimization based on an extensive literature review (Won and Cheng 2017). Authors considered eight BIM uses have an effect on C&D waste from the 23 BIM uses found in the literature. The opportunity of using BIM for the EOL phase was reported by several authors (Azhar et al. 2015, BCA 2013, Bloomberg et al. 2012).

Generally, the BIM Uses found in the literature are those that can be implemented in the planning, design, construction and Operation & Maintenance phases. There is a lack of studies proposing to identify the BIM Uses having a potential for SEOL management.

7.2.2 BIM Uses: Comparison with previous studies

For this study, the main findings from two previous review papers are used as a base. The results of Shou et al. 2015 are confronted with the results of Won and Cheng (2017). After comparison of the BIM Uses of both studies, it appears some inconsistencies. Indeed, Won and Cheng (2017) have 21 BIM Uses that match with the 24 BIM Uses listed by Shou et al. (2015), for the building lifecycle.

Among three remaining, two are inconsistent. For instance, Won and Cheng (2017) have two BIM Uses, “Facility Management” and “asset management” that are similar. For the study, four documents, compared in Table 50, has been taken as a basis for the definition of the BIM Uses (Shou et al. 2015, Won and Cheng 2017, Harvard University 2012, CIC 2011) A total of 39 BIM uses were identified by at least one document, and eight were added by the researcher based on the interviewees’ feedback (Tables 51-52).

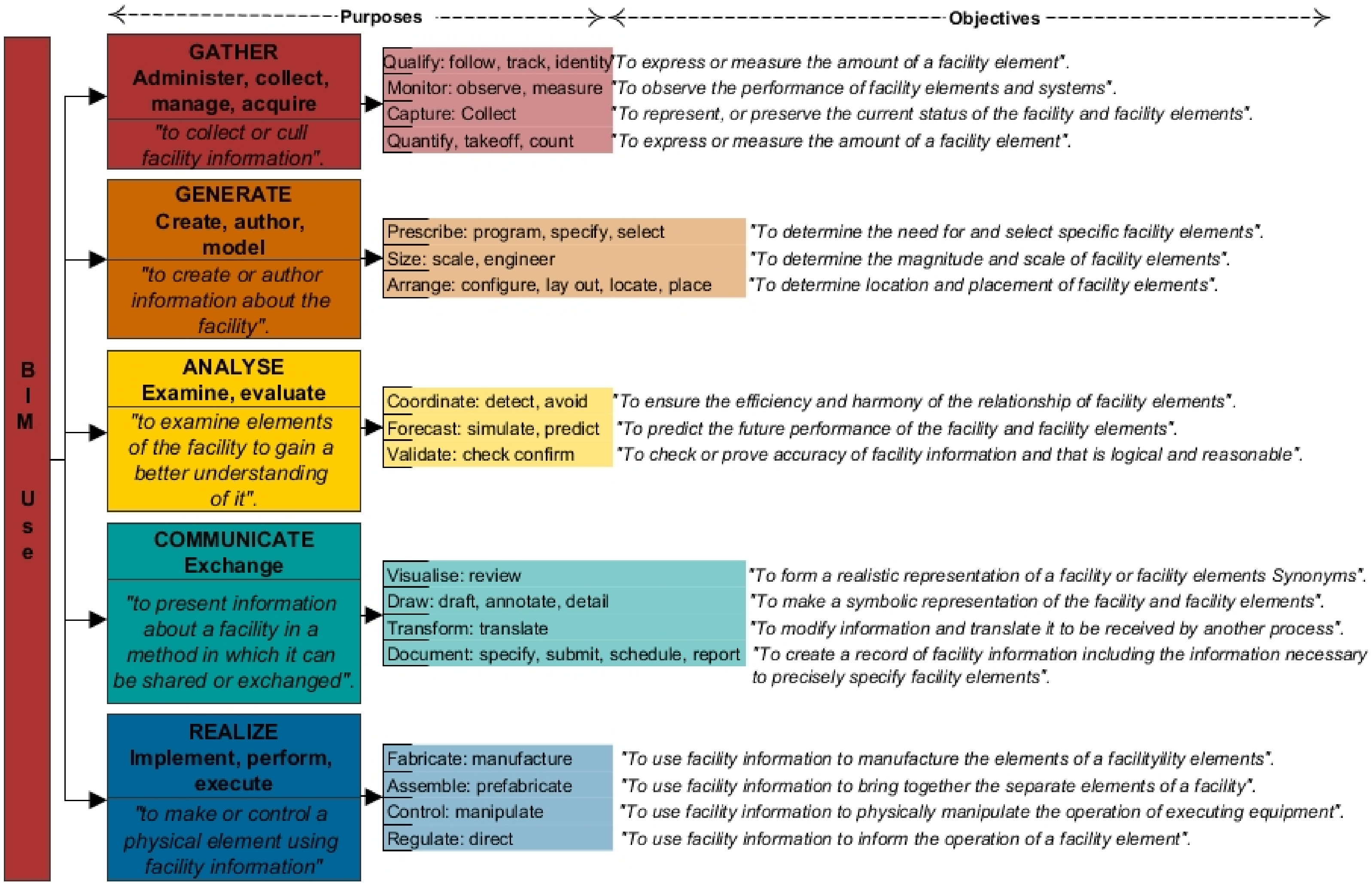


Figure 50: BIM Uses: different possible purposes and objectives (Source: based on Kreider and Messner, 2013)

7.2.3 BIM Uses exclusion reasons

A. **BIM Use appears in only one reference**

The first exclusion is because the BIM Uses are identified by only one reference and are not raised by the interviewees (table 50). They are not taken into account for the research.

Table 50: The BIM Uses not taken into account for the research (Source: Author)

BIM Uses number	BIM Uses	References				Results interviews	Materials Life cycle							Exclusion Reason
							Asset life cycle							
		CIC (2011)	Shou et al. (2015	Won & Cheng (2017)	Harvard University (2012)		Programming	Design	Construction	"In Use"	End-Of-Life	Material Recovery	Material Banks	
E-BU27	Architectural Modelling		✓					•						(1) Appears in only one reference
E-BU28	Spatial and material design models		✓					•						
E-BU29	Virtual testing and balancing		✓					•						
E-BU30	Lighting analysis		✓					•						
E-BU31	Communication of construction		✓						•					
E-BU32	Lift planning		✓						•					
E-BU33	COBie/Commissioning		✓							•				
E-BU34	As-built models		✓							•				
E-BU35	Construction Layout				✓					•				
E-BU36	Field supplements				✓					•				
E-BU37	Design documents				✓			•						
E-BU38	Facility Management			✓						•				
E-BU39	Supply chain management			✓						•				

B. **BIM Uses having no impacts on the EOL**

The second set of BIM Uses excluded are identified by the number (2) in Table 51. The reason for the exclusion is the absence of an impact on the asset EOL. For instance, E-BU23 and E-BU24 are used only on the Operation and Maintenance phase. The set engineering analysis (MEP, structural, mechanical and lighting) and sustainability take place only in the design phase for the purpose of analysing (Table 51) are excluded from this research.

C. **BIM Uses discussed by several authors**

The third reason for excluding some BIM Uses from the discussion is because this has already been discussed in several documents, whether by Won and Cheng (2017), in CIC (2011) or in Harvard University guide (2012).

Won and Cheng (2017) have undertaken research to look for the potential opportunities to use BIM in construction and demolition (C&D) waste management and minimisation (Won and Cheng 2017). Authors have come up with twenty-three BIM-Uses taken from previous studies including guides, guidelines of several countries, such as Singapore, Canada, US, Finland and Australia. Won and Cheng (2017) have identified 8 BIM-Uses over the 23 that can be used for C&D waste management and minimization: (1) Phase planning, (2) Quantity take-off, (3) Design review, (4) 3D coordination, (5) Site utilization planning, (6) 3D control and planning, (7) Digital fabrication and (8) Construction system design.

The eight BIM Uses have already been discussed by the authors and will be less discussed here than the new BIM use set up in this research. For the BIM Use E-BU02 related to "cost estimation and quantity take-off", two bullet points were added in Table 51, columns "Material Recovery" and "Material Banks". Indeed R15 stressed that as we are giving a COBie to Facility Managers to incorporate the data from the BIM Model, it is possible to use the data collected for the SEOL management in the DIM and extract a COBie destined to those who will deal with the recovered materials, whether the recycling or reuse plants managers, the landfill managers, the material banks managers, etc.)

Another set of BIM Uses excluded for discussion is those, that are discussed in the "Penn State" document (Nine in total) (CIC 2011). However, the interviewees' feedback has identified that BIM can be used for the EOL or material recovery phases. For instance, the E-BU01 "existing condition modelling" can be used for several activities such as Laser Scanning, Diagnosis before deconstruction etc. R18 reported, that knowing the whole story of the site and building is crucial before starting any project with the CE approach. In the context of SEOL or CE approaches, the "code validation" BIM Use (E-BU15) can be used for the EOL and material recovery phase.

In fact, R09, R10 and R11 stressed the importance to assess the circularity of the building throughout its entire lifecycle. In addition, R19 felt that an assessment must be done before re-launching recovered materials into the loop. Authors should tested and brought to the standards level. The BIM Use E-BU25 "Space management and tracking" can also be used during the asset EOL phase. Indeed, during the SEOL activities, having, by essence the aim of recovering materials, space management is fundamental. This BIM Use will enable the SEOL manager to track appropriate spaces and related resources within the asset. This will be very useful during a project renovation with a partial deconstruction.

Even if the BIM Use E-BU26 "Design communication" will be used for the SEOL approach, it is already discussed in the BIM uses guides from the Harvard University (Harvard University 2012).

7.2.4 BIM Uses created based on the results of the interviews

As shown in Table 51, thirty-four BIM Uses were identified by the researcher based on the 20 semi-structured Interviews about the barriers for the incorporation of the SEOL into the asset lifecycle and the improvement that suggested by the participants. The white bullet points in Table 51 refer to existing utilisation of the BIM Uses while the pink bullet points invoke an utilisation of the BIM Use extended to further phases (in use SEOL, materials recovery and bank) dedicated to the SEOL approach. The completely new BIM Uses are identified and "ticked" in red.

Table 51: BIM Use based on the literature review and interviews results (Source: Author)

BIM Uses number	BIM Uses	References: CIC (2011)	Shou et al. (2015	Won & Cheng (2017)	Harvard University (2012)	Results interviews	Materials Life cycle – Asset life cycle: Programming	Design	Construction	"In Use"	End-Of-Life	Material Recovery	Material Banks	Exclusion Reason
E-BU01	Existing conditions modelling	✓	✓	✓	✓	✓	●	●	●	●	●			(3) Discussed in CIC (2011)
E-BU02	Cost Estimation & Quantity take-off	✓	✓	✓	✓	✓	●	●	●	●	●	●	●	(3) Discussed by Won & Cheng (2017)
E-BU03	Phase planning (4D Modelling)	✓	✓	✓	✓	✓	●	●	●		●			
E-BU04	Programming (space & validation)	✓	✓	✓	✓	✓	●	●			●	●		(3) Discussed in CIC (2011)
E-BU05	Site Analysis	✓	✓	✓		✓	●	●			●			
E-BU06	Design authoring	✓	✓	✓	✓	✓		●						
E-BU07	Contruction system design	✓	✓	✓		✓		●	●		●			(3) Discussed by Won & Cheng (2017)
E-BU08	Design Reviews	✓	✓	✓	✓	✓		●	●		●			
E-BU09	Engineering analysis	✓	✓	✓	✓	✓		●						(2) No impact on the EOL
E-BU10	Structural analysis	✓	✓		✓	✓		●						
E-BU11	MEP Modelling & analysis	✓	✓		✓	✓		●						
E-BU12	Mechanical analysis	✓	✓		✓	✓		●						
E-BU13	Lighting analysis	✓	✓		✓	✓		●						
E-BU14	Sustainability (LEED.)	✓	✓	✓	✓	✓		●						
E-BU15	Code validation	✓	✓	✓	✓	✓		●			●	●		(3) Discussed in CIC (2011)
E-BU16	Building system analysis	✓	✓	✓		✓		●		●	●			
E-BU17	Digital Fabrication	✓	✓	✓	✓	✓		●	●		●			(3) Discussed by Won & Cheng (2017)
E-BU18	3D Coordination	✓	✓	✓	✓	✓		●	●		●			
E-BU19	Site utilization planning	✓	✓	✓		✓			●		●			
E-BU20	3D control and planning	✓	✓	✓		✓			●		●			
E-BU21	Disaster Planning	✓	✓	✓	✓	✓		●	●	●	●			(3) Discussed in CIC (2011)
E-BU22	Turnover/Record BIM	✓	✓	✓	✓	✓			●	●	●			
E-BU23	Asset Management	✓	✓	✓	✓	✓				●				(2) No impact on the EOL
E-BU24	Building maintenance & scheduling	✓	✓	✓		✓				●				
E-BU25	Space Management & Tracking	✓	✓	✓	✓	✓				●	●			(3) Discussed in CIC (2011)
E-BU26	Design communication		✓		✓			●						(3) Discussed in HU (2012)
N-BU01	Digital model for EOL (DIM)					✓					●			
N-BU02	Logistics planning					✓			●		●	●		
N-BU03	Material passport development					✓		●			●	●	●	
N-BU04	Project's Database					✓		●	●	●	●			
N-BU05	Data checking and update					✓		●	●	●	●	●	●	
N-BU06	Circularity assessment (8D)					✓		●	●	●	●			
N-BU07	Materials' recovery processes					✓	●	●			●	●		
N-BU08	Materials' Bank					✓	●	●			●	●	●	

● (pink)	New BIM uses
●	Existing BIM uses: can be used for the SEOL management
✓ (red)	BIM uses identified only by Interviewees
✓ (green)	BIM uses identified by the interviewees and Won and Cheng (2017 for their potential use for C&D waste management and minimization
✓ (blue)	BIM uses also identified by Interviewees: potential use for a SEOL management
✓ (cream)	BIM uses identified by the interviewees as having a potential use for the SEOL
✓ (grey)	BIM uses that can be used for C&D waste Management and Minimization, according to Won and Cheng (2017)
(red)	BIM uses purpose "Gather"
(orange)	BIM uses purpose "Generate"
(yellow)	BIM uses purpose "Analyse"
(green)	BIM uses purpose "Communicate"
(blue)	BIM uses purpose "Realise"

They are Digital mock-up for EOL, Logistics planning, Material passport development, Project database, Data checking (updated technologically), Circularity assessment, Materials' recovery and Materials' Bank, as shown in Table 51. The BIM Uses colours refer to their purpose, explained in Figure 50 based on the "Penn State" document (CIC 2011).

A. Digital mock-up for EOL (DIM): BIM Use N-BU01

At the end of the use of the asset, the client will recover a Digital "as-maintained" Record containing all the asset history. In the case of deconstruction of a part of the asset for refurbishment or the deconstruction of the entire building, the client has the data for the SEOL stage implementation. De "D" of the DIM stands for Deconstruction-Disassembly-Demountabie-Decommissioning. So the D-Information Model (DIM) will be used for implementing the SEOL activities.

During the SEOL process (whatever deconstruction or disassembly), the DIM will be used to check and test if the Deconstruction strategy is planned or done according to the Employer Information Requirements. In fact, the EOL engineers can extract the data regarding all components constituting the asset, and among others, their capability to be reused or recycled. As recommended by respondent R14, the stakeholders must "think data" rather than "models".

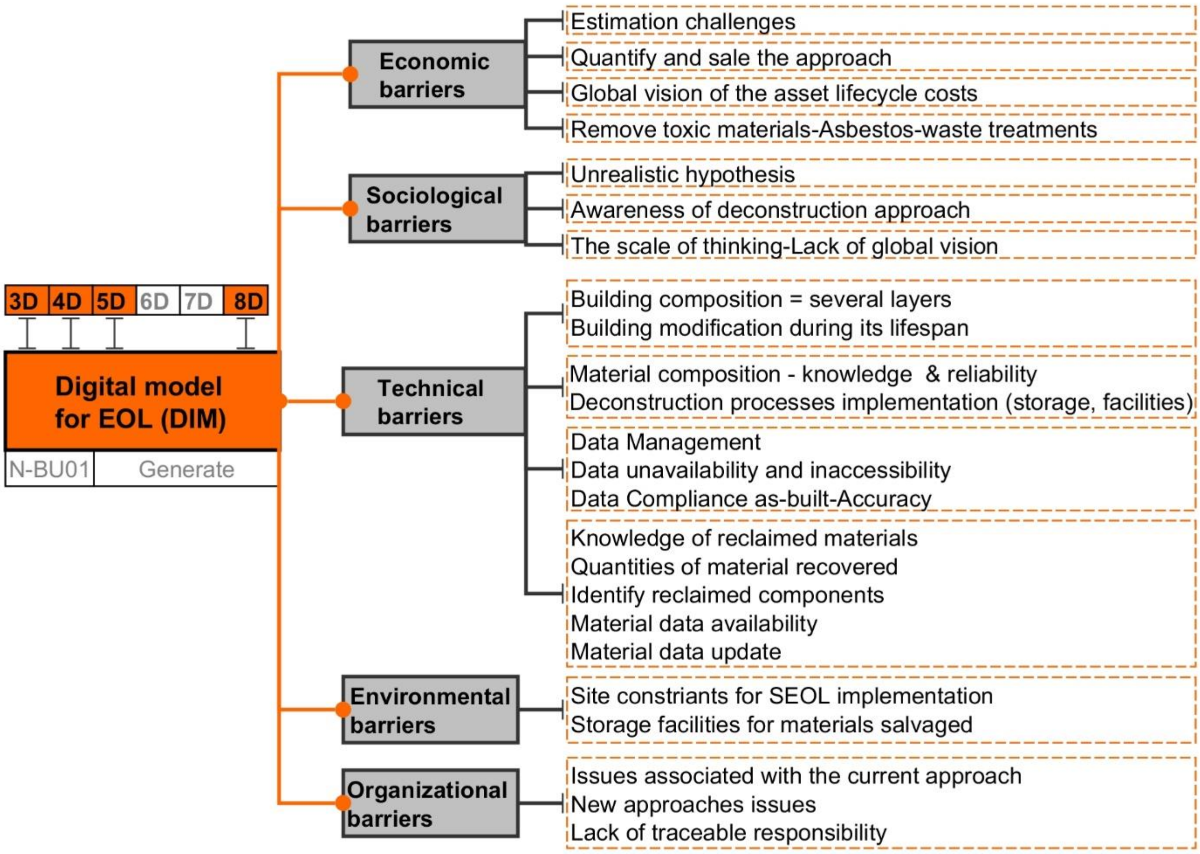


Figure 51: BIM Use N-BU01 to overcome barriers for the adoption of a SEOL approach (Source: Author)

The DIM can be seen as a Model View Definition, a filter enabling to gather the data available in the database relevant for the EOL activities. It can be graphical data and non -graphical data. As seen in Chapter 6, subsection D, the database will contain all the information generated during the asset lifecycle.

The BIM Use "N-BU01" will help to overcome some barriers raised by the participants, summarized in Figure 51. N-BU01 is a 3D Digital model that can be associated with 4D (Schedule), 5D (Cost) dimensions and the 8D (SEOL). These BIM dimensions are discussed deeply, in the sub-section 7.3.

B. Material passport development: BIM Use N-BU03

As seen aforementioned, the creation of a special SEOL model or MVD is crucial. In parallel, respondent R18 has stressed the necessity to develop materials' passports for the CE approach. He highlighted that the importance to know, what exists on the site before start any project. Based on an ongoing project where it kept 60% of the raw materials of the existing building, they developed materials' passports to define what exists, what is removed, and what will be added. The data collected helped them to assess which scenario was better from different levels: carbon footprint, transport, local workforce. Without the materials' passports, they would not have been able to take the right decision. The CE for the built environment is still in its infancy. But some authors started to investigate the area (Honic et al. 2019a, Akanbi et al. 2019, Debacker et al. 2017, Tebbatt et al. 2017, UK GBC 2019, Merrild et al. 2016).

According to Honic at al. (2011) the material passport aims to support the Circular Economy approach (Honic et al. 2019b). The EU-funded project BAMB aims to implement the CE approach in the AEC industry by using Material Passports (BAMB2020 2018). In the BAMB project, the Materials' Passports are defined as "digital sets of data describing defined characteristics of materials and components in products and systems that give value for present use, recovery, and reuse"(Mulhall, Douglas et al. 2017) and considered as a tool leading to get information about the circularity of products. The Materials Passports use the product composition breakdown: systems, products, sub-components and ingredients. It was stressed by several interviewees that not knowing the materials' composition is a crucial barrier. The use of the Materials Passports integrated into BIM can help to overcome the barrier. It was highlighted in the final project's deliverable that the Material Passport Platform developed during the project "is BIM enabled but not dependent" (Mulhall, Douglas et al. 2017).

According to Honic et al (2019), it is crucial to know the materials' composition of buildings. Therefore, the material passport is able to detail information about qualitative and quantitative material composition. It can then be used as a design support tool (Honic et al. 2019a). For this study, the BIM Use N-BU03 will enable to overcome several barriers listed in Figure 52. The Materials' Passports will enrich the 3D BIM model and the other dimensions (from 4D to 8D).

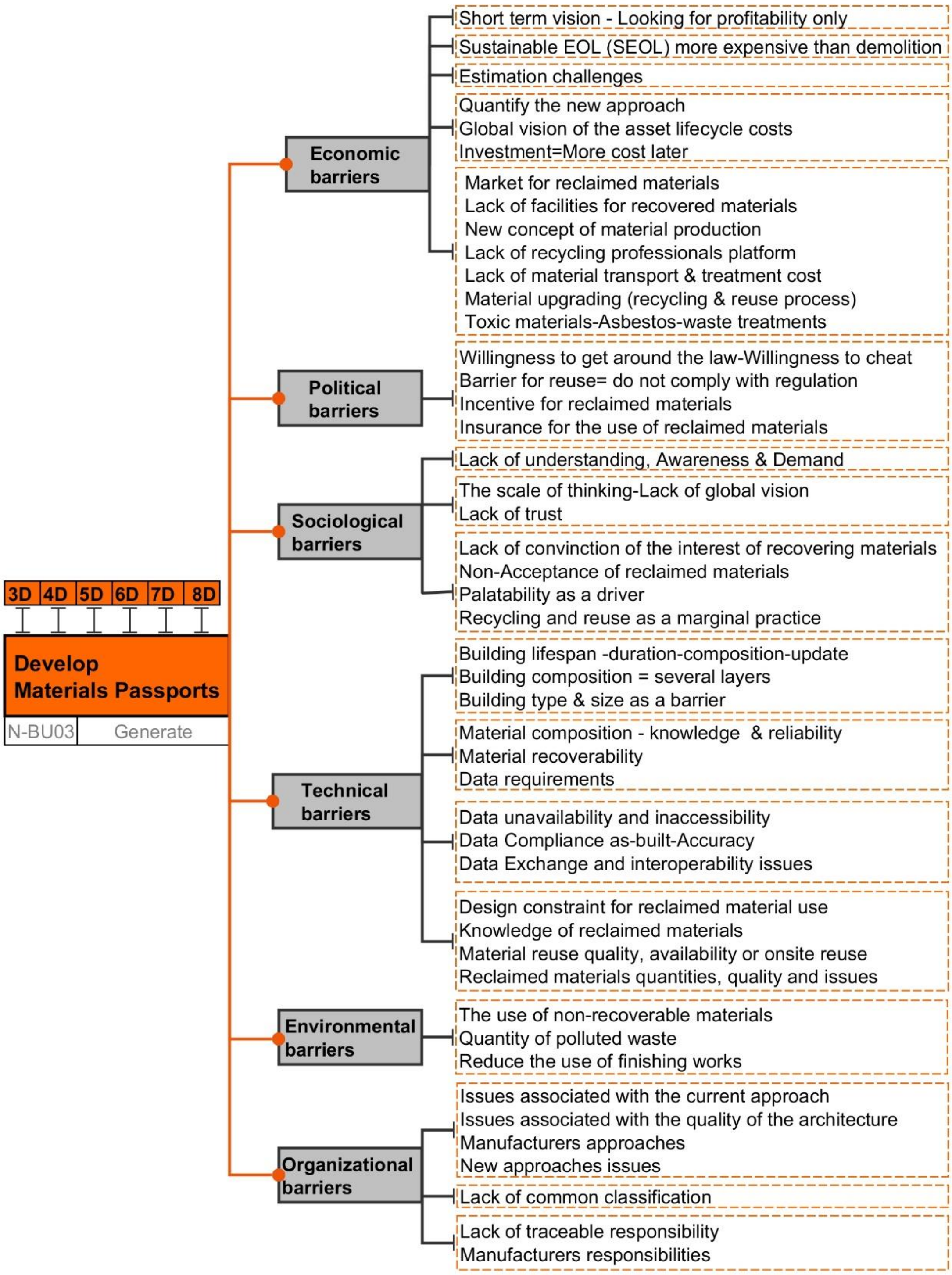


Figure 52: BIM Use N-BU03 to overcome barriers for the adoption of a SEOL approach (Source: Author)

C. **Project database: BIM Use N-BU04**

The project database is the second BIM Uses raised by respondents as a manner to solve a range of barriers. R20 a residential building client already uses for his project collaborative projects' platforms. R14, a BIM Manager, also reported the importance of using a collaborative platform for the projects they are involved in, as Assistant to the Contracting Authority (ACA).

R15 also uses for his project a collaborative platform, the CDE. The respondent stressed that each entity has his own CDE, the design team, the Facility Management team, the Structural engineer team, and so on. The researcher has proposed the cloud databases summarized in Figure 38 section 43-F, summarising. The cloud computing was addressed by Underwood and Isikdag (2011) reporting that the construction industry is moving towards cloud computing including software as a service (SaaS), platform as a service (PaaS) and infrastructure as a service (IaaS). According to them, the construction industry can benefit from cloud computing by putting all the project information backbone in a virtual data centre, offered as a service (Underwood and Isikdag 2011). Cloud technologies are usually chosen due to their high-performance capabilities (uptime), accessibility, and scalable storage capacities (Alreshidi et al. 2018). For this research, the projects' databases will help to overcome some sociological, technical and organizational barriers (Figure 53). The database will also contain all the data related to the project, including the various BIM model developed during the asset lifecycle from its inception to its EOL management (3D to 8D).

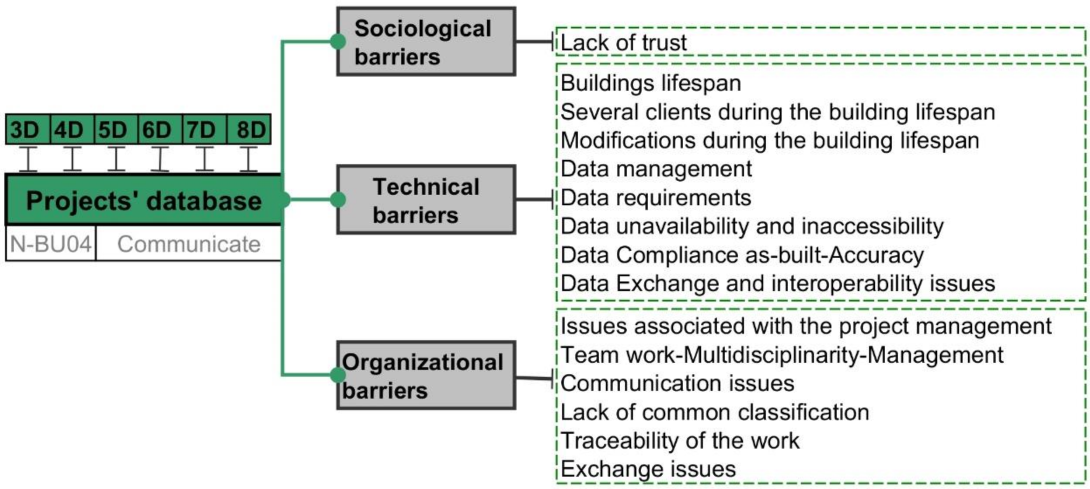


Figure 53: BIM Use N-BU04 to overcome barriers for the adoption of a SEOL approach (Source: Author)

D. Materials' Bank: BIM Use N-BU08

The materials' banks are declined in two types: for the reclaimed materials and for the new materials. They are web-based collaborative platforms for materials. Both can be linked and used by the design team as a database for the prescription of projects' material. The new material bank will be alimented by manufacturers and will be provided via this platform all the BIM compliant data related to their products. R20 reported that when they have to deconstruct buildings, they work with start-ups dealing with construction recovered materials. They are involved at the beginning of the project to assist the client for the SEOL activities. Their roles and responsibilities are to avoid waste as much as possible. They propose various strategies for the asset components they have identified. They also manage virtually and in reality, the materials finding storage possibilities. They have a web site containing all the reclaimed components and the description of their characteristics available online (Cycle Up n.d.).

According to R20, the materials are stored on-site or on another project site, not too far to be reused for the new building. In line with that concept, Grilo and Jardim-Goncalves (2013) have presented the Cloud-Marketplace concept to create interoperable communities of e-platforms (Grilo and Jardim-Goncalves 2013). Digital (or sometimes physical) platforms for re-use for building materials have begun to flourish. But it's a good start but not enough to change the sector. As pointed out by several respondents, the lack of structure and reclaimed and recycling plants, lack of training and the data dispersion must be tackled to see the sector of reclaimed materials grows more speedily. An open and collaborative database was developed by "Future of Waste" (Future of waste n.d.).

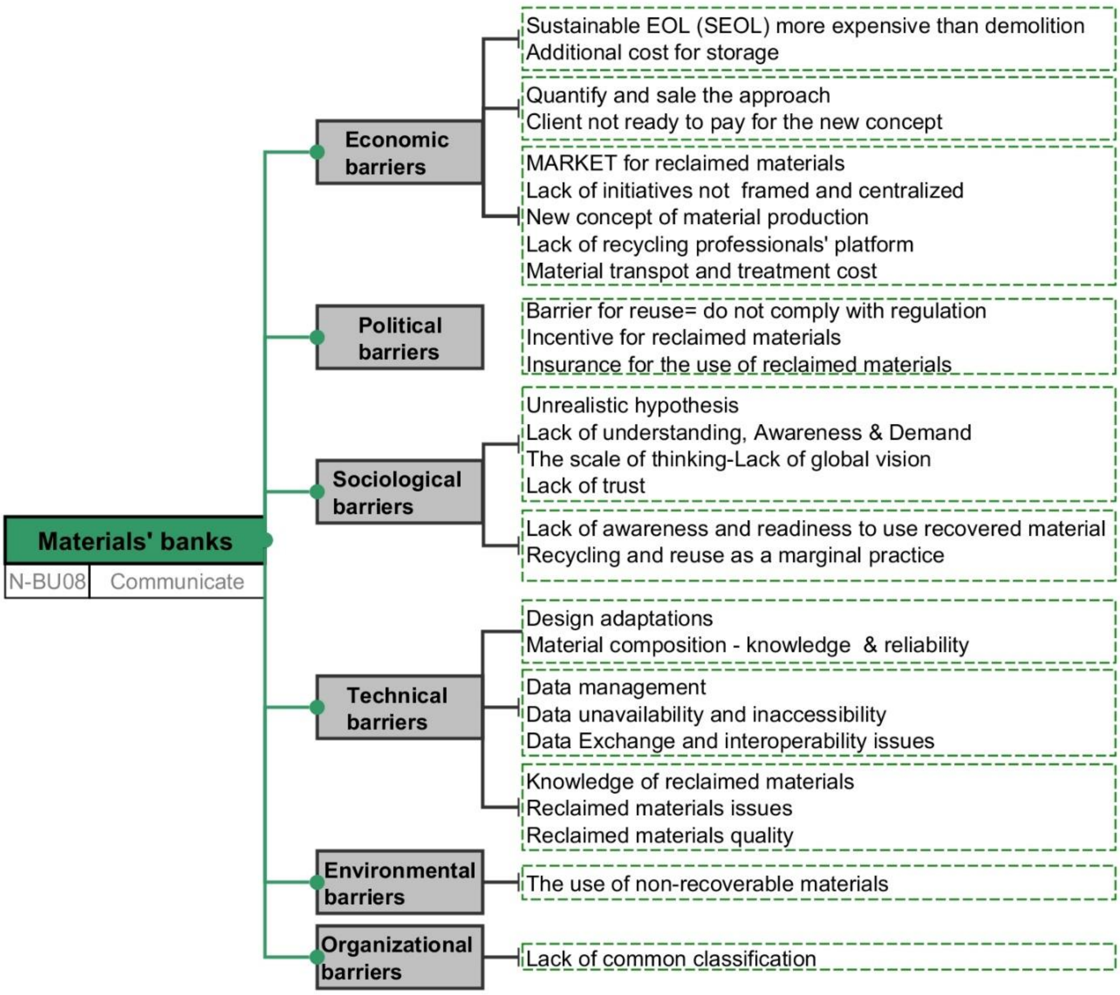


Figure 54: BIM Use N-BU08 to overcome barriers for the adoption of a SEOL approach (Source: Author)

Grilo and Jardim-Goncalves (2013) have defined the e-marketplace as a “virtual space in an electronic network, an inter-organizational information system that allows the participating buyers and sellers to exchange information about prices, product offerings, and an Internet-based electronic commerce platform that matches multiple buyers and suppliers in transactions along with traditional project-based collaborative functions”. The material banks presented for the research is a similar concept.

The advantages seen by the respondents were to be able to locate and quantify the reclaimed materials. R20, a client and several architects (R06, R07, R09 and R16) expressed the lack of awareness, quantity, quality and data of the recovered materials are a crucial barrier. R09 reported that sometimes, they need to adapt their design to the reclaimed components, for instance, windows. Having a material bank accessible will help to overcome the barriers raised by the interviewees regarding the lack of data on the reclaimed components.

> *“You also have to know what you have in hand, in **terms of quality**. This is where the almost chemical aspect is important.”*
>
> Circular Economy strategist and Architect, R18

In a SEOL or CE approach, having Materials’ banks will help to remove some barriers stressed by the interviewees (Figure 54). This was also supported by the EU-funded project BAMB (Buildings as materials banks) where materials passport platform was developed for the purpose to implement the CE approach in the AEC industry (BAMB2020 2018).

E. Data validity and update checking: BIM Use N-BU05

In a context of materials’ banks, the accuracy and availability of the data seem crucial. It was highlighted by several respondents (R14, R16, R10 and R13, among others). According to Eastman et al. (2011), the use of BIM technology leads to having an accurate virtual 3D Model containing precise data needed by the construction, fabrication, and procurement activities (Eastman et al. 2011). The accuracy and completeness of the data were also stressed by Whyte et al (2010), especially for hand-over stage. Authors also raised the concern about the updating of the data in use (Whyte et al. 2010).

In the case of the use of BIM throughout the entire asset lifecycle (Ustinovichius et al. 2017), the accuracy of the data appears as fundamental (Lavy and Jawadekar 2014). The checking process is central and should be done at different stage rigorously to ensure good quality and accuracy of the data. This aspect was the core of Du et al. (2014) study proposing cloud-based BIM performance benchmarking application (BIMCS) that include the data accuracy checking (Du et al. 2014). The interoperability issue was reported by several authors and is still a high concern (Mazza et al. 2015, Afsari et al. 2017, Prada-Hernandez et al. 2015, Boyd 2013). Hjelseth (2016) proposed a framework classifying the BIM-based model checking (BMC) concepts. The author has identified 2 types of BMC, compliance and design solution checking (Hjelseth 2016).

Another issue raised by R16 and R14 was to be able to update the data technologically. Indeed, technologies evolve rapidly and continuously leading to the need to update the data andkeep it accessible. Several studies have tackled the issue through the use of RFID (Radio Frequency Identification) technology to enable the accessibility of the data. For instance, Motamedi and Hammad (2009) proposed to use RFID tags attached to asset components to make the data accessible to a range of players even if they do not have access to a central database (Motamedi and Hammad 2009).

In consonance with the previous authors, Iacovidou et al. (2018) suggested using the (RFID) for tracking and archiving the properties of structural construction components. This could be a solution to make the data not depending on its vendor format (Iacovidou et al. 2018). However, R13 stressed the difficulty to recycle materials with RFID. The BIM Use N-BU05 will enable to overcome a range of barriers listed in Figure 55. The data validity and update checking must be done throughout the asset lifecycle. Actors responsible for those activities must be clearly and contractually identified during all asset phases.

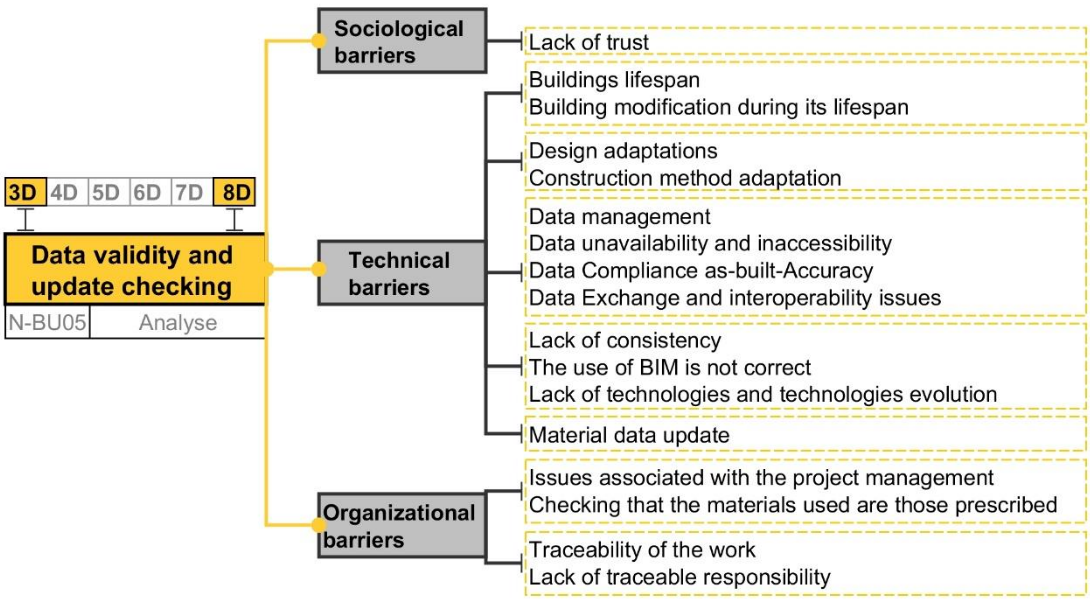


Figure 55: BIM Use N-BU05 to overcome barriers for the adoption of a SEOL approach (Source: Author)

F. **Logistics planning: BIM Use N-BU02**

The logistics planning was raised by multiple respondents, R04, R10, R15, R20 and R17. Indeed, a specific BIM Use, the N-BU02 can be allocated to these activities. R04 and R20, for instance, reported the issue encountered for their projects. The storage of recovered material in the case of reuse or recycling of some reclaimed materials onsite was determinant for the duration of the overall project. R09 reported that he was dependent on the exact quantities and dimension of the recovered windows that he wants to include in his project. The architect was not able to perform his design without this data.

This BIM-use will help to tackle the recovered materials management, including compulsory processes such as materials storing, transporting and processing to make them reusable (Yudin 2010, Simon 2007). These processes were identified by several authors as a real concern (Guequierre et al. 1999, Gorgolewski 2008, Won and Cheng 2017). Figure 56 reports the barriers that the use of BIM for Logistics planning can overcome. The 3D model can be associated with the 4D, 5D and 8D dimensions.

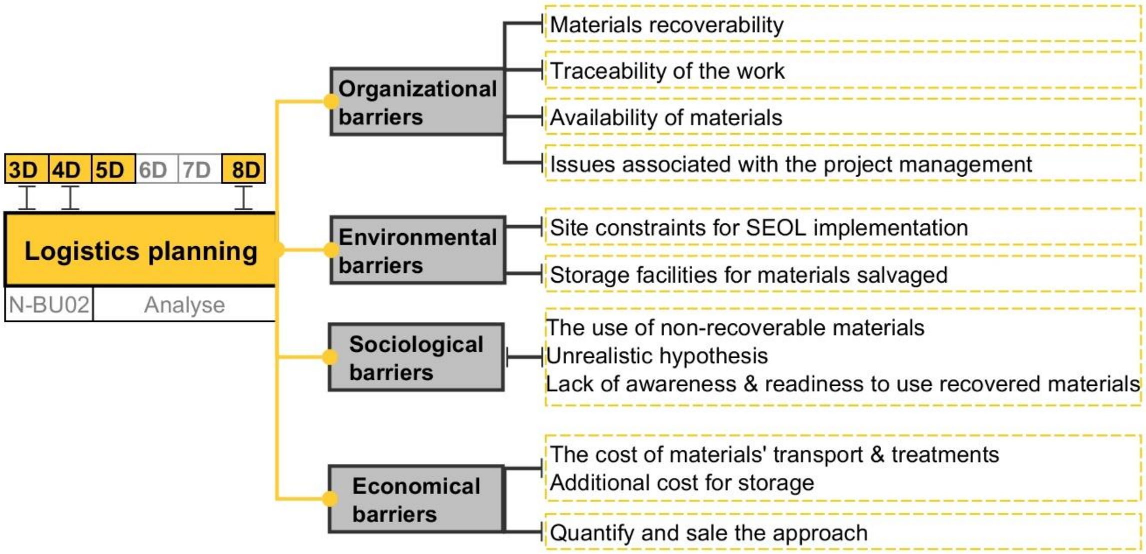


Figure 56: BIM Use N-BU02 to overcome barriers for the adoption of a SEOL approach (Source: Author

G. Circularity assessment: BIM Use N-BU06

The need for assessing the circularity of buildings in a SEOL or CE approach was stressed by many interviewees (R01, R10, R11, R14, R15, R18 and R20). A specific BIM Use is allocated to this activity. The use of BIM will be beneficial for the assessment of the circularity due to the data embodied into the 3D Model. Besides, the 8D Model will contain EOL activities linked with the 3D model and will enable to simulate EOL scenarios. When a more sustainable EOL scenario is being sought, the N-BU06 will be supportive for decision-making.

The need for assessing the circularity of a building was also brought by a few studies (Pomponi and Moncaster 2017, Luscuere, L. et al. 2019, Elia et al. 2017). In fact, Elia et al. (2017) have conducted a critical analysis of strategies for measuring circularity. Authors reported a lack of research on circularity assessment. They critically analysed and compared the current environmental methodologies used for measuring the level of application of CE to companies, products or services (Elia et al. 2017). Ellen McArthur Foundation has also undertaken studies to set up Circularity Indicators for products (McArthur 2015), followed by several authors (Saidani et al. 2017, 2019). In 2016, Verberne (2016) had developed Building Circularity Indicators to assess circularity performance in the building industry (Verberne 2016). The author reported that the potential of linking circularity assessment with the Building Information Model. He has developed four types of indicators (1) Technical indicators, (2) Functional indicators, (3) perception indicators, and (4) Economic indicators. The research area is still in its infancy, and more research is needed for the built environment specifically.

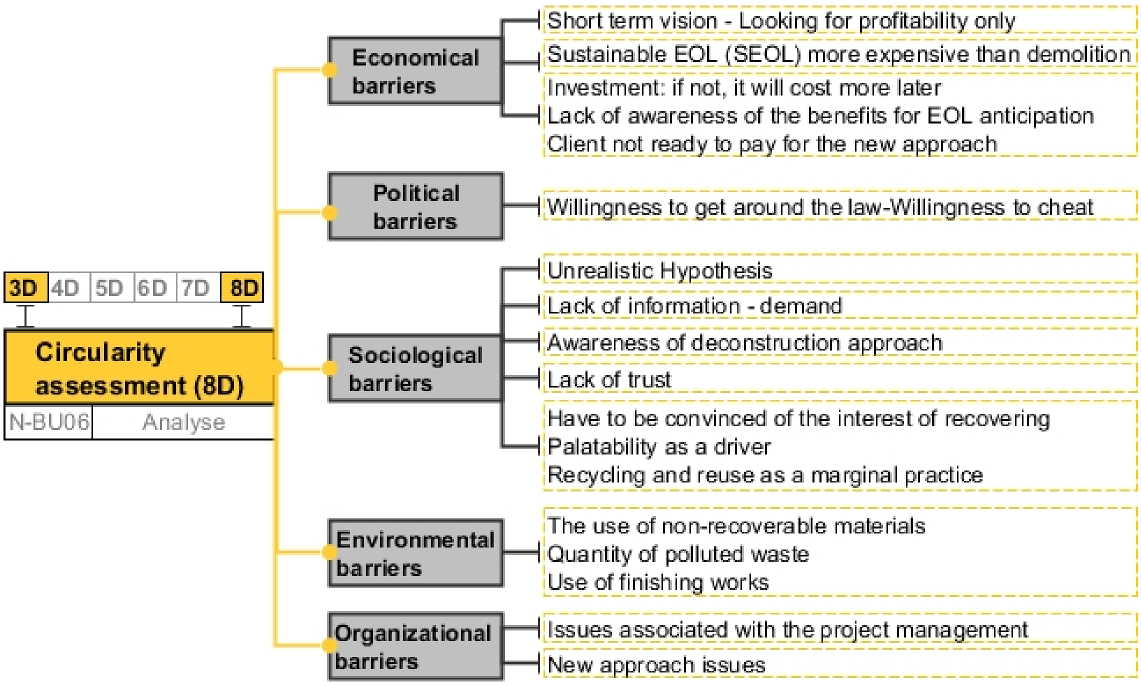


Figure 57: The BIM Use N-BU06 to overcome barriers for the adoption of a SEOL approach (Source: Author)

The BIM Use dedicated to the circularity assessment will have a positive impact on several barriers raised by the 20 interviewees. They are listed in Figure 57.

H. Materials' recovery: link with the recovery plants and landfill: BIM Use N-BU07

To be able to move from the linear to a circular approach, the recovery of materials must be sought. According to many respondents, plants and infrastructure for materials recovery are lacking (R10, R17, R19 and R20). By switching from the demolition to deconstruction, the amount of reclaimed materials will increase. Therefore, materials recovery infrastructure to support the SEOL approach must be developed. As mentioned by respondent R14, “we need to think “data and not models”. After the completion of the SEOL, the client will inherit a set of data embedded in the 8D model containing all the data used for the SEOL management in the form of, data sheets, model (8D) and materials’ passports, among others. Like the construction stage, the deconstruction or disassembly phase will be handed over the project with a Digital Record "As deconstructed".

The data collected in several forms can be used by the recovery facilities. The BIM Use N-BU07 Materials recovery processes are suggested even if the use of the BIM Model by the recycling and reuse facilities is not relevant today. As R14 pointed out, "…we could make the Building Information Model (BIM) without a model. That's what Americans do with COBie. So, you really need to think about structuring the data…” The BIM Use N-BU07 will enable to transfer the data from the SEOL phase to the materials recovery phase, through COBie and materials’ passport. Recovering facilities will also feed the Recovered Materials’ Bank in the same manner.

This is already the way data is exchanged to enable Facility Managers to use the data collected through the projects via BIM. It was reported by respondent R15 as a good way to use structured data. The benefits of using COBie is also largely highlighted, in the literature review, by many authors (Lavy and Jawadekar 2014, Anderson et al. 2012). Figure 58 shows the barriers reported by the respondents that could be overcome with the BIM Use N-BU07.

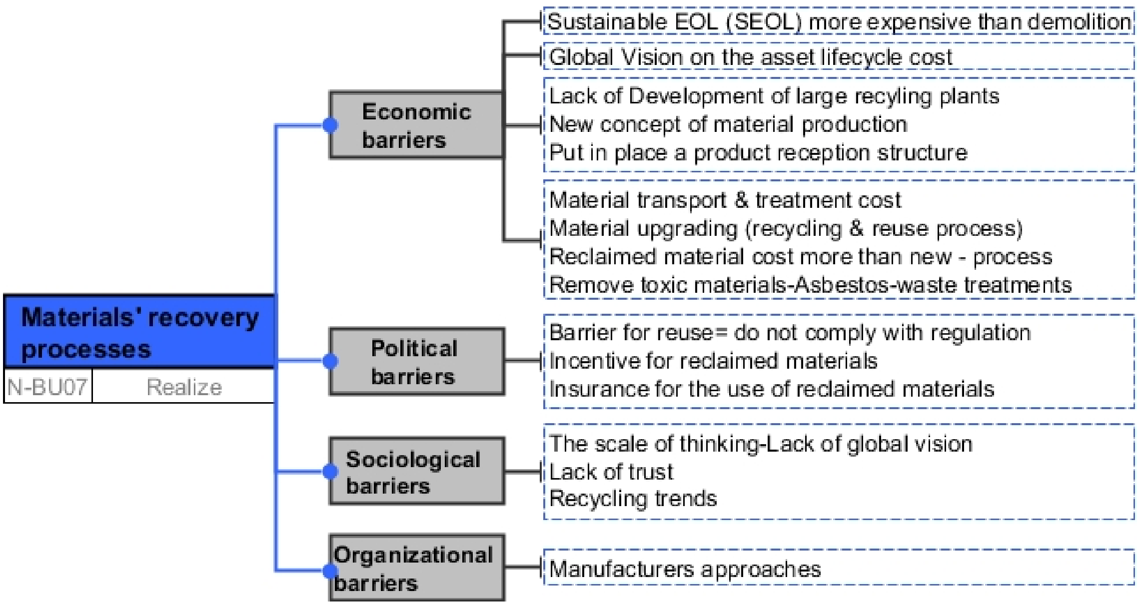


Figure 58: BIM Use N-BU07 to overcome barriers for the adoption of a SEOL approach (Source: Author)

As presented in the “Penn State” document for the existing BIM Uses, the BIM Uses for a SEOL approach were explored, and eight new BIM uses were identified. The researcher has illustrated what barriers raised by the interviewees can be overcome with the new proposed BIM Uses. Figure 59 is a summary of the connection between the new identified BIM uses and the barriers discussed in Chapter 5.

The “Penn State” document, also recommends setting process mappings for supporting the BIM implementation for each BIM Uses. Then, the project BIM deliverables, based on the BIM Use, must also clearly be defined (CIC 2011). Due to the time scale, the processes will not be set up in this thesis but could be areas that the researcher can explore further in the future.

In the following sub-section, the various BIM dimensions are explained, and the eighth dimension related to EOL activities is discussed.

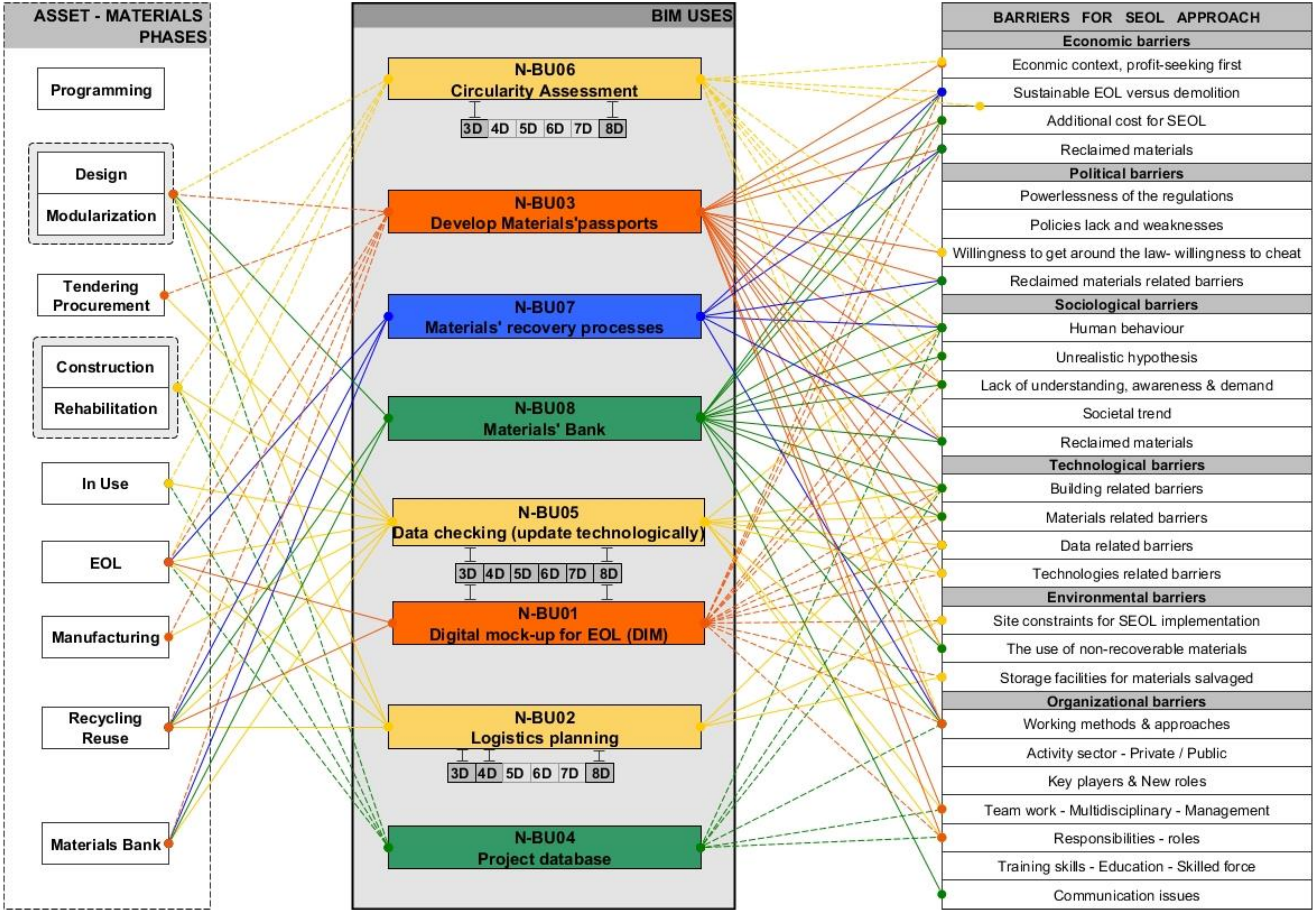


Figure 59: BIM Uses and related barriers (Source: Author)

7.3 Several BIM dimensions

7.3.1 BIM dimensions: A lack of clarity

The authors have conducted a study to assess the level of clarity or confusion on what the numbers of dimension refer to after the 3rd dimension (Charef et al. 2018). Three objectives were set up to achieve this aim. The two first objectives were to investigate what activities are most commonly referred to, like the 4th, 5th and above dimensions in BIM according to academics and practitioners. Then academics and practitioners' views have been were compared to highlight where consensuses are, and where the confusion exists. A systematic review was conducted to collect the academics state of the art, and an online survey enabled to figure out the practitioners' point of views (subsection 2.2.2 and Appendix 2).

Table 52 presents a comparison with the systematic literature review. Therefore, the confusion depicted in the systematic review for 6D and 7D is not in agreement with the results of the questionnaire which shows that in the EU, the attribution of the 6D, respectively 7D is more clearly attributed to sustainability, respectively Facility Management.

Table 52: Comparison between Academics and Practitioners for the BIM dimensions (Source: Author)

<table>
<tr><th>Dimensions</th><th>Systematic literature review</th><th>Practitioners</th><th>Practitioners using the selected Dimensions</th></tr>
<tr><td>4D</td><td>Consensus on Time</td><td>86% Time</td><td>83% Time</td></tr>
<tr><td>5D</td><td>Consensus on Cost</td><td>84% Cost</td><td>88% Cost</td></tr>
<tr><td rowspan="5">6D</td><td>2 papers assigning FM</td><td rowspan="3">28% FM</td><td rowspan="3">14% FM</td></tr>
<tr><td>1 paper assigning Safety</td></tr>
<tr><td>1 paper assigning Resource</td></tr>
<tr><td>1 paper assigning Project Lifecycle Information</td><td rowspan="2">68% Sustainability</td><td rowspan="2">86% Sustainability</td></tr>
<tr><td>3 papers assigning Sustainability</td></tr>
<tr><td rowspan="2">7D</td><td rowspan="2">1 paper assigning Sustainability</td><td>18% Sustainability</td><td>18% Sustainability</td></tr>
<tr><td>56% FM</td><td>85% FM</td></tr>
</table>

The results showed a clear agreement on what the 4th and 5th dimensions refer to. Academics and practitioners agreed that in a BIM environment, the 4D is related to time (or planning or scheduling) and the 5D to cost. The systematic review and the online survey conducted across the 28 European countries raised up discrepancies for the 6D and 7D, related to Sustainability, Facility Management or Safety. Indeed, the practitioners actually using these dimensions usually refer to Sustainability for the 6D (86%) and Facility Management activities for the 7D (by 85%).

This lack of clarity on BIM dimensions beyond the 5th dimension leads to the risk to lose the benefits brought by these extra BIM dimensions. In fact, the industry has seen excellent gains regarding the 4th and 5th dimensions mainly because there is a broad agreement on what these "n" dimensions refer to. So as to gain clarity for the 6th and 7th BIM dimension, professional bodies should take the lead to give a consistent approach to professionals by designing appropriate standards. Without that, BIM wouldn't be able to achieve anything tangible in terms of safety, sustainability and all other activities that have been tried attached to BIM.

7.3.2 A dimension for the SEOL management

Moreover, the potential of BIM could be expanded, as a dimension, to new activities not yet found in the literature. For example, the willingness to take advantages of the data embodied in the 3D model also exists in the area of construction and demolition waste issues. The EOL Dimension would contain data related to demolition or deconstruction activities and could be an area for future research.

A. 8D BIM advantages

The 8D BIM refers to an additional dimension of data that can be used to support decision-making for component selection during the design process, but also to facilitate the deconstruction process, once the asset cannot be used anymore.

At the design stage, 8D information will enable the design team to simulate the cost of the deconstruction and the deconstruction itself. Various scenarios with different component could be examined to maximise the rate of material reusability, recyclability and those that need to be sent to the landfill, and thus increase the "circularity" rate of the asset at the end of its life (Figure 60). The 8D will help designers to control the environmental impact of buildings throughout the lifecycle, including the EOL of the building.

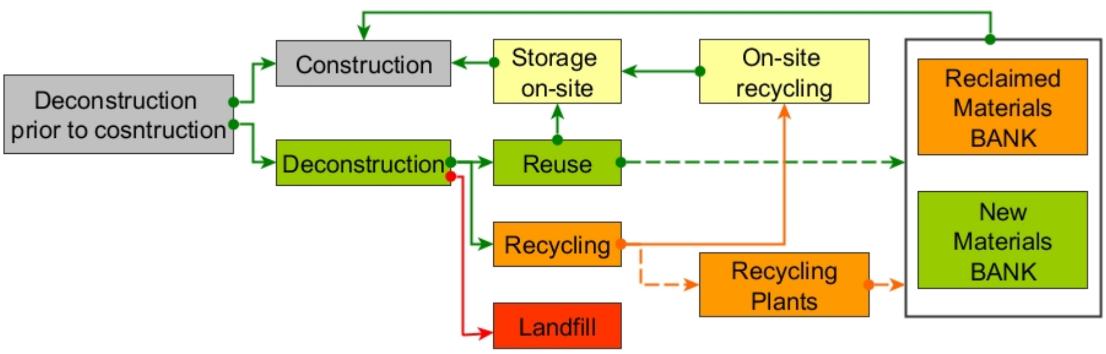


Figure 60: The various scenarios for a construction project with prior deconstruction (Source: Author)

At the end of the asset lifecycle, the owner will inherit a model, the Deconstruction Information Model (DIM) that will contain the entire lifecycle traceability of the building (including asset refurbishment), component data, deconstruction processes and the fate reserved for each component, whether it be reuse, recycling or sent to landfill. The demolisher managers will use the DIM, a digital model that will provide them with a set of data to enable them to control better and manage their tasks. The 8D should facilitate the Site Waste Management Plan, waste sorting, waste analysis and components classification, quantity extractions, pre-deconstruction audit and scenario analysis. It would help to plan the activities completely and simulate virtually the process set up to avoid all unexpected events and cost. The 8D BIM is linked with other established BIM dimensions, discussed previously, such as 4D and 5D. In fact, through the 8D model, the EOL of the asset can be simulated according to time and cost. With data linked to each building component, the deconstruction cost will be determined easily. The use of the 8D will be beneficial for demolisher contractors that could deliver a better and safe deconstruction.

The easy access to building components information, their quantities and specific requirement for their dismantlement, recycling and dispose of will enable demolishers to plan, control the dismantlement and the management of the materials from deconstruction. This will help them to decrease demolition waste and avoid raw material depletion as well as controlling their respective environmental impacts. It is much more practical than the unorganised folders that are traditionally given to EOL managers.

B. 8D BIM content

The 8D BIM would contain data related to demolition or deconstruction activities. Each component of the asset would contain information needed by End-of-Life managers to enable them to conduct the deconstruction appropriately and efficiently. The data would include details about the components, their history, such as when they were installed, replaced, the necessary precaution to adopt during the deconstruction, and how to recycle, reuse them. The Facility Manager will update the model containing all this information during the asset exploitation.

7.4 Several BIM models

Three models will be generated throughout the asset lifecycle: First, the Project Information Model (PIM), developed during the design and construction phases, is given to the Owner during the handover stage. Secondly, the Asset Information Model (AIM), which is the Model containing information for the Operation & Maintenance phase is updated by the Facility Managers until the EOL of the asset. Lastly, the Deconstruction-Disassembly-Demountability-Decommissioning. (DIM) will be used for the asset EOL management. The tree models are discussed in the following subsections.

7.4.1 The Project Information Model (PIM)

Considering the information Delivery Cycle (British Standards Institution 2013), the Model of a new building is developed throughout the design process, the PIM (project information model), responding to the client requirements mentioned in the Employers Information Requirements (EIR) and agreed contractually when the project starts. The PIM, as depicted in Chapter 4, is the first model that will be generated increasingly during the design and construction phase to be delivered to the Employer in the Handover stage.

The crucial aspect is the accuracy of the data. For that, the PIM content is checked several times, as mentioned in the Information Delivery Cycle adapted by the author for EOL incorporation (see Figure 24 in Chapter 4, section 4.3.1)(British Standards Institution 2013).

The PIM will contain a set of federated building information models, graphical and non-graphical data covering the design and construction phases and provided by stakeholders involved in the project. This Model is created using different discipline software combined in one federated model. The design team usually has the responsibility for the PIM until the handover stage. This Model will also be used in the construction stage. At the end of the construction, the PIM is updated to be “As Constructed” or “As-Built”, representing the project in content and dimensional accuracy. The Digital “As Built” Record contains construction and fabrication information, the manufacturer's maintenance and operation documentation, commissioning records, Health and Safety requirements of all aspects of the project and the final COBie information exchange. Because BIM implementation is quite costly, it is preferable to use it throughout the entire lifecycle.

7.4.2 The Asset Information Model (AIM)

In that case, the PIM will generate the Asset Information Model (AIM) needed by the Facility Managers (FMs) for the Building Operation & Maintenance. It contains all the data and geometry describing the asset. The purpose of the AIM is to document the asset "as-maintained" by FMs and to be compliant with buildings’ components updated throughout the facility lifecycle.

The Asset Information Model will “*support the whole life of an asset from creating/acquire, through use/maintain and on to renew/dispose*”(Manning 2014). In the UK, at BIM Level 2, the AIM aims to be a federated Model “consisting of a number of discrete parts. The extent and nature of these parts shall be related to the complexity, purpose and scale of the asset” (British Standards Institution 2014). The AIM should be the single source of approved and validated information. It contains all the data and geometry describing the asset. The requirements of the data that the AIM needs to contain are multiple. In fact, it should include all information concerning the design stage, brief and the design intent and more specific information relating to the facilities for the construction and maintenance stages. The type of data that is required is the performance of the asset, Operation and Maintenance manuals, health and safety information and specifications. As mentioned by (Navendren et al. 2015), the data incorporated in the AIM makes it crucial for the Facility Manager. It is like the ID card of the asset that must be kept up to date indicating all asset transformations, changes and replacements occurring during its lifecycle. The property rights related to the asset are also critical information that should be in the AIM. This data can be stored within the Model or linked to an existing information system.

7.4.3 The Deconstruction Information Model (DIM)

At the End-of-Life of the building, the researcher suggested that the AIM correctly updated by FMs is given to the EOL contractors for tailoring it for the asset EOL management according to the Owner requirements. It would become the Deconstruction Information Model (DIM) and would be given to the Owner when the EOL Management is completed. During the Deconstruction process, the DIM would be used to check and test if the Deconstruction strategy is planned or made according to the Employer Information Requirements.

This model would be enriched with the Demolition, Deconstruction or Dismantling strategies which may also be done alongside other scenarios. The model will enable to know what the building's composition are and to extract quantities correctly. In fact, the demolition contractors can extract the data regarding all components constituting the asset, and among others, their capability to be reused or recycled. The model could also contain links with specification information associated with each building element. Data related to performance level as structural loads and strength, the chemical composition of materials, etc.

Because no dimension is currently allocated to the End-of-Life (EOL) management, this study proposes to address this gap by linking the 3D BIM with the 8^{th} BIM dimension (8D) whether demolition or deconstruction, the information related to the EOL management will be assumed by a specific 8D BIM model linked to the initial 3D Model delivered by designers.

7.5 Guidelines for a SEOL approach

In the format of the RIBA plan of work, the guidelines for the implantation of a SEOL approach formalised by the conceptual framework developed in chapter 6, are summarized in the following Table. The French system equivalence is given on the top row of the table (see also Chapter 4). The Guidelines are inspired by the document, RIBA Plan of Work "Designing for Manufacturing and Assembly overlay" (Sinclair et al. 2016). The results of the research lead to add another stage, "stage 3.5" dedicated for the modularization of the design. This was requested by R15 who worked many years for a DFMA contractor.

7.6 Summary

In this chapter, were developed supplementary tools to facilitate the implementation of the holistic conceptual BIM-based framework for a SEOL approach in a BIM environment. The first set of tools was developed as new BIM-uses related to the BIM-framework. Those BIM-uses are a guidance for implementing some aspects of the framework that cannot be covered by existing BIM-Uses. The second set of tools is embodied in the current and new BIM dimensions (8D that manage the SEOL). Those dimensions are discussed to clarify how they can be useful to the BIM-framework implementation. The last set of tools deals with the BIM models to be used throughout the asset lifecycle and therefore, in the BIM-Framework. Lastly, guidelines in the format of the RIBA plan of work are given as a summary of tools developed previously.

Table 53: Guidelines for the adoption of the SEOL approach (Stage 0 to 3) (Source: based on interviewees' answers and the RIBA Plan of Work DFMA)

DESIGNING FOR A SUSTAINABLE END-OF-LIFE (SEOL) IN THE CONTEXT OF THE CIRCULAR ECONOMY (CE)

		0	1	2	3
	French	Opening of an administrative file	Preliminary studies	Sketches	Pre-project Summary
	UK Stages / Tasks	Stage 0 Strategic Definition	Stage 1 Preparation and Brief	Stage 2 Concept Design	Stage 3 Developed Design
A	Core objectives from the RIBA Plan of Work	Identify client's **Business Cases** and **Strategic Brief** and other core project requirements	Develop **Project Objectives**, including **Quality Objectives** and **Project Outcomes**, **Sustainability Aspirations**, **Project Budget**, other parameters or constraints and develop **Initial Project Brief**. Undertake **Feasibility Studies** and review of **Site Information**	Prepare **Concept Design**, including outline proposals for structural design, building services systems, outline specifications and preliminary **Cost Information** along with relevant **Project Strategies** in accordance with the **Design Programme**. Agree alterations to brief and issue **Final Project Brief.**	Prepare **Developed Design**, including coordinated and updated proposals for structural design, building services systems, outline specifications, **Cost Information** and **Project Strategies** in accordance with the **Design Programme**.
B	SEOL Strategy	1- Consider opportunities for applying a SEOL approach across portfolios or programmes of projects. 2- Consider how a SEOL approach might impact on the Business Case or Strategic Brief. 3- Consider whole life issues in the Strategic Brief including options for reuse or repurposing and recycling of components at the end of the building's life. 4- Consider Research and Development that might assist Feasibility Studies or the Concept Design including intellectual property issues. 5 -Consider opportunity for using modular design and prefabrication 6- Consider the possibility to use **reclaimed components** from the **Material Ban**k. 7- Set the **circularity rate** expected. 8- **Prepare the market** for SEOL materials if they don't exist. 9-Condiser to be **assisted** by a **SEOL or Circular Economy Specialists.** 10- Consider **training** for the use of **LCA tools** and **Circularity Assessment Tools**. 11- For existing building consider to avoid demolition and waste generation. 12- Set up the EIR, BEP and MIDP 13- Waste generated during construction is under manufacturers' responsibility.	1-Initiate SEOL thinking and incorporate client requirements into the Initial Project Brief. 2- Involve the SEOL or CE specialists 3- Involve the contractor to set his requirements 4- Involve the facility managers (set his requirements, approval for reclaimed materials or equipment) 5- Involve manufacturers and express your needs to be able to achieve the circularity goal. 6- Set clearly the asset circularity level expected. 7- Project budget distribution 8- Collect site information (available BIM data) 9- Identify storage space for recovered materials. 10- Consider the use of excavation soil. <u>**For existing building**</u> 11- Identify the site constraints for materials reuse & recycling. 12- Existing services: disconnection confirmation obtention 13- Waste stream establishment 14- Identify materials that can be reused/recovered 15- Consider the use of RFID for data update requirements 16- Identify hazardous materials	1- Test initial Concept Design options against the SEOL targets expressed during the Initial Project Brief. 2-Prepare construction strategy: To achieve the SEOL approach, use of new construction approaches (modular, prefabrication, DfMA, use of reclaimed materials...) 3- For new building take into account the SEOL cost (less landfill, use of less new materials....) 4- Risk Assessments and Health & Safety: Consider SEOL approach for the design of the new building and reuse/recycling of onsite existing materials. 5- Storage issue for reclaimed materials used for the project, coming for the Materials' Bank 6- Consider the use of excavation earth for the new construction, instead of landfilling them. 7- Consider SEOL aspects for Maintenance & Operations strategies (Facade maintenance for instance). <u>**For existing building**</u> 8- Project cost: take into account the reclaimed materials resale. 9- Storage issues for reclaimed material planned to be used for the new project 10- Storage issues for reclaimed materials waiting for buyers and their evacuation planning 11- Waste stream establishment	1- Update the Construction Strategy taking into account the SEOL approach appropriate to the Developed Design and coordination activities. 2- Adjust the design according to the reclaimed component if applicable 3- Consider national (or other) standards appropriate for SEOL approach. 4- Verify the deconstructability or disassembly of the project. 5- Consider buildability, including how the erection sequence, fabrication or manufacturing techniques and tolerances impact on interfaces. 6- Update Cost Information taking into account discussions with potential contractors, specialist subcontractors, suppliers and incomes from the sale of reclaimed materials. 7-Update Risk Assessments and the Health and Safety and Maintenance and Operational Strategies taking into account the SEOL approach. 8-Deliverables validation by the client: the recyclability and reusability of the components.
C	Suggested BIM Tasks for DfSEOL	<u>**For existing and new buildings**</u> 1- Set the project's circularity level goal. 2- Seek for SEOL or CE specialist for assistance 3- Identify neighbouring construction projects for the sale/purchase of reclaimed materials. 4- Gather cost and programme data from previous projects to set benchmarks. 5- Consider establishing a BIM object library if components are going to be used across multiple projects. 6- Identify if the reuse/recyclable materials are available in the market. If not, consider describing what are the requirements and bring manufacturers together to prepare the market. <u>**For existing buildings**</u> 7- Consider the use of scan technology for deonstructing the building with BIM. 8- Identify the missing data and if necessary schedule probes to get data 9- Identify polluted materials (cores & samples)	<u>**For existing and new buildings**</u> 1- Use BIM for the preparation of Feasibility Studies including data-rich 'placeholder' objects with limited geometry to assist in the preparation of Cost Information. 2- Test & optimise the Initial Project Brief via BIM. 3- Include the Level of Development required at each stage when preparing the Design Responsibility Matrix. 4- Consider the implications for professional services contracts and the Design Responsibility Matrix where a client is using their own BIM library, including intellectual property and professional indemnity insurance. 5- Identify materials reused or recycled for the project: storage on-site 6- Identify reclaimed materials that go for sale via the online platform 7- List, describe, advertise via photos the reclaimed materials in the Materials Bank 8- Identify the reclaimed materials available near the project location (via Material Bank) <u>**For existing buildings**</u> 9- Identify available data and if no BIM Model: proceed to scan the asset 10- Identify the nearest sector where the "waste" can be sent for revalorisation 11- Identify materials that could be reused or recycled on-site for reuse in the new building 12- Structural diagnostic 13- Procede to the building scan	<u>**For new buildings**</u> 1- Develop the BIM model and components to the Level of Development set out in the Design Responsibility Matrix. 2- Validate the model against the client's information requirements. 3- Enrich the BIM with the components data (technical sheets and material passport...) <u>**For existing buildings**</u> 4- Develop the BIM model, based on the scan and incorporate the data coming from cores and test during the diagnostic phase. 5- Identify, in the model, polluted materials, reclaimed that can be reused directly and those that will be recycled on-site/outside 6- Use the 8D technology to simulate the deconstruction of the existing building, assess the circularity of the building and identify the better scenario for a SEOL.	<u>**For new buildings**</u> 1-Progress the BIM Model and components to the next Level of Development as set out in the Design Responsibility Matrix. 2- Use 5D technologies to check project cost 3- Use 4D technologies to set up construction sequencing. 4-Use 8D technologies to check circularity and deconstructability <u>**For existing building**</u> 5- Use 8D technologies to check the deconstructability 6- Use 4D technologies to check the deconstruction cost (transport, landfill cost, recycling cost, sale incomes, etc.) 7- Use the 5D technologies to set up deconstruction sequencing (polluted, soft-strip and technical phases and handover).
D	Suggested Procurement Tasks for DfSEOL	1- Ensure lessons learned from previous projects have been incorporated. 2- Consider how SEOL or CE impacts on the assembly of the project team including how the project team will achieve a collaborative approach and how innovation can be incentivised. 3- Consider E-Permits to Work adoption and E-procurement	1- Emphasise the importance of eliminating the waste at the asset EOL in the Initial Project Brief. 2- Select the project team appropriately by having SEOL or CE specialist or expert in Sustainable Buildings among the stakeholders and experts in BIM. 3- Ensure that all the parties are able to work collaboratively by using BIM (design, E-permits to Work, E-Procurement, etc.) 4- Ensure that any tender information encourages the behaviours required for effective collaboration and the experience needed to embrace the SEOL approach. 5- Bring together manufacturers at the beginning of the project to explain what is expected of their products, in terms of reuse and recycling.	1- Adapt the Procurement Strategy and hold discussions with CE or SEOL specialists and if required, prefabrication contractors, to test the SEOL objectives set out in the Concept Design including the Construction Strategy and the disassembly or deconstruction. 2- Require early contractor involvement. 3- Require early facility managers involvement. 4-Prepare Project Roles Table and Contractual Tree	1- Hold further discussions with CE specialists relevant to the procurement route to test the circularity of components set out in the Developed Design including the updated Construction Strategy. 2- E-Permits to Work

(BPA) Building Permit Application, (TD) Technical Design, (TP) Tendering Package, (PPA) Procurement Process Assistance

Table 54: Guidelines for the adoption of the SEOL approach (Stage 3.5 to 8) (Source: based on interviewees' answers and the RIBA Plan of Work DFMA)

DESIGNING FOR A SUSTAINABLE END-OF-LIFE (SEOL) IN THE CONTEXT OF THE CIRCULAR ECONOMY (CE)

		3.5	4	5	6	7	8
	French	Design for Assembly	BPA TD TP VISA PPA	Management of the execution of works contracts	Handover	As-Built	As-Deconstructed /Dismantled
	UK Stages Tasks	Stage 3.5 Modularization	Stage 4 Technical Design	Stage 5 Construction	Stage 6 Handover and Close Out	Stage 7 In Use	Stage 8 End-of-Life
A	Core objectives from the RIBA Plan of Work	**Does not exist yet**	Prepare **Technical Design** in accordance with the **Design Responsibility Matrix** and **Project Strategies** to include all architectural, structural and building services information, specialist subcontractor design and specifications, in accordance with the **Design Programme**.	Offsite manufacturing and onsite **Construction** in accordance with the **Construction Programme** and resolution of **Design Queries** from site as they arise.	Handover of building and conclusion of the **Building Contract**.	Undertake **In Use** services in accordance with **Schedule of Services.**	Not considered in the RIBA
B	SEOL Strategy	1- Exchange the 3D BIM Model with the DFMA contractor for modularization of the design 2- In case of DFMA, the adaptation of the design project to the DFMA principles 3- Assess the compliance of the design modularized with the original project 4- Assess the level of circularity of the new project modularised 5- Verify the deconstructability or disassembly of the project. 6-Update the Construction Strategy according to the project modularized 7- Consider buildability, including how the erection sequence, fabrication or manufacturing techniques and tolerances impact on interfaces. 8-Update Risk Assessments and the Health and Safety and Maintenance and Operational Strategies taking into account the DFMA approach. 9-Deliverables validation by the client: the recyclability and reusability of the components.	1- Develop the module more accurately 2- Check the demountability of the components 3- Check the circularity of the project 4- Develop accurately the prefabrication part of the project. 5- Develop the interfaces and specifications (structural, water/moisture/vapour penetration and acoustic issues). 6- Update the Construction Strategy considering the lifting, handling and transportation strategy for each component and sub-assembly. 7- Consider the use of "waste" coming from the excavation and the existing building 8- Deliverables validation by the client: the recyclability and reusability of the components 9- Develop a commissioning plan optimising the use of factory acceptance testing for prefabrication.	1- Update the Construction Strategy, including a logistics plan that ensures the right materials, plant and operatives are deployed in the right place at the right time. 2- Commission the building progressively and capture 'As-Constructed' Information. 3- Check the conformity of materials used for the construction as prescribed. 4- On-site waste minimizing 5- Waste generated during construction is under manufacturers' responsibility	1-Consider how to capture commissioning and 'As-built' information in a manner that will assist the In Use stage including the potential disassembly of the building. 2- Set up the collaborative **Digital "as-built" Record**	1- Monitor the replacement of components during the In Use phase and check the compliance with the circularity requirements. 2- Monitor disassembly or potential reuse of materials during the EOL 3- Keep the Asset Information Model updated according to the asset transformation 4- Update the collaborative Digital "as-built" Record	1- Client set up the requirement for the SEOL. 2- Client decision point 3- Risk Assessments and Health & Safety: locate polluted materials
C	Suggested BIM Tasks for DfSEOL	1- Include the mocules into the project 2- Progress the BIM Model and components to the next Level of Development as set out in the Design Responsibility Matrix. 3- Use 5D technologies to check project cost 4- Use 4D technologies to set up construction sequencing. 5-Use 8D technologies to check circularity and deconstructability.	1-Progress the BIM Model and components to the next Level of development as set out in the Design Responsibility Matrix. 2- Model validation against the client's information requirements 3- Use **4D** to test and rehearse the sequencing set out in the construction strategy. 4- Use of the 8D technologies to check the demountability, deconstructability, circularity of the asset. 5- In case of prefabrication or DfMA consider logistics and assembly before work starts on site. 6- In case of reuse of material on site or recycling material onsite for reuse for new construction, consider logistic for recycling and storage space. 7- In case of use of reclaimed components from the Material Bank, take into account their eventual storage on site before their implementation.	1- Use digital technologies to track each step of the waste generated (quantities, recoverability, processes). 2- Use BIM for just in time delivery of materials (logistics, quantities, processes) 3- Each component used for the construction must be in the BIM Model to get an accurate "As-constructed" model (history and location) for future use. 4- Link components to assembly manuals, method statements and quality records including identifying any aspects of the design which may be reused in the future.	1- Ensure that "As-constructed" Model contain documentation related to component used for the construction. 2- Ensure Material passport are updated and contain all the data required for the SEOL management.	1- Consider configuration management techniques to maintain an up-to-date record (BIM model) of the building. 2- Make sure that any replacement is compliant with the original specifications for the circularity and included into the AIM Model. 3- Check the circularity of the asset during its lifecycle by updating the Model (8D).	1- Asset Information Model (AIM) updated is used for the DIM 2- Reclaimed materials identification 3- Materials sent to recycling/reuse channels: COBie exchange 2- Deconstruction contractors Information Exchange 3- The SEOL strategy would be checked and tested according the client's requirements. 4- Use of 4D for EOL activities planning 4D, including storage and sorting 5- Use of 5D for cost simulation and decision making for best scenario. 6- Use of 8D for waste organisation and management scheme. 7-Use of 8D for polluted waste location, quantification. 8-SEOL Handover: A Digital "As-deconstructed" Record
D	Suggested Procurement Tasks for DfSEOL		1- E-Permits to Work : Add a clauses on Building Circularity 2- E-Procurment: Consider reclaimed materials		1- Capture Feedback including lessons learned from site installation to inform the Procurement Strategy of future projects. 2- Ensure that "As-constructed" Model contain documentation related to component used for the construction. 3- Ensure that a Digital "As-Built" Recorder will be delivered.		

(BPA) Building Permit Application, (TD) Technical Design, (TP) Tendering Package, (PPA) Procurement Process Assistance

8 CHAPTER 8: Conclusions and recommendations

8.1 Introduction

There is a need for drastic changes in the asset lifecycle management to improve its sustainability. That is why the asset End-of-Life (EOL) concern and the Construction and Demolition (C&D) Waste are of increasing interest to researchers. Upstream of this trend, the interest and the willingness to link the design phase with the End-of-Life of the asset, was introduced by Lawson in 1994 (Lawson 1994; Uher and Lawson 1998) followed later by a second wave of interest and with a continuing interest until today. (Hicks, Crittenden, and Warhurst 2000; Crowther 2000; Kibert and Chini 2000). Then, a set of studies addressed, in several ways, the management of C&D Waste. More recently, researchers have expressed a considerable interest to link the EOL activities with the use of BIM (Building Information Modelling) (Akbarnezhad, Ong, and Chandra 2014; Ajayi et al. 2017; Akinade et al. 2015; Ajayi and Oyedele 2017; Bilal et al. 2016; Akinade, Oyedele, Ajayi, et al. 2017; Akinade, Oyedele, Omoteso, et al. 2017).

Despite the undeniable usefulness of the studies mentioned above, they are focussing on the design and the deconstruction or disassembly phases only. They are not addressing the asset lifecycle as a holistic system. There is a lack of studies producing a holistic approach considering all phases from design to EOL management in the Circular Economy (CE) context. Moreover, the impact of considering a building's lifecycle from inception until EOL management has not been explored yet.

For the researcher, the philosophy choice was pragmatism allowing the researcher to integrate the use of multiple research approaches, research strategy & multiple research methods. The study, combining elements of positivism and interpretivism, has used a mixed-method and has collected qualitative (through semi-structured interviews of experts) and quantitative data (through questionnaires sent to BIM managers). The study has proposed a conceptual BIM-based framework destined to help construction practitioners to have a holistic project strategy and to implement the SEOL approach to move from the linear system to the Circular Economy.

Firstly, the research achievements based on the research's aim and objectives are presented. Secondly, the key research contributions to existing knowledge are listed and explained briefly. Finally, recommendations for further research are presented.

8.2 Achievement of the research aim and objectives

This study aimed to consider the Sustainable End-of-Life (SEOL) of the asset as a part of its lifecycle that needs to be integrated into construction processes in the same way as the “design”, “construction” and “In Use” phases. The study explored the interplays between phases and stakeholders when the SEOL, whether deconstruction, disassembly or dismantling, was added to the asset lifecycle, in a BIM environment. Five objectives have been set up to address the research aim. The achievement of each objective is discussed in the following subsections.

1) Achievement of the first objective

The first objective was to investigate the current elements assigned to BIM Dimensions beyond the third dimension (3D) to reveal if there is already a BIM dimension linked to the EOL phase. This was achieved by using systematic review and survey methods.

Several other “dimensions” linked to 3D BIM exists. The results of the questionnaire showed an explicit agreement on what the 4th and 5th dimensions refer to. Academics and practitioners agreed that in the BIM environment, the 4D is related to time (or planning or scheduling) and the 5D to cost. However, for the 6th and the 7th “dimension”, there is no consensus. The results of the systematic review show that these two areas are still in their infancy, illustrated by some ambiguities on what these BIM dimensions refer to. There is no dimension linked with the EOL activities in the literature. The questionnaire results for the dimension above the 5D, in line with the systematic review findings, confirmed discrepancies for the 6D and 7D, related to Sustainability, Facility Management or Safety. Indeed, the practitioners using these dimensions usually refer to Sustainability for the 6D (86%) and Facility Management activities for the 7D (by 85%).

2) Achievement of the second objective

The second objective was to explore the various sustainable EOL approaches and identify the barriers to their adoption by conducting an extensive literature review.

First, it was crucial to try to clarify the many approaches and concept surrounding the sustainability in the built environment, such as deconstruction, dismantling, disassembly, Reverse Logistic, Closed Loop and, Circular Economy, amongst others. A definition of buildings’ SEOL is not yet given in the literature, probably because the notion of sustainability in the building industry is not as mature as sustainability in the manufacturing industry. The development of the concept of sustainability has logically started with the design and construction phases. The awareness of Design for specific architecture/purpose “Design for **…/…”** is relatively new and still far from being the mainstream in the AEC industry. It means that in the EU, most of the buildings that currently attain their EOL phase were “designed for construction” and their deconstruction or disassembly will be intricate. That is why there is a lot of work done on down-cycling since recycling or reuse merely is more difficult for those buildings, as not planned upstream.

Most of the new design strategies focused on the building process from the manufacture, assembly and disassembly and not any more focused in design for construction. All those relatively new “design for” related to the deconstruction and prefabrication family concepts have been included in the research as enabling a potential SEOL. Besides, designs for CE family concepts are included as well because the research aims to achieve a building lifecycle in the CE.

3) Achievement of the third objective

The third objective was to create a theoretical BIM-framework to incorporate the asset sustainable End-of-Life phase into BIM environment based on the literature review. Two key documents, found in the literature, were used as a basis to draw the theoretical BIM-framework: First, the “Penn State” document has defined the BIM Uses and their related processes. Secondly, the work conducted by Liu et al. (2015), consisting of developing design decision-making in a BIM-based framework for the improvement of the construction waste minimisation. However, there is a lack of data from the literature to draw a theoretical framework illustrating the interplays between the phases and the stakeholders, when the EOL phase is incorporated into asset lifecycle. To fill the gap, the theoretical BIM-based framework for the SEOL integration in the asset life cycle in the Circular Economy context has to be improved by the expert opinions (from semi-structured interviews). The BIM-based theoretical Framework thus would become a “conceptual BIM-framework” (objective 4-5).

4) Achievement of the fourth objective

The fourth objective was to identify the barriers to the incorporation of the SEOL phase into the asset lifecycle and to improve the theoretical framework through the stakeholder’s perspective engaged in using Eco-friendly material approach. The twenty selected participants for the interviews have a background of using particular approaches to achieve sustainable building or to limit the environmental impact of their buildings. The interviewees’ skills and positions in the companies covered the whole lifecycle of the building management. Moreover, most of the interviewees were working in companies that were leaders in a field related to the aim of the research (deconstruction, low carbon building, modular building, BIM, DfMA,) and had substantial experience. Indeed, the approaches used by the interviewees to achieve sustainable building are: (i) Circular Economy Approach, (ii) Flexibility/modularity, (iii) Reuse reclaimed material and building components, (iv) waste minimisation by finishing works avoidance, (v) deconstruction, (vi) DFMA and (vii) Develop product 100% recyclable for life.

In the context of incorporation the SEOL into the asset lifecycle, the respondents of the semi-structured interviews have raised six categories of barriers: (1) economic barriers, (2) political barriers, (3) sociological barriers, (4) technological barriers, (5) Environmental barriers and (6) organisational barriers.

Dozens of obstacles were identified with the reconsideration of the asset lifecycle from inception to EOL phase and even beyond with the reclaimed materials bank. The barriers are impacting the stakeholders, the asset phases and the models generated throughout the asset lifespan. Barriers have shown that the inter-relationships between disciplines, stakeholders, phases and BIM models make the holistic approach a sine qua non.

5) Achievement of the fifth objective

The fifth objective was to draw the Conceptual BIM-Based Framework, identify BIM Uses, and guidelines for the implementation of a SEOL approach. Several areas of the Theoretical BIM-Based Framework were improved as following. As requested by one respondent, the general structure of the Framework was modified. Indeed, one of the first change is that the BIM-Based Framework is organised through the RIBA stages and according to the PAS 1192-2. (2013) and ISO 19650. The other modified areas are explained below.

First, the stakeholders' missions were modified to enable their early involvement in the project. The purpose was to allow design, even programming, that takes into account the whole lifecycle, including the asset's SEOL and specifically all the constraints brought by stakeholders in the different phases. This type of work organisation, a multidisciplinary collaborative work, prevents issues upstream and ensures the sustainability of the building project during its entire lifespan.

Secondly, the interviewees raised the necessity to integrate new actors, notably, experts in the Circular Economy (CE) assessment that would be involved in the very beginning of the project but also throughout the project. The CE specialist would also take part in the management of the asset's End-of-Life by supporting the EOL contractors to comply with the CE requirements.

Thirdly, improvements were made to the asset phases by applying some changes and adding new phases, at the asset and materials' level. Inside the asset's phases, from design to “In Use”, changes were aimed at ensuring the data quality in each stage. The SEOL phase activities include the definitions of its sub-phases and the deconstruction-types' process. The re-processing phase consists of the reuse and recycling activities to re-introduce materials into the loop, including re-characterisation and making reclaimed materials compliant with applicable regulations.

Lastly, the impact of the SEOL phase on the stakeholders and the project phase is detailed. The BIM-Based Conceptual Framework has the potential to give an overview of who should be involved and when. It can be used by practitioners who want to adopt a SEOL or a CE approach.

Based on the barriers raised by the interviewees, tasks related to the incorporation of the SEOL into the asset lifecycle were identified and classified into three categories. Current BIM Uses for the asset EOL activities were determined based on the literature and the interviewees' responses.

In addition, guidelines in the format of the RIBA Plan of Work are developed. They are destined for practitioners, especially designers, and explained each stage (from 0 to 8) from Strategy (stage 0) to SEOL (stage 8). Stage 8 was added for the study. BIM tasks are also suggested for Designing for a Sustainable End-of-Life (DfSEOL). Procurement tasks for DfSEOL are also suggested.

The results show that the integration of the SEOL into the asset lifecycle is conceptually feasible and understandable by the interviewed practitioners. Therefore, the BIM-Based Framework might be useful for the French and British AEC practitioners desiring to adopt the SEOL or CE approaches. Doing it via the BIM technology would facilitate the implementation by having better control of the huge amount of data generated during the asset lifecycle. It would also enable the EOL practitioners to take advantages of the work done during the previous stages. Finally, the BIM-Based Conceptual Framework shows that having a holistic view of the asset is crucial.

8.3 Contribution to knowledge

The research provides seven main contributions to knowledge: (1) Data management, (2) complementary processes, (3) New BIM Uses for the SEOL activities, (4) A BIM Models for the EOL management, (5) The 8D as a new dimension for a SEOL, (6) A BIM-Based Conceptual Framework and (7) Guidelines for the adoption of a SEOL approach.

1) The data management

Managing the data in the BIM environment is crucial. Indeed, in the approach of the asset a holistic system, data is moving from one phase to another, and its quality, accuracy and validity must be checked and secured to enhance the trust between the stakeholders on the data exchanged. So, the Conceptual BIM-Framework has expatiated this topic. Details are given first, on the data requirement processes, then on the data validation to secure the validity and accuracy of the data. The exchange must also be addressed by specifying the data format, and lastly on the data update. This last point of data update has to be very clearly defined as the ambition of the research is to deal with the entire lifecycle of the buildings from cradle to cradle that can last for decades.

2) Complementary processes

A set of 80 classified tasks were extracted from the interviewees' feedback on the theoretical BIM-framework but also on the barriers they had raised. These tasks were classified into three categories (organisational, Contracts rules and guidelines, and technologies related tasks). These tasks are considered by the interviewees to overcome barriers for the integration of the SEOL into the asset lifecycle and facilitate the practical use of BIM throughout the asset's lifecycle.

To look at which stakeholder is involved in which tasks and at the impact of each task on the project phases, the BIM models, the collaborative platforms, the material bank and the stakeholders, the researcher has classified the tasks into nine groups: (i) Contracts, rules and guidelines, (ii) Design approach, (iii) Requirements, (iv) Deliverables, (v) Team organisation and stakeholders' roles, (vi) Database, (vii) Checking and validation, (viii) Materials selection and market preparation, (ix) SEOL activities.

For each category, a process was drawn to help the reader to visualise the relation between the task and the Collaborative platforms (project and materials), the BIM models, project phases and stakeholders. Existing tasks adapted for the SEOL and new tasks are distinguished. Similarly, new links and modified existing links are also represented differently.

3) New BIM Uses for the SEOL activities

The impacts for the incorporation of a SEOL into the asset lifecycle on the existing BIM uses were identified. However, eight new BIM Uses were identified that could be added to those found in the Literature review. The new BIM Uses are (1) Digital Model for EOL, (2) Logistics planning, (2) Material passport development, (4) Project database, (5) Data checking, (6) Circularity assessment, (7) Materials' recovery processes and (8) Materials' Bank.

4) A BIM Models for the EOL management

Throughout the asset lifecycle, different models would be created and would have to change to fulfil the research aim and be consistent with the BIM-Framework: The PIM (Project Information Model), the AIM (Asset Information Model), the Digital As-Built Record and the AIM (Asset Information Model). For the research, the DIM (Deconstruction Information Model) was added and will be based on the Digital As-Built Record updated and the AIM updated.

Insights on how to create and manage the collaborative platform were given. It was also proposed to use a model view definition (MVD) for the SEOL to enable to classify the data according to the business view.

5) A new dimension for a SEOL: 8D

The third (3D), fourth (4D), fifth (5D), sixth (6D) and seventh (7D) are BIM dimension that already exist and are used by practitioners. A new BIM dimension, the eighth (8D) is proposed to manage the SEOL. The eighth dimension of BIM (8D) will add an extra level of information to the model in the form of EOL management data. It would contain data related to deconstruction/disassemble activities. Each component of the asset would encompass information needed by End-of-Life managers to enable them to conduct the deconstruction appropriately and efficiently. The data would include details about the components, their history, such as when they were installed, replaced, the necessary precaution to adopt during the deconstruction, and how to recycle, reuse them. The Facility Manager will update the model containing all this information during the asset exploitation. During the SEOL management, the 4D (time) and the 5D (cost) can also be used for SEOL management.

6) A BIM-Based Conceptual Framework

This research has presented a BIM-Based Conceptual Framework, as one of the key contributions of this research and fills a gap in the area of considering a holistic asset lifecycle from inception to EOL management. Indeed, no similar Framework currently exists. The purpose of the BIM-Based Conceptual Framework is to help practitioners to embrace the SEOL approach and to have a holistic view of the project. The research has been designed for the stakeholders involved in the asset lifecycle. The BIM-Based theoretical Framework was improved by the feedback of a range of experienced professionals working to minimize the impact of their project on the environment. The Framework includes all the asset lifecycle phases and also the lifecycles of the materials.

The BIM-Based Conceptual Framework also provides the foundation for the use of BIM for the SEOL and CE approaches and can be used as a decision-making tool during the design phase for new buildings or during the diagnostic phase for existing buildings planned for deconstruction. The BIM-Based Conceptual Framework also supports designers and owners in making informed material choice decisions during the prescription stage.

The BIM-Based Conceptual Framework can be used as a guideline to the construction supply chain willing to move towards a more circular approach. Barriers to moving towards the new asset lifecycle concept were also addressed, reported upon and discussed. BIM has the potential to help the move from a linear economy to a Circular Economy.

7) Guidelines for the adoption of a SEOL approach

Lastly, guidelines for the SEOL approach implementation, in the format of the RIBA plan of work are given. Indeed, the detailed guidelines, for each stage from strategic design (Stage 0) to End-of-Life (stage 8 added for the research), the SEOL strategy, the checking, suggested tasks for Designing for a Sustainable End-of-Life (DfSEOL) and suggested procurement tasks for DfSEOL. The guidelines are also structured in the same way as the existing RIBA Plan of Work 2013 Designing for Manufacture and Assembly (DFMA).

8.4 Main conclusions

The main conclusions of the research can be summarized as follow:

- Data management: from inception to SEOL phase and materials' banks
- Eighty tasks were identified for the incorporation of the SEOL into the asset lifecycle. We seek to understand the relations between each task and
  - Stakeholders involved during the asset lifecycle
  - Asset's phases
  - BIM models generated during the asset lifecycle (PIM, AIM and DIM)
  - The various BIM dimensions used during the asset lifecycle
  - Collaborative platforms used by the stakeholders and the central Facility Repository Asset lifecycle database.
  - Materials ' banks for new and recovered materials
- Eight new BIM Uses were identified for the management of the EOL activities
- Definition of the DIM, a BIM model for the EOL activities
- Identification of the 8D, a new BIM dimension for the SEOL management
- Creation of a BIM-based conceptual framework, improved by the AEC stakeholders
- Creation of guidelines for the implementation of the SEOL approach

8.5 Recommendations for future research

- Since the BIM-Based Framework was designed for the UK and the French context, future research could investigate the generalisability of the findings to other countries.
- Future research could also extend the scope of this study to the drivers of the incorporation of the SEOL in the asset lifecycle. In this research, the drivers have been collected from the literature and from the interviews, but due to the limited time and the limited length of the manuscripts, they were not presented. The data will be analysed after the PhD completion for publications in journal papers.
- A following logical work would be the internal validation of the BIM-Based Conceptual Framework by requesting interviewees' feedback about the Framework.
- Then, external validation could be performed by asking the opinion of other stakeholders. That action would strengthen the outputs of this study.
- Finally, further research could be undertaken for the development of the existing BIM uses that are modified by the integration of the SEOL into the asset lifecycle. That is to say developing new aspects in those BIM-uses to be added that would be compliant with the BIM-Based Conceptual Framework.
- Individual processes could be developed for each new BIM use to go deeper, as suggested by the "Penn State" document.

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