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

Charef, Rabia

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

- TOWARDS THE CIRCULAR ECONOMY -

By

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PhD

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1 Appendix 1

Building Information Modelling Adoption in the European Union : An Overview

Abstract

Building information modelling (BIM) is one of the most promising recent developments in the Architecture, Engineering, Construction and Operation (AECO) industry. However, its adoption remains a challenge for the AECO industry because it requires a shift to a new way of working, leading to a current discrepancy in the adoption of BIM in the EU. The paper aims at assessing the gaps in the BIM adoption between the 28 EU countries and the barriers related to its implementation. The methodology adopted here is twofold: first, secondary data are given by a systematic literature review, completed with the review of current projects funded by the European Commission, and dealing with fostering the BIM adoption. Second, primary data are provided by a questionnaire survey to classify BIM initiatives regarding policies, the level of adoption and the barriers encountered in the 28 EU countries. In order to grade the heterogeneity of BIM adoption in the EU, we have classified the countries into four categories with different levels of awareness, from early adopters (BIM already mandated) to countries without any plan. The survey has enabled the analysis of twenty barriers to BIM adoption using the four grades in relation to the respondent country. We found barriers that are acknowledged by all countries irrespective of their level of BIM adoption. Other barriers have been already tackled by the early adopters but not by the newcomers who have yet to experience some of these issues. Finally, the assessment of the disparities of BIM adoption within the EU can help the European Commission towards unifying European standard on BIM.

Keywords: Building Information Modelling, BIM adoption, European Union, barriers, implementation.

Paper type – Research paper

1.1 Introduction

Across the world and in Europe, the Architecture, Engineering, Construction and Operation (AECO) industry faces challenges in relation to construction projects that are fragmented and, in many cases, not particularly well integrated. The consequences are negative regarding energy efficiency, cost, sustainability, resource depletion, the wellbeing of end-users, and efficiency of installers (Peng 2016)(Shy 2017)(Motamedi and Hammad 2009). Meanwhile, the AECO industry is experiencing one of the biggest recent developments: the arrival of new technologies such as Building information modelling (BIM). The economy is entering into the digital revolution that is more important than the shift from paper to computer. The BIM process gives a framework to set up collaborative work in the construction industry and therefore gives the way to improve the overall quality of the whole value chain. BIM is a faster and more efficient method for construction management, it enhances design and construction qualities and reduces rework during construction (Masood, Kharal, and Nasir 2014). BIM technology allows the creation of an accurate virtual model of a building, that is first digitally constructed. This model can be used throughout the entire value chain from design to demolition, allowing all the stakeholders to work collaboratively rather than in a fragmented manner (Charef, Alaka, and Emmitt 2018).

BIM implementation requires significant technical expertise and in the short-term increases the operating costs of businesses in relation to implementation and training costs. These requirements, together with the construction industry's well-known resistance to change (Kouider, Paterson, and Thomson 2007; Arayici et al. 2011b), have generally hindered the rate of adoption of BIM. Many studies have however shown that BIM's benefits clearly outweigh its disadvantages hence the government's drive for adoption in various developed countries (Terreno et al. 2015) (Barlish and Sullivan 2012) (Love et al. 2016) (Azhar 2011)(Succar and Kassem 2015)(Kassem and Succar 2016).

The BIM adoption is now a world concern, and in developed countries, some related studies are becoming comparatively old (Gu and London 2010)(Arayici et al. 2011a)(Tao-chiu Kenny Tse, Andy Wong, and Francis Wong 2005). Recently developing countries have also engaged studies on the implementation of BIM. For example in Egypt, Khodeir et al. 2018 have examined the status of the adoption of BIM and building energy models in architectural firms (Khodeir and Nessim 2018). In Malaysia, Hanafi et al. 2018 have studied the organizational readiness of BIM adoption through architectural practices (Hanafi et al. 2016). In India, Arunkumar et al. 2018 have studied the implementation of BIM from the architects' and engineers' perspective (Arunkumar, Suveetha, and Ramesh 2018). In China, Li et al. 2017, the barriers against the adoption of BIM have studied Li et al. 2017 (Li et al. 2017). This helps to demonstrate the different rates of adoption around the globe.

In the European Union, some countries are early adopters (e.g. Finland, Netherlands and Denmark). Although Finland has not yet mandated BIM usage, in 2007, the Finnish government's own real estate owner mandated BIM usage in its own projects managed by the national agencies of State Properties and Senate Properties. (Kouider, Paterson, and Thomson 2007). Even if the literature on BIM has progressively increased during the last decade, other countries currently do not yet have any specification about the use of the BIM process (e.g. Bulgaria, Greece and Malta) (Santos, Costa, and Grilo 2017).

From a European standpoint, it seems crucial to ensure that all the EU countries engage in a collective effort based on common ground and to ensure that they are working towards a common goal and direction. If not, the BIM European standardisation may be weakened, as highlighted by the EU BIM Task Group, “Without this top-down leadership, the sector’s low and uneven adoption of information technology is likely to continue which would limit its opportunity to significantly improve productivity and value for money.” The handbook delivered by the EU BIM Task Group “is a direct result of the European Commission’s call for funding to form a European public sector network sharing best practices on BIM and for the development of a handbook of recommendations” (EU BIM Task Group 2017). It appears that a fundamental requirement is to avoid the gap between the EU countries getting worse. For that, measures should be taken at an EU Level (EU BIM Task Group 2017). Regarding BIM divergence in the definitions and practices, a response needs to be given for the current non-standardised approach leading inevitably to a fragmented market. Difficulties resulting from the various practices and skills across Europe have created barriers to working in different markets. Although the European Commission is working to tackle the discrepancy in the application process of BIM, we still need to have a clear picture of the stage of BIM adoption in the EU to foster a narrowing of the gap.

This paper aims to assess BIM adoption across the EU and to raise the issues and risks of divergence across different national markets. To fulfil this aim, we define three objectives:

1. To conduct a comprehensive systematic review to identify the current awareness and use of BIM in EU countries and the major barriers to BIM implementation.
2. To perform a survey to complement the findings of the systematic review. We have conducted a survey across the 28 EU countries regarding BIM implementation, the government position and the main barriers to BIM adoption.
3. To introduce recommendations based on the analysis of the findings of the two previous objectives.

1.2 Research Method:

We first collected data through a systematic review to help to design the questionnaire for primary data collection. The systematic literature review was conducted in the academic field, but also included official documents from the European Commission and reports/projects dealing with BIM implementation in Europe (*Figure 1*). This paper focuses on the 28 European countries as currently defined by the European Union[1].

[1] https://europa.eu/european-union/about-eu/countries_fr#tab-0-1

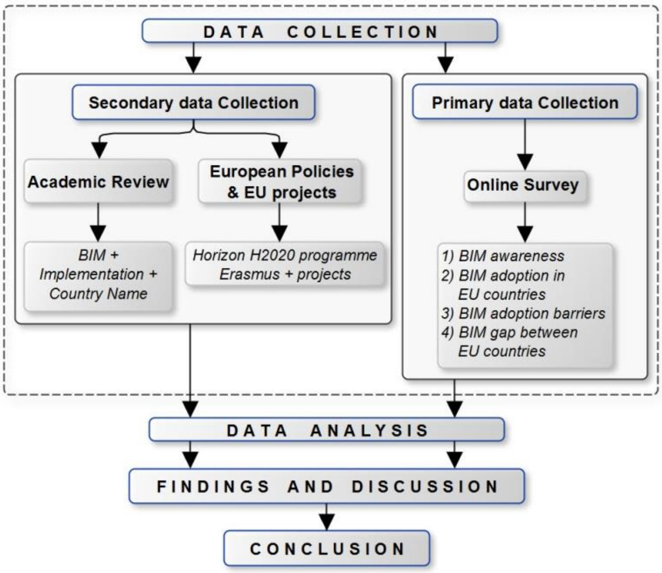

Figure 1: The methodology for this study

1.2.1 The Systematic Review

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 2. 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 2 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 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).

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, Calcerano, and Cessari 2016) or the analysis of risk and rewards of adopting BIM for SMEs in the UK (Thanh LAM, Mahdjoubi, and Mason 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).

1.2.2 Initiatives across the world and European Directives/policies

In addition, secondary data was also collected from reports about BIM implementation in Europe. The projects funded by the European Commission within the H2020 framework were also studied because they have the political backing of Europe’s leaders and the Members of the European Parliament[2]. Moreover, the selection and monitoring of the research projects funded by the EU are highly challenging ensuring the reliability of the reports. The search engine used is the Community Research and Development Information Service (CORDIS) website. Words such as “BIM”, redefined by the programme “Horizon 2020” and content “Project”. Six relevant projects were found and analysed.

1.2.3 Questionnaire survey

As professionals are key actors in the implementation of BIM in the construction industry, we sought their opinion through an online questionnaire. We used an online questionnaire due to the geographical spread of the 28 EU countries. The survey was processed through the Bristol Online Survey (BOS) 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 participants.

The purposive sampling was adopted (Palinkas et al. 2015; Merriam 1998; Miles and Huberman 1984) because we had to pick BIM professionals from each of the 28 European countries. Authors have decided to have a representative sample composed of 6 BIM professionals per country to send them a request via LinkedIn with the aim of getting at least one response per country and 50 respondents in total. The selected sample was purposely targeting people with a position with a high level of responsibilities in the companies and knowledge in BIM. The population picked out is architects, engineers, contractors, facility managers, BIM Managers, training providers among others. A combination of the first author’s private contacts 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).

[2] https://ec.europa.eu/programmes/horizon2020/en/what-horizon-2020

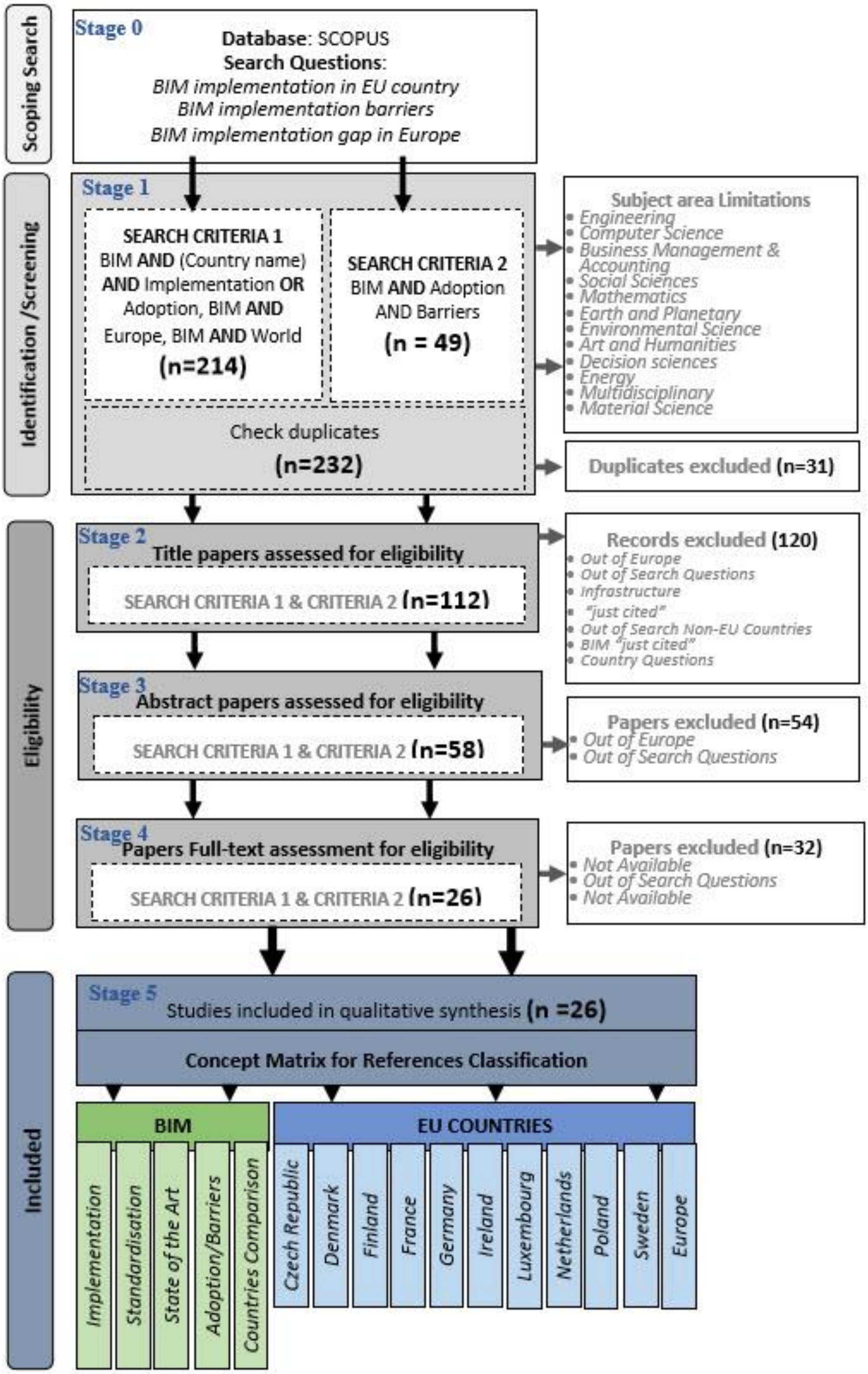

Figure 2: Prisma Flowchart for the systematic literature review

For each LinkedIn Group, we clicked on account of the first 200 members, following this, we checked their location from the account and listed them. In these groups, each of the members was checked and selected by their expertise in BIM and their countries they are working in. 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 profile of the potential respondent was checked on LinkedIn to make sure that the potential respondents are working in BIM area and that they have a key role in the company. Once we had six potential respondents for a given country, we stopped picking respondents from that country and so on.

Then, we addressed an email to the potential respondents as follows: “In the context of my PhD, I am interested in BIM in Europe. I am looking for people who are involved in this area. I wanted to get your perspective, and I will be glad if you can accept to be connected”. After checking up to 3000 people and when we have had 6 people per country willing to give their perspectives , we stopped searching. Therefore 168 requests were sent, amongst them 110 accepted to be involved in the survey. An email with the questionnaire’s link was sent to the 110 potential respondents: “Thank you for accepting my invitation to connect. In the framework of my thesis, I am conducting an academic survey on the use of BIM in Europe. I will be very grateful if you can spend 10 minutes to answer the questions using the following link: https://coventry.onlinesurveys.ac.uk/bim-in-europe”. After ten days, follow-up emails were sent in order to increase the response rate (Table 1).

Table 1: List of the countries and the number of professionals contacted, survey sent and filled

Countries	Survey sent	Survey filled
Lithuania	5	3
Finland	5	3
Croatia	4	2
Poland	5	1
Hungary	2	1
Spain	4	1
Latvia	5	3
Belgium	5	1
Greece	3	1
Germany	4	2
France	4	3
Slovakia	4	3
The UK	3	1
Austria	4	3
Portugal	5	1
Romania	4	3
Cyprus	4	3
Italy	3	1
Estonia	4	2
Denmark	4	1
Sweden	4	2
Ireland	4	1
Slovenia	5	2
Bulgaria	4	1
Malta	3	1
Luxembourg	4	2
Netherlands	3	1
Czech Republic	2	2
Total questionnaire sent	110	
Total questionnaire filled		51

Eventually, a total of 51 respondents filled the questionnaire, giving a response rate of 46% which is close or better to similar studies (K. Davies 2010; Gustavsson, Samuelson, and Wikforss 2012) (Dulaimi, Ling, and Bajracharya 2003; Hadzaman, Takim, and Nawawi 2015; Yu et al. 2013).

The questionnaire was structured in four sections described in Table 2. The set of questions of section 4 of Table 2 was designed according to the literature review and aimed at getting information on BIM awareness, State of the art in BIM implementation in your country, BIM implementation barriers and BIM in Europe. Two types of structuration were used for the questionnaire: multiple choice (single or multiple answers) and Likert scale questions (scale of 1-5). (Table 2).

Table 2: Questions asked in the online questionnaire

1 – Consent		
2 – Identification		
Questions text	Rank values	Question type
Company name	Non-relevant	Single line free text question
Current role		
City / Country		
Email address		
3 - Company Description		
Questions text	Rank values	Question type
What is the business sector of your company?	Architecture, Engineering, Project Management, Quantity Surveyors, Construction, Training, Others	Multiple choice questions, multiple answers
What is the sector of your company?	Public, Private, Both	
What is the size of your company?	0-5 Employees, 6-20 Employees, 21-50 Employees, 51-100 Employees, 100+ Employees	
4.1 - BIM adoption		
Questions text	Rank values	Question type
In your opinion, what is the state of the art in BIM implementation in your country?	Early Adopters", "Late Adopters" and "Very Late Adopters	Multiple choice questions, multiple answers
4.2 - BIM adoption barriers		
Questions text	Rank values	Question type
In your opinion, what are the cultural and individual issues?	Lack of awareness	Multiple choice questions, multiple answers
	Cultural change required	
	Resistance to change (cultural/staff)	
	Lack of demands	
	Doubt about ROI, the vision of benefits	
	BIM is not yet mature	
	BIM is too complex	
In your opinion, what are the economic and technology issues ?	ICT barriers	
	Lack of in-house expertise /skilled personnel shortage	
	Lack of training/education in universities	
	Interoperability of BIM software/data translation	
	Cost of BIM implementation (Software & Training)	

In your opinion, what are the political and legal issues?	Lack of Government lead
	Lack of guidance for BIM implementation and utilisation
	Lack of National standard, procedures and guidelines
	Lack of new or amended form of construction contracts
	Legal issues: Data ownership and responsibilities
	Change in procurement methods
	Insurability issue
	Property Rights issues

1.3 Data Analysis

1.3.1 Reliability of questionnaire data

The SPSS (Statistical Package for Social Sciences) computer package was used to analyse the Likert scale questions in the questionnaire and their responses. These are the questions under part '4.2 - BIM adoption barriers' shown in Table 2. Results revealed a mean value of 61.8 and a standard deviation value of 6.98, showing the standard deviation is at just over 10% value of the mean. This shows good consistency between the responses of the professional respondents, depicting some level of reliability in the responses received. Following the advice of social scientists and statisticians, such as Spector, 1992; Field, 2005; Nunnally and Bernstein, 2007 among others, the reliability of the responses was checked further statistically using the Cronbach's alpha coefficient (Spector 1992; Field 2005; Nunnally and Bernstein 2007). The fundamental objective of the Cronbach's alpha test is to examine if the questions in the questionnaire and the corresponding responses scale actually measure the construct they were intended to measure, which relates to BIM adoption barriers to its, by checking the consistency of the data.

The dimension of Cronbach's alpha coefficient is between 0 to 1, and as a general rule, George and Mallery (2003) suggested 0.7 as the minimum acceptable score and 0.8 as a sign of decent internal consistency (George and Mallery 2003). The results of the test are displayed in Table 3. The resulting Cronbach's alpha coefficient from a first run of the test was 0.757, showing an acceptable consistency and reliability of the questionnaire responses.

To scrutinize the data further for possible improvement, and establish if responses to some questions in particular reduced the quality of the result, the third column of Table 3 titled 'Cronbach's Alpha if Item Deleted' was inspected. According to Field (2005), if a variable (i.e. responses to a question) is reducing/worsening the overall reliability and consistency of data, and therefore is not as good a measure of the construct as other variables, its associated Cronbach's alpha coefficient would be higher than the overall coefficient (0.757) (Field 2005). Such variable can be removed, and the test re-ran on the remaining variables. A total of four tests were ran in this analysis. From Table 3, questions' responses (i.e. variables) 4.2.4.1, 4.2.2.4 and 4.2.2.5 had higher associated Cronbach's alpha coefficient than the overall Cronbach's alpha coefficient in the first, second and third runs of the test respectively. For every next run, the questions' responses with higher associated Cronbach's alpha coefficient in the previous run was removed. After removing these three questions' responses from each run, Cronbach's alpha coefficient became 0.805 in the fourth and last run, depicting very reliable responses. In this final run, there were no questions' responses (variable) with a higher associated Cronbach's alpha coefficient than the overall Cronbach's alpha coefficient of 0.805 (see 6th column of Table 3). This means data for the remaining questions and associated responses have a high consistency and reliability and highly measure the construct. However, since the Cronbach's alpha coefficient was acceptable when all questions are considered together, none of the questions and their responses was discarded for the remaining analyses and discussion of this paper.

Table 3: Results of reliability analyses of the Likert scale questions in the questionnaire

		1st run	**2nd run**	**3rd run**	**4th run**
	Overall Cronbach Alpha Coefficient	0.757	0.786	0.792	0.805
S/N	**Questions (variables)**	**Cronbach's Alpha if Item Deleted**			
4.2.1.1	Lack of awareness	0.731	0.776	0.782	0.793
4.2.1.2	Culture Change Required	0.730	0.779	0.785	0.796
4.2.1.3	Resistance to change (cultural/staff)	0.725	0.774	0.779	0.790
4.2.1.4	Lack of demands	0.732	0.778	0.783	0.796
4.2.1.5	Doubt about Return on Investment (ROI), vision of benefits	0.733	0.779	0.785	0.797
4.2.1.6	BIM is not yet mature	0.719	0.771	0.778	0.792
4.2.1.7	BIM is too complex	0.721	0.772	0.781	0.796
4.2.2.1	ICT barriers	0.735	0.782	0.787	0.799
4.2.2.2	Lack of in-house expertise/skilled personnel shortage	0.733	0.782	0.789	0.800
4.2.2.3	Lack of training/education in universities	0.732	0.779	0.785	0.796
4.2.2.4	Interoperability of BIM software/ Data translation	0.745	0.792		
4.2.2.5	Cost of BIM implementation (Software & Training)	0.752	0.796	0.803	
4.2.3.1	Lack of Government's lead	0.720	0.768	0.773	0.785
4.2.3.2	Lack of guidance for BIM implementation and utilisation	0.724	0.772	0.780	0.791
4.2.3.3	Lack of National standard, procedures and guidelines	0.723	0.770	0.776	0.790
4.2.3.4	Lack of new or amended form of construction contracts	0.730	0.778	0.785	0.796
4.2.3.5	Legal issues: Data ownership and responsibilities,	0.732	0.783	0.791	0.804
4.2.3.6	Change in procurement methods	0.726	0.777	0.784	0.797
4.2.3.7	Insurability issue	0.718	0.770	0.776	0.787
4.2.3.8	Property Rights issues	0.715	0.767	0.775	0.788
4.2.4.1	In your opinion, what is the state of the art in BIM implementation in your country?	0.786			

1.3.2 Initiatives across the world and European Directives/policies

1.3.2.1 Initiatives across the world

Before focusing on Europe and its 28 countries, it may be useful to check if initiatives could be found across the world regarding BIM implementation. There is a collaboration between the UK, Ireland and the USA to deliver the NBIMS-US standard improvement. "Through this agreement, our friends in the UK and Ireland will be helping to provide content for NBIMS-US™ as they develop a national standard governing BIM for the UK and Ireland. This contribution, combined with the efforts of other BuildingSMART member nations, will help us to grow the content of NBIMS-US™ (National Building Information Modelling Standard – United States) exponentially in a much shorter period of time than we could do ourselves" (National Institute of Building Sciences 2012).“ Another initiative taking place in Oceania is the union of two countries to set up a Revit (software used in the BIM process) standard that will be used by both countries Australia and New Zealand (Australia and New Zealand Revit Standard) (ANZRS)(National Institute of Building Sciences 2012). The NBS International Report (NBS 2016), written by five countries (UK, Canada, Denmark, Japan and the Czech Republic) has the aim to improve construction information for design professionals through the International Construction Information Society (ICIS).

Some organizations such as the Institute of International Studies and Training (IIST) in Japan aimed to facilitate exchanges of experience and know-how between EU and Japanese business and thus improve competitiveness and cooperation between each country. The International BIM implementation guide (Sawhney et al. 2014), published by the RICS (Royal Institution of Chartered Surveyors) based in the UK is a form of guidance note highlighting BIM international high-level principles. Another initiative based in the UK is the BRE Academy/ALPIN: BIM International Education (2015).

And the last initiative is driven by the International Standard Organization, ISO/WD 19650-2: Organization of information about construction works - Information management using Building Information Modelling.

1.3.2.2 Initiatives in Europe

Several European initiatives around BIM were found. First, the European Union Public Procurement Directive (EUPPD) published in January 2014 allows all 28 EU member states to encourage, specify or mandate the use of BIM for publicly funded construction and building projects in the EU by 2016 (Official Journal of the European Union 2014). The 28 EU members must follow the same path as the UK, Netherlands, Denmark, Finland and Norway in the construction sector. In fact, it mentioned that “for works contracts and design contests, Member States may require the use of specific electronic tools such as building information electronic modelling tools or similar”. In 2016, a guide was also made available (CCS 2016).

The European Commission has co-founded the EU BIM Task Group, for two years (2016-2017) aiming to bring Europe into a common and aligned approach in the construction sector and unifying BIM policy across Europe. The project involves fourteen EU countries for designing a handbook explaining the common practices and principles for European countries (The European Union 2016b). The handbook was delivered in 2017 and gives general guidance and action recommendations for harmonization of the BIM strategy at a European level (EU BIM Task Group 2017). The BIMTrain EU project (2013-2015) addressed the lack of relevant skills, knowledge and tools related to BIM during the building construction process. The aim was to promote the use of BIM technology in the Baltic States through the development of a BIM training tool, which can be used by academic institutions and private companies. The main project outcome was the creation and adoption in various languages of the BIM training tool (English, Lithuanian and Latvian). The training in BIM was dedicated to both educational institutions and private companies. Training system, BIM tools and methodologies are available online (The European Union 2013). The project CERTI4TRAIN (2014-2016) funded by Erasmus+ and based on CertiTrain project (2013- 2015), focused on the provision of Continuous Vocational Education & Training (CVET) and the development of an EU certification scheme to facilitate mobility of trainers within Europe (The European Union 2013). The BIM4VET (2014-2017) purpose is to give an overview of the BIM curriculum in European countries. The project goal is the classification, standardization and certification of a BIM training programme. In fact, the main outcome will be a repository of BIM expertise and Method of BIM qualification maturity assessment, classification of BIM curriculum in EU and BIM actor competence matrix and finally training recommendations. This project will give an overview of the BIM curriculum offer in Europe (The European Union 2013). BIM4PLACEMENT (2016-2018) is an Erasmus+ funded project that is still ongoing. The aim is to develop key competencies in building and construction linked to BIM in the area of VET education (The European Union 2016a). Recently granted, the BIMplement and NEWCOM (2017-2020) projects aim to develop a qualification & certification scheme for blue-collar workers by using BIM process (The European Commission 2017b, 2017d). The BIMEET project will provide a harmonized skills matrix related to BIM and energy efficiency. The sustainability of the project will be done thanks to the accreditation scheme developed during the project (The European Commission 2017a). The TRAINEE and BIMcert project (2018-2019) are focusing on market-based skills for sustainable energy efficient constructions (The European Commission 2018c, 2018d). The projects BIM4REN, BIM-SPEED (2018-2022), and BIMERR (2019-2022) are dedicated to improve the efficiency of the renovation of existing buildings (The European Commission 2018a, 2019). BIM4REN targets specifically residential buildings and the two others aimed at improving energy efficiency (The European Commission 2018b).

All these European programmes aim at fostering the BIM implementation through Europe. Each country, such as the United Kingdom or France is, at the same time developing National programmes to facilitate BIM adoption (Republique Francaise n.d.; GOV.UK 2016). But, as highlighted in the EU BIM Task Group Handbook this will increase the risk of divergence across Europe and raise new barriers for working in different markets increasing the cost of compliance to the construction sector (EU BIM Task Group 2017).

1.3.3 Academic literature Review findings

In Table 4, papers selected as relevant to the topic were analysed, and a matrix was set up aiming to classify the 28 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 4). The UK has a total of 16 documents including five Journal papers addressing BIM implementation in the UK (Eadie et al. 2013; Rezgui, Beach, and Rana 2013; Dainty et al. 2017; Alreshidi, Mourshed, and Rezgui 2017), barriers associated with BIM adoption, and BIM standardisation (Maradza E., Whyte, and Larsen 2013). Furthermore, three review papers were in the search area among them one developed a roadmap for BIM implementation and one addressed specifically costs related to BIM implementation, Table 4. Kassem et al. went further and compared BIM publications (guidelines, protocols and requirements) from eight countries aiming to organize the knowledge and facilitate their access (Kassem, Succar, and Dawood 2014). In addition to that, Abdirad 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 and Björk 2014) and organisation in the construction sector (Gustavsson, Samuelson, and Wikforss 2012) and BIM standardisation (Hooper 2015). Two Journal papers were found for Denmark (Jensen and Johannesson 2013)

The study made by (R. Davies et al. 2015) involved the continent level and (Wooyoung Jung and Lee 2015) specifically France, Sweden and the UK. For Finland, one among the five documents is a Journal paper addressing BIM Implementation by comparing various countries across the world (A. K. D. Wong, Wong, and Nadeem 2010) and the other addressing BIM implementation in various countries, Denmark, Finland and Norway, USA, Singapore and Hong Kong (A. K. D. Wong, Wong, and Nadeem 2010). Jensen et al. proposed a comparison between Denmark and Ireland regarding BIM implementation in order to use the experience of Nordic countries for the Icelandic AEC industry (Jensen and Johannesson 2013). Young and Lee proposed a numerical chart for assessing quickly the level of BIM adoption and implementation. They focus on three regions, North America, South Korea and Western Europe (W. Jung and Ghang 2016). Cheng et al., reviewed the public efforts for BIM implementation in four regions, the United States, Asia, Australasia and Europe (Cheng and Lu 2015). The category the most addressed by the 26 documents is BIM implementation, barriers and challenges associated with it and countries comparison. In fact, ten papers have made a comparison between various countries. Smith conducted a literature review on BIM implementation across the world, including some European countries (the UK and Scandinavian region) (Smith 2014). The literature review showed that there was no comparison between all EU countries regarding BIM implementation.

Table 4: The papers (Journals, Conferences & Reviews) addressing BIM implementation in EU countries

Type of Documents	Paper's Number	AUTHORS	BIM						Countries												
			Implementation	Standardisation	State of the art	Countries Comparisons	Adoption assessment	Barriers /Challenges	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)	✓			✓		✓					✓								✓

1.3.4 Online survey

1.3.4.1 Respondent background and company

Respondents were asked to provide background information on their discipline and the size of their company. The Company size more than 50 Employees represent (39%) followed by small companies with a maximum of 5 Employees (33%). Companies having a size between 6 and 50 Employees are the less represented (28%). Respondents are distributed in much the same way across all types of company size. The sector of activity of the majority of respondents is Architecture (63%). Project management and training sectors represent 53% of the respondents. Facility Managers, Quantity Surveyors and Construction sectors account for 16-18% of respondents. The total is more than 100% because some companies have activities in multiple sectors.

1.3.4.2 BIM adoption/Awareness

The BIM awareness, targeted via 3 questions is part of the primary data provided by the questionnaire. Table 5 summarises the results and gives a classification of the 28 European countries, in three categories: (i) Early Adopters, (ii) Late Adopters, and (iii) Very Late Adopters. The confidence of the results is low due to the number of respondents per countries (represented by three respondents while others are represented by two or one respondent). Therefore, other sources of information were used to check the BIM mandate date of Table 5. For example, the CitA report (Mcauley, Hore, and West 2017), the NBS International BIM report (NBS 2016), the SmartMarket Report (SmartMarket Report 2010) and the European Analytical Report (The European Commission 2017c).

Table 5: BIM implementation mandatory date in EU countries and their classification according to BIM adoption level (Online Survey May 2017)

		Already Mandated countries							Already planned countries						
Sources	Regulation/ Adoption State	Finland	Estonia	Luxembourg	Sweden	Denmark	Netherlands	UK	Austria	Lithuania	Germany	Italy	Spain	Poland	Portugal
Questionnaire	Date of BIM mandate	2002/2007	2013	2016	2015	2012	2012	2016	2020	2018/2020	2016/2020	2016/2017	2018	2020	2020
	Early Adopters	✓✓✓				✓	✓	✓		✓✓					
	Late Adopters		✓✓	✓✓	✓✓				✓✓✓	✓	✓	✓		✓	✓
	Very Late Adopters										✓		✓		
CitA Report	Date BIM adoption Verifications	2007			No Regulation	2007	No Regulation	2016	2018		2020	2016	2018		No Regulation

		Will be planned countries						Not yet planned countries							
Sources	Regulation/ Adoption State	France	Latvia	Slovakia	Croatia	Czech Republic	Ireland	Slovenia	Cyprus	Romania	Belgium	Bulgaria	Greece	Hungary	Malta
Questionnaire	Date of BIM mandate	planned	planned	planned	planned	planned	planned	×	×	×	×	×	×	×	×
	Early Adopters		✓			✓	✓			✓					
	Late Adopters	✓✓		✓✓	✓	✓		✓✓	✓	✓	✓			✓	
	Very Late Adopters	✓	✓✓	✓	✓				✓✓	✓		✓	✓		✓
CitA Report	Date BIM adoption Verifications	2017				No Regulation					No Regulation				

Most dates were consistent with the questionnaire, except for Denmark (2007 in the CitA report) and for Italy according to CoBuilder, the BIM will be mandatory in three stages with a start in 2019 and to be mandatory for all projects in 2022 (“BIM in Italy - CoBuilder” 2017). From left to right, in Table 5, responses are more scattered. For early adopters, BIM is already used, and respondent knowledge about it is consistent, whereas late-comers respondent response is more variable.

As illustrated in Table 5 and according to the questionnaire results, 25% of the EU countries have already mandated the use of BIM and 25% have already planned the date to mandate its adoption. More than one-fourth of Europe has no plan yet for BIM implementation. Results showed very low BIM adoption levels in most countries and a big gap between early adopters, late adopters or very late adopters (Figure 3, Table 5).

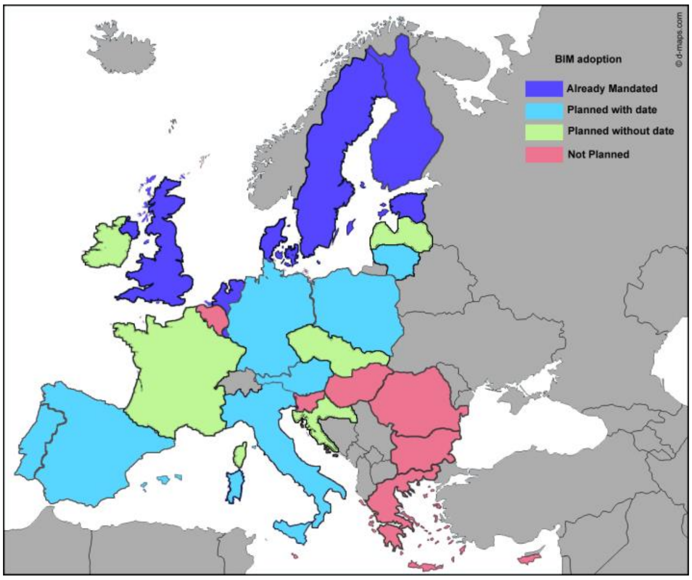

Figure 3: State of the Art of BIM adoption across Europe according to the questionnaire and verification of results (May 2017).

1.3.4.3 BIM implementation barriers

Kouider et al. 2007, highlighted the significant barriers and obstacles to the use of BIM. They agreed that the greatest resistance came from the unwillingness of practitioners to change traditional working practices (Kouider, Paterson, and Thomson 2007). However, there are more barriers already identified in the literature and listed in Table 6.

To complement the assessment of the main barriers for BIM adoption in the 28 EU countries, questions with a Likert scale (Strongly agree, Agree, Disagree and Strongly Disagree) were asked. For the analysis of the responses, the scale was simplified, “strongly agree” and “agree” were merged together in Table 6. The 28 EU countries were also grouped in four categories according to the Table 5 on their BIM adoption level: (a) Already mandated, (b) Already planned, (c) Will be planned and (d) Not yet planned.

To analyse the results of the questionnaire regarding the origin of the respondents (from 4 different groups), we have calculated the mean of the four group responses in the last column of Table 6. If the coefficient of variation is greater than 0.03 (3%), then the value of the mean is considered not relevant, and some correlation with the origin of the respondent is sought. Therefore all the values of mean plotted in the last column have a coefficient of variation smaller than 3%.

For the other results, to study the correlation between the responses and the origins of the respondent company, we have only considered the two extreme groups (“Already Mandated” and the “Not Planned Yet”) in order to study the highest gap between the countries. We have calculated the relative difference between the columns “Already Mandated” and the “Not Planned Yet” in %. We have therefore divided the difference of the two columns by the sum of both, times 2. When this result, in absolute value, is greater than 0.24 (24%), we will discuss the correlation considering this value as relevant compared to the actual variation of the data.

Table 6: Barriers for the EU countries, according to the questionnaire and the literature review

	Questions	(Numbers refer to articles listed in Table 2)								% of strongly aggree and agree				
		Finland	Sweden	Denmark	UK	Germany	France	Czech Republic	Ireland	Already Mandated	Already planned	Will be planned	Not planned yet	Mean, Coef. Var. <3%
Cultural and individual issues	*Lack of awareness*				(10)					67%	83%	85%	100%	C-
	Cultural change required		(23)	(3)	17)(22)(23)		(23)			92%	92%	85%	93%	90%
	Resistance to change (cultural/staff)		(7)	(3)	(28)(5)(6) (10)(12)(22)					83%	100%	77%	86%	86%
	Lack of demands				(11)(12)					75%	100%	69%	93%	NR
	Doubt about ROI, vision of benefits		(7) (23)		(28)(10)(11) (12)(17)(22)					50%	67%	92%	79%	C-
	BIM is not yet mature				(10)					33%	58%	38%	14%	C+
	BIM is too complex				(28)(17)					25%	25%	62%	43%	C-
	Age factor reluctance for change				(17)									
	Lack of motivation				(10)(11)									
	Trust issues				(10)									
	Lack of practical use				(11)			(24)						
Economic and technology issues	*ICT barriers*		(7)		(5)(10) (11)(12)(22)	(28)		(24)		58%	67%	31%	50%	NR
	Lack of in-house expertise /skilled personnel shortage		(7)(8)		(13)(28)(10) (11)(12)			(24)		83%	100%	100%	86%	92%
	Lack of training/education in universities				(28)(5)(6) (10)(11)(12)	(28)	(23)			75%	92%	77%	93%	84%
	Interoperability of BIM software/data translation		(7)		(28)(5)(10)(3)				(18)	75%	58%	77%	36%	C+
	Cost of BIM implementation (Software & Training)		(7)		(5)(10)(11) (12)(17)(22)			(24)	(18)	50%	75%	69%	79%	C-
	Processes/Collaboration issues/new working practices		(8)(23)	(3)	(13)(5)(6)(10) (12)(17)(23)		(23)		(18)					
	Lack of research and development				(17)									
	Data management/Exchange/storage/Tracking/		(7)		(5)(10)(12)				(18)					
	Classification		(8)											
	Roles & Responsibilities				(10)(22)									
	Project team fragmentation		(23)		(5)(6)(10)									
	Risk of various approaches development		(8)											
	Lack of common interest software vendor's				(22)									
	Lack of development of new FM systems		(23)											
Political and legal issues	*Lack of Governement lead*		(8)					(24)		50%	100%	92%	93%	C-
	Lack of guidance for BIM implementation and utilisation		(8)		(13)					75%	75%	85%	93%	82%
	Lack of National standard, procedures and guidelines		(7)(8)		(28)(10)(3)	(28)			(18)	58%	100%	92%	93%	C-
	Lack of new or amended form of construction contracts	(16)			(5)(10)					100%	83%	77%	86%	86%
	Legal issues: Data ownership and responsibilities	(16)		(16)	(5)(10) (12)(17)				(18)	67%	67%	77%	50%	C+
	Change in procurement methods				(5)(10)(17)					75%	83%	100%	71%	NR
	Insurability issue				(10)(17)					33%	58%	38%	43%	C-
	Property Rights issues	(16)	(23)		(5)(10)(17)(23)		(23)			25%	50%	38%	36%	C-
	Security issues/Liability		(7)		(10)(12)				(18)					
	Lack of legal framework		(23)		(22)(23)		(23)	(24)	(18)					

(C-) Barriers already tackled by the “Already mandated” group
(C+) Barriers less perceived by the “Not planned yet” group
(NR) No correlation to any group

1.3.5 BIM adoption disparities across Europe

The respondents were questioned about their awareness and opinion regarding the gap between EU countries. The results revealed that 51 respondents are aware of the existing gap (Figure 4). Sixty-three per cent of them considered that the difference between BIM adoption across Europe would have an impact on the EU economy. Eighty-eight per cent of the respondents considered that an EU BIM standardisation would help to smooth the gap. And 94% of them would volunteer for the march toward the standardisation of BIM across Europe to avoid the widening gap between "the haves and have-nots".

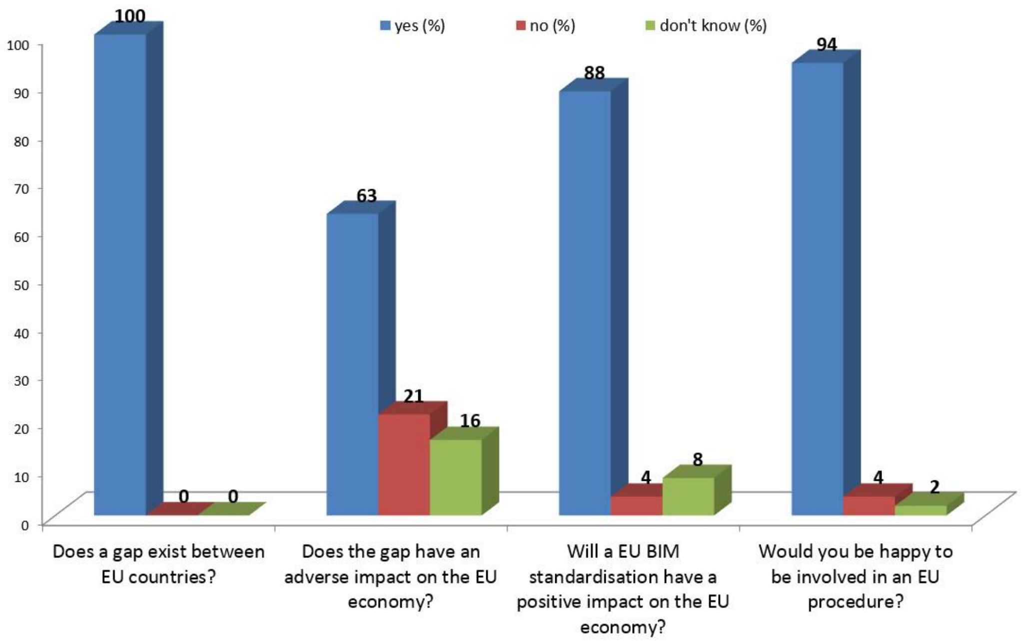

Figure 4: Awareness of the European gap in BIM implementation from the questionnaire

1.4 Discussion

In Table 6, we have divided the responses regarding the barriers, into three sets:

- the ones acknowledged with less than 3% of the coefficient of variation between respondents' groups, where we consider the mean value as consistent irrespective of the respondent group.
- the ones where the responses can be correlated with the category of the respondent. (coefficient of variation greater than 3% and the difference between the column "Already Mandated" and the "Not Planned Yet" divided by the sum of both times 2, greater than 24%). The cells of *Table 6* have a C+ or C-.
- The data which are not represented in the two previous sets, and noted NR (no relevant correlation) in the last column.

In the set (i), six barriers are acknowledged by more than 82% of the respondents (highlighted in yellow in the last column of *Table 6*): “Cultural change required”, “Resistance to change (cultural/staff)”, “Lack of in-house expertise /skilled personnel shortage”, “Lack of training/education in universities”, “Lack of guidance for BIM implementation and utilisation”, “Lack of new or amended form of construction contracts”. As this type of barriers is acknowledged by all the respondent groups, it is not possible to rely on existing established strategies to tackle them. New initiatives must be developed.

Set (ii) of barriers can be divided into two types. The barriers have already started to be tackled in the mandated BIM group, due to their older practice (marked with a C-): “Lack of awareness”, “doubt about ROI (return on investment)”, “BIM is too complex”, “cost of BIM implementation”, “Lack of Government lead”, “Lack of National standard, procedures and guidelines”, “insurability issues”, “Property Rights issues”. For this type of barriers, the “already mandated” category has fewer concerns, showing that the experience of this group would certainly help to smooth the gap of the “not planned yet” group.

The second type of barriers of this set is marked by a C+ in Table 6. These barriers are less acknowledged by the “not planned yet” group, because the respondents have not yet perceived these barriers, due to their lack of practice of BIM. This is the case for: “BIM is not yet mature”, “Interoperability of BIM software/data translation”, “Legal issues: Data ownership and responsibilities”. Again, for this type of barriers, the “already mandated” group experience can help to accelerate the uptake of BIM skills of the “not planned yet” group.

In the set (iii) we have the following barriers: “ICT barriers”, “Lack of demands”, “Change in procurement methods”. There is no consensus clearly linking the concern to any set, (marked NR in Table 6). However, the ICT barriers seem less relevant than the two others with a range of 31% to 67% compared to a range of 69% to 100%.

In Figure 4, to avoid asymmetries that could have harmful implications for the construction sector, BIM implementation had to be mandated in a good way (Dainty et al. 2017) and at a European level. In fact, policies should be set to serve those who have resources and power but also the smallest companies (Pearce and Rice 2013). If BIM implementation policies are not correctly framed, the “Matthew Effect” where the rich get richer will be an unavoidable risk. As a matter of fact, for SMEs and small projects, the barriers to BIM implementation appear more important than the advantages generated by its adoption (Kouider, Paterson, and Thomson 2007).

1.5 Recommendations

1.5.1 Gap growth risk and the EU construction market

Across the world and in Europe, the same awkwardness has followed construction projects which are fragmented and silo working. Also, the inadequate information management was identified as leading inevitably to an unsustainable performance of the Architectural, Engineering, Construction and Operation Industry (AECO). The low productivity highlighted in the report “Rethinking productivity across the construction industry" due to poor coordination between the various stakeholders, will keep on if the gap of BIM implementation is not reduced (Fister Gale and Lara 2015). The use of BIM process implies a significant change for the EU countries enabling them to reduce the cost of projects but also "tremendously boost the EU industry's global competitiveness in winning international building contracts." The early adopters, mainly large companies, would quickly harvest benefits from it.

The current lag between the BIM users and the low productivity of the others will then be increased. Therefore, the gap between large companies and SMEs, EU countries and inequalities in the national market or EU market will keep growing (Mellon and Kouider 2016).

1.5.2 Discrepancies in BIM adoption: Mobility of workers and skills recognition

The construction sector is moving from a local scale to a European scale, pushing the boundaries. Indeed, the current trend is to develop a construction project in different part of the globe (Ilich, Becerik, and Aultman 2006). This tendency is hugely stimulated by the use of BIM-cloud technologies that provide a real-time communication platform (J. Wong et al. 2014). It implies that the construction project has to face national issues but also international issues (different BIM workers skills and different culture, skills recognition). The international dimension will continuously be increased by the use of the BIM process. Migration starts to be an important factor in the labour distribution in Europe (The European Commission 2017c). So, technical aspects of BIM process need to be taken into account, but also other parameters should be examined such as the work culture (Kouider, Paterson, and Thomson 2007).

It is imperative to investigate how to reduce the gap between EU countries in BIM implementation to open new market opportunities across the EU, especially for SMEs (Small & Medium Enterprises) by helping them to penetrate markets abroad. They have to be working to the same standards so that all companies are able to engage and work effectively with partners within the EU without any problem. Regarding the European scale, the recognition of skills is a mandatory step. With skills recognition and BIM European standardization, the rules of the labour market will profoundly change and enhance transparency between countries to facilitate mobility of construction workers within Europe, while also improving Europe's competitiveness.

1.5.3 Aggravation of the non-attractivity of the blue-collar professions

Currently, the BIM process is widely used during the design phase. Lastly, the use of BIM during the asset lifecycle including on-site activities, facility management and EOL management would enable the valuation of blue-collar professions and establish continuity in the use of new technologies (Charef, Alaka, and Emmitt 2018). All the stakeholders involved in the asset lifecycle (White and Blue collars) will be able to enter the revolution brought by BIM in the construction sector. Blue collar professions would become more attractive, and then the shortage of workers could be fixed. As highlighted in the European Commission, the bad image of the construction sector lead to a youth labour shortage. In fact, the age of the construction sector workforce is a real barrier to the uptake of BIM. The digitalisation of the sector which is blossoming worldwide might be a great opportunity to attract youngsters to the construction industry (The European Commission 2017c).

1.5.4 Benefits of the BIM adoption standardisation

As highlighted by the EU BIM Task Group, to enact BIM adoption by the entire EU countries, a common EU BIM implementation should cover four foremost areas: People & skills, policy, technical and process. These areas must be defined and developed uniformly across EU countries. To avoid damaging consequences due to the BIM adoption gap across Europe, a European standard on BIM need to be developed. Three main benefits of a common European approach are identified. First, it will accelerate national efforts by pulling up the latecomers. By learning from the others, each EU country will accelerate its own BIM initiatives. Secondly, by avoiding to "reinvent the wheel", by using the good practices, standards and guides developed by early adopter countries will lead to costs reduction for BIM implementation initiatives. Lastly, the trade barriers will be reduced at a shared cost.

1.6 Conclusion

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. This research provides a picture of the heterogeneity of the BIM uptake in the EU, thanks to the analysis of the literature review and the online questionnaire. Although the number of respondents is very small in comparison to the number of people working within the construction sector in Europe, we have drawn on informed opinion and hence are able to offer a unique insight. The results reveal that BIM implementation at the national level does not yet exist in some countries while some EU countries have been using BIM technology for more than a decade.

Despite the positive impact on the productivity and the Architecture Engineering Construction and Operation Industry recognition, the use of BIM still encounters reticence and various barriers depending on the EU countries.

We have highlighted the main barriers to BIM adoption by a questionnaire disseminated in all EU countries and compared the results with the barriers described by academics. If nothing is done on a European scale to tackle the barriers, then it might become difficult for BIM late comers to adopt BIM and work at the same standard as the BIM early adopters. This may hinder cross border projects and collaborations. EU countries need to have a common ground by sharing the best practices, enabling BIM leading countries to pull the late adopters upwards. Exactly how this will be achieved is open to further investigation.

2 Appendix 2

Paper accepted (April 2018) in Journal of Building Engineering

Beyond the Third Dimension of BIM: A Systematic Review of Literature and Assessment of Professional Views

Rabia Charef[1], Hafiz Alaka[1], Stephen Emmitt[2]

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3 Appendix 3

3.1 Organizational barriers

			CE-DfCE	Cv	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	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38	P39	P40	P41
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																																									
Approach/Methods Drawback	Discontinuity between phases	Construction industry suffers from disconnection of				x																																											x													
Sector/organisation Fragmented	Fragmentized nature of the sector and the high	Fragmentized nature of the sector and the high number				x									x					x				x	x																x	x						x													
Sector/organisation Fragmented	Linear/sequential relationship between	Linear, sequential relationship between the design and				x																			x																																				
Sector/organisation Fragmented	Responsibilities fragmentation	The fragmentation of responsibility in the construction																		x				x																																					
Sector/organisation Fragmented	Fragmentized nature of the sector	Fragmented nature of construction supply chains				x																																				x																			
Sector/organisation Fragmented	Fragmentized nature of the sector	The fragmented structure of the construction supply				x																																										x													
Sector/organisation Fragmented	Fragmented supply chain	fragmented supply chain for reused materials													x																										x																				
Sector/organisation Fragmented	Fragmentized nature of the sector and the high	Way the construction industry is organised (Large				x																																				x																			
Sector/organisation Fragmented	Organisation segmentation	Strong segmentation of an organization’s departments																		x				x																																					
Approach/Methods Process	Linear process	Construction as a linear process entailing sequential				x																																										x													
Sector/organisation	Material flow	Complicated and fragmented nature of the materials				x																																									x														
2-Inapropriate organisation/method of the sector			x		x	x		x			x			x		x	x		x	x																																									
Design phase			x					x			x			x		x	x			x																																									
Approach/Methods Process	Detached from the design process	detached from the design process															x																						x																						
Approach/Methods Requirements	Deconstruction requirements in the design phase	Incorporation of deconstruction issues into the design												x																																										x					
Approach/Methods process	Possibilities to apply integrated design processes	Possibilities to apply integrated design processes																		x				x																																					
Approach/Methods Process	Repetitive design leading to monotony Design	Repetitive design leading to monotony Design process						x																													x																								
Approach/Methods	Lack of methods	lacks powerful methods for design phase						x								x				x				x		x										x																									
Approach/Methods Adoption	Lack of circular and green design methods	Lack of circular building principles and green design	x																							x																																			
Approach/Methods	Unfamiliarity with methods	unfamiliarity of the design team and contractors with SB																		x				x																																					
Approach/Methods Drawback	Conflict between some design for disassembly	Conflict between some design for disassembly principles									x																																												x						
Approach/Methods effectiveness	Lack of priority for minimization during the design	minimization is still not given priority during the design															x																										x																		
Construction phase								x			x									x																																									
Approach/Methods	Lacks of suitable methods	Lacks a suitable method or principle considering the						x																												x																									
Approach/Methods effectiveness	Current Design & Construction processes	The established design and construction processes																		x																				x																					
Approach/Methods effectiveness	Current construction practice	Current construction practice									x									x				x																x															x						
EOL						x					x																																																		
Approach/Methods effectiveness	Use of erroneous methods	Use of erroneous deconstruction methods									x																																																x		
Approach/Methods effectiveness	Approach unappropriate	Necessary time and labour for disassembly of buildings				x																																									x														
Lifecycle																			x	x																																									
Approach/Methods	Methodology for reusing materials	Major issue (methodology for reusing materials) is how																	x																						x																				
Approach/Methods	Lack of lifecycle performance focus	Lack of focus on the life cycle performance in terms of																		x						x																																			
Inapropiate sector organisation/method			x		x	x								x		x	x			x																																									
Sector/organisation Inappropriate	Deficient structure of the industry	Deficient structure of the industry for adopting RL				x																			x																																				
Sector/organisation Inappropriate	Inappropriate organisational structure (and size)	Inappropriate organisational structure (and size)				x																			x																																				
Sector/organisation	Far behind other sectors	The construction industry is far behind other sectors in				x																																				x																			
Sector/organisation	Nature of construction products & activities	Barriers due to the nature of construction products (e.g.				x																			x																																				
Approach/Methods effectiveness	Current methods unappropriate	Existing methods entail significant amount of extra work																		x				x																																					
Approach/Methods Evenness	Lack of common practice	Not common practice at this time												x						x				x																																	x				
Approach/Methods effectiveness	Inadequacy of technologies	Inadequacy of technologies (emphasis on information				x																			x																																				
Approach/Methods effectiveness	Inadequate development of capital project	Inadequate development of capital project planning	x																							x																																			
Approach/Methods	The models of cooperation and networking	The models of cooperation and networking																		x				x																																					
Approach/Methods	Lack of methodologies	Lack of science-based user-friendly methodologies in the														x										x																																			
Approach/Methods	Lack of methods	Lack of methods for comparisons, quality control and																		x				x																																					
Approach/Methods Adoption	Lack of development and adoption of methods	Lack of development and adoption of methods																		x				x																																					
Approach/Methods Adoption	Challenging to implement	Closing material loops in construction remains the most			x	x																																						x		x															
Approach/Methods Adoption	Implementation on static perspective	Waste minimization strategies are usually implemented															x																																				x								
Approach/Methods Adoption	Capital building project process	Capital building project process	x																							x																																			
Approach/Methods Adoption	Challenging to implement	RL is considered one of the most difficult initiatives to				x																																								x															
Sector/organisation	Restraining organisational policies	Restraining organisational policies (e.g. overlooking				x																			x																																				

			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	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38	P39	P40	P41
3-Lack of holistic approach						x												x		x																																									
Approach/Methods	Lack of a hollistic approach	Lack of a hollistic approach																x		x				x		x																											x								
Approach/Methods	Lack of hollistic approach	lack holistic framework																x																																			x								
Approach/Methods	Lack of hollistic approach	No hollistic view of the supply chain																		x				x																																					
Sector/organisation Awareness	Lack of awareness within the organisation	Lack of awareness within the organisation				x																			x																																				
4-Health and safety												x		x	x																																														
Health & Safety	Health risks	Health risks													x																																														x
Health & Safety	Workers safety	Dismantling buildings is extremely hazardous										x		x																									x																							
Health & Safety	Workers safety	workers safety pollutants and dust												x																									x																							
b-Lack of support from the top management team						x												x																																											
Sector/organisation Management	Lack of support from management	Lack of support from management				x																			x																																				
Sector/organisation Management	Management and information systems	Immaturity and low investment in knowledge				x																			x																																				
Additional Resources & effort	Resources and effort necessary	Resources and effort necessary for continuous planning				x																																											x													
Budget /Cost repartition	Budgetary allocations for CDW Management	Lack of specific budgetary allocations for CDW																x																																		x										
c-New approach issues					x	x		x		x				x	x			x		x																																									
1-Complexity to implement new approaches					x	x														x																																									
Approach/Methods Difficulties	Close loop built environment difficult	Closing materials loops for built environment more			x	x														x				x								x										x													x						
Approach/Methods Difficulties	Difficulties for new process & working methods	Difficult to adopt new processes and working methods																		x				x																																					
Approach/Methods Difficulties	Difficulty to applicate	Generic theories on RL developed outside the				x																																				x																			
Approach/Methods Difficulties	Difficulty to applicate due to complexity &	The complexity and the temporary nature of projects				x																																				x																			
2-Implementation						x								x						x																																									
Approach/Methods	Lack of support in organisations	Risks, uncertainties and potential liabilities for using				x																			x																																				
Approach/Methods	Challenges for designers	Implementing RL in construction projects is fraught with				x																	x																																						
Approach/Methods	Support for implementation	Customer support, top management support,				x								x											x																					x		x														
Approach/Methods	Lack of steering	Lack of steering (direction) or the wrong type of steering																		x				x																																					
Approach/Methods	Lack of support in organisations	Lack of support in organisations				x																			x																																				
Approach/Methods	Lack of support in organisations	Risks, uncertainties and potential liabilities for using				x																																									x														
Approach/Methods	Support for implementation	Top-management support; formalisation;				x																			x																																				
Approach/Methods	Not widely implemented	Deconstruction has not been widely implemented												x																															x																
Approach/Methods	Lack of support from parties in the supply chain	Lack of support from parties in the supply chain				x																			x																																				
3-Flexibility								x							x																																													
Approach/Methods Flexibility	Design flexibility	Requires the designers to be far more flexible and willing						x							x																						x			x																					
Approach/Methods Flexibility	Lack of Flexibility	Lack of Flexibility for using prefabrication						x																													x																								
Approach/Methods Flexibility	Design flexibility	there may be a need to vary the design to suite available													x																									x																					
Approach/Methods Flexibility	Fexibility	Not flexible enough						x																													x																								
Approach/Methods Flexibility	Inflexibility in respect of design modifications	Inflexibility in respect of design modifications and higher						x																													x																								
4-Planning						x								x	x					x																																									
Approach/Methods Planning	Scheduling	The right timing and the presence of all needed actors				x								x	x					x			x	x	x																													x				x				x
Approach/Methods Planning	Careful planning	Planning for deconstruction=careful planning and additional time												x																																								x								
Approach/Methods Planning	Difficulty of scheduling	Difficulty of scheduling													x																																														x
Approach/Methods Planning	Scheduling	The need for rapid demolition and clearing of the site													x																																											x				
Approach/Methods Planning	Scheduling	Timing of operations;				x																	x																																						
Approach/Methods Planning	Tight scheduling	Tight scheduling of building projects				x																			x																																				
5-Methods effectiveness										x				x				x																																											
Approach/Methods effectiveness	End of pipe treatments unappropriate for waste	End of pipe treatments = limited tendencies of reducing																x																																			x								
Approach/Methods effectiveness	Existing CDW Mana = ineffective and poorly	Existing CDW Mana are largely ineffective and poorly																x																																			x								
Approach/Methods effectiveness	CDW Ma and LCA are inadequately explored	CDW Ma and LCA are inadequately explored																x																																			x								
Approach/Methods effectiveness	Major changes requirements	Major changes requirements in terms of the way								x																																			x																	
Approach effectiveness assessment	Approach effectiveness assessment	Different CDW Mana approaches but no benchmark for												x				x																																			x			x					
Approach effectiveness assessment	Lack of effectiveness assessment methods	Development of methodologies to assess, test and												x																																											x					
6-Methods contract						x														x																																									
Approach/Methods Contracts	Procurement practice: Focus on price	Focus on price in procurement practices				x														x				x	x																																				
Approach/Methods Contracts	Rules of competition and tendering processes	Rules of competition and tendering processes																		x				x																																					
Approach/Methods Contracts	Bureaucratic issues	Bureaucratic problems in granting of licences and				x																			x																																				

			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	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38	P39	P40	P41
7-Methods requirement						x								x	x					x																																									
Approach/Methods Requirements	Lack of clear requirements	Difficulty to define measurable requirements				x								x	x					x				x									x														x									x					
Approach/Methods Requirements	Requirements for the CLC approach	Reuse alone does not meet the requirements for a CLC													x																		x																												
Approach/Methods Requirements	Lack of clear requirements	to express the targets and requirements clearly and																		x				x																																					
Approach/Methods Requirements	Requirements should be considered in the design	RL requirements are not taken into account in design				x																																									x														
Approach/Methods Requirements	Lack of knowledge/skills	Insufficient knowledge to develop a project brief with																		x				x																																					
Approach/Methods Requirements	Measurable requirements definition	Difficulty to define measurable requirements																		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																																									
Approach/Methods Changes	Changes in the industry	Significant changes in the industry is needed			x									x	x																	x							x				x													x				
Approach/Methods Changes	Change in approach and process	The reuse of reclaimed components often requires a													x																									x																					
Approach/Methods Changes	General supply shortages	General supply shortages,		x																							x																																		
Approach/Methods Changes	Processes changes	Changes in processes needed															x											x																																	
Approach/Methods Changes	No significant progress has been made:	Significant progress has not been made institutionalizing												x																														x																
Approach/Methods Changes	Building systems changes	Deconstruction, DfD and the application of IFD building												x																													x																	
Approach/Methods Changes	Demolition process changes	changes in the demolition process to include sorting of													x																																									x				
Approach/Methods Changes	Design & construction processes changes	This can affect the whole design and construction process													x																									x																					
Approach/Methods Collaboration	Lack of development of competence and team	Lack of development of designers’ competence and team																		x				x																																					
Approach/Methods Collaboration	Lack of cooperation among team	Lack of cooperation among these				x																																											x													
Approach/Methods Collaboration	Lack of a coordinated supply chain	Lack of a coordinated supply chain that ensures a													x																									x																					
Approach/Methods Collaboration	Team working	Team working																		x				x																																					
b-Multidisciplinary team										x										x																																									
Sector/organisation Management	Systematic cooperation and a multidisciplinary	Need for a systematic cooperation and a								x																																	x																	
C-Communication issues						x		x			x									x																																									
a-Lack of communication						x					x									x																																									
Approach/Methods Communication	Lack of communication	Lack of communication				x																		x																																						
Approach/Methods Communication	Communication	Communications,				x														x				x	x																																				
Approach/Methods Communication	Lack of communication	Lack of communication																		x				x																																					
Approach/Methods Communication	Communication	Cooperation and effective communication between the																		x				x																																					
Approach/Methods Communication	Communication	Issues in management and communication-related																		x				x																																					
Approach/Methods Communication	Models of communication	models of communication																		x				x																																					
Communication	Lack of communication	Lack of communication									x																									x																							
b-Late communication between designer-contractor								x																																																					
Approach/Methods Collaboration	Early collaboration between architects,	The design process is an interactive process that requires						x																												x																								
c-Lack of common classification																				x																																									
Approach/Methods Evenness	Lack of a common language	Lack of a common language																		x				x																																					
D-Key players			x	x	x	x		x						x	x					x																																									
a-Multiple stakeholders			x	x	x	x								x						x																																									
Sector/organisation Actors	Custom-designed/built by a large group of	Buildings are custom-designed and custom-built by a			x	x																			x																	x		x																	
Sector/organisation Actors	All stakeholders involved are concerned	DfD is an issue for all stakeholders involved		x										x													x																													x					
Sector/organisation Actors	Roles of different actors	Roles of different actors																		x				x																																					
Sector/organisation Actors	High number of actors involved	Large number of parties and decision makers involved,				x																			x																																				
Sector/organisation Actors	Stakeholders involvement	Discontinuity in the involvement of key stakeholders in		x																							x																																		
Sector/organisation Actors	More stakeholders	More stakeholders	x																								x																																			
Sector/organisation Actors	The large number of parties involved	The large number of parties involved make it harder for				x																																					x																			
b-Architects																x																																													
Sector/organisation Actors	Limited liability	In many cases standard specifications prevent or inhibit													x																									x																					
Approach/Methods Changes	Design & construction processes changes	The reuse of materials in buildings is site-specific and													x																									x																					
Approach/Methods Changes	Design & construction changes	The design and construction process may need to change													x																									x																					
c-Contractor					x																																																										
Sector/organisation Actors	Stakeholders barriers	Contractor barriers include reluctance of field personnel		x																							x																																		

			CE-DfCE	Cv	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	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38	P39	P40	P41
d-Manufacturer								x							x					x																																									
Sector/organisation Actors	Complex supply chain/competing interests	Complex supply chain with competing interests																		x				x																																					
Sector/organisation Actors	Lack of suppliers	Lack of suppliers						x																													x																								
Material/Product Process	Manufacturers are not associated with the end	No single ‘manufacturer’ is associated with the end			x																																							x																	
Sector/organisation Actors	Manufacturers’ lack of involvement and	Manufacturers’ lack of involvement and responsibility to													x																																											x		
e-Owner				x											x																																														
Sector/organisation Actors	Owner barriers	Owner barriers include a lack of concept awareness, false		x																							x																																		
Budget /Cost repartition	Client has to spend money up front purchasing	at this stage the contractor is often not appointed yet, so													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																																																					
Skills /Expertise/knowledge	Lack of industry expertise	Lack of industry expertise						x																													x																								
Skills /Expertise/knowledge	Lack of knowledge	Lack of knowledge in the industry				x																			x																																		
2-Architects incompetence				x		x		x							x	x		x		x																																									
Skills /Expertise/knowledge	Lack of competences & team working	Lack of development of designers’ competence and team working																		x				x																																					
Skills /Expertise/knowledge	Management skills	Skills for managing/ leading the design of a SB:																		x				x																																					
Skills /Expertise/knowledge	insufficient knowledge	insufficient knowledge to develop a project brief with clear targe				x									x	x		x		x			x	x	x	x																					x				x								x		
Skills /Expertise/knowledge	Lack of management skills	Lack of skills for managing, leading the design of a SB (aware		x				x												x				x			x																																		
3-Blue and white collars				x		x		x			x			x	x	x	x			x																																									
Skills /Expertise/knowledge	Lack of experienced skilled volunteers	Finding appropriately experienced skilled volunteers with a		x		x		x						x						x				x	x		x										x								x																
Skills /Expertise/knowledge	Lack of a developed knowledge	Lack of a developed knowledge base for DfDi									x																							x																											
Skills /Expertise/knowledge	Lack of in-house expertise	Lack of in-house expertise/experience				x		x																	x												x																								
Skills /Expertise/knowledge	Lack of management support	Lack of support from customer and top management support				x																	x																																						
Skills /Expertise/knowledge	Lack of new concepts and services.	Lack of development of new concepts and services.													x					x				x																																	x				
Skills /Expertise/knowledge	Knowledge gaps	Part of this is due to the knowledge gaps about reused materials' reliability														x										x																																			
Skills /Expertise/knowledge	Lack of experience	Lack of experience																		x				x																																					
Skills /Expertise/knowledge	Lack of expert	Lack of expert personnel,		x																							x																																		
Skills /Expertise/knowledge	Lack of human resources with necessary adequate	Lack of human resources with necessary qualifications and exper				x																			x																																		
Skills /Expertise/knowledge	Lack of research and development	Lack of research and development into the treatment of contaminated building waste													x																																										x				
Skills /Expertise/knowledge	Lack of acquaintance	Lack of information and education													x																																											x		
Skills /Expertise/knowledge	Lack of knowledge/ignorance of Sustainable techn	Lack of knowledge of RL practices				x																																									x														
Skills /Expertise/knowledge	Lack of knowledge on stakeholder's expectations	Lack of knowledge on stakeholder's expectations on how to use BIM for CDW Mangement															x																						x																						
Skills /Expertise/knowledge	Lack of a developed knowledge	Lack of a developed knowledge base for DfDi									x																							x																											
Skills /Expertise/knowledge	Knowledge gaps in reused materials’ reliabilit	Knowledge gaps about reused materials’ reliability														x										x																																			
Skills /Expertise/knowledge	Lack of new concepts and services.	Lack of development of new concepts and services.													x					x				x																																	x				
b-Competence improvement needed			x	x		x				x	x			x			x			x																																									
Approach/Methods Comprehension	Lack of comprehension	Lack of comprehension of SB																		x				x																																					
Lessons learned	Lack of benefits evidence	Application of DfDi is restrained by uncertainties regarding its global benefit									x																																								x									
Lessons learned	Lack of lessons learned	lack of lessons learned documentation,		x																							x																																		
Lessons learned	Lack of study providing clear instruction	No study provided clear instructions on how BIM could be used for CDW M								x							x																						x					x																	
Lessons learned	Pilot project effectiveness demonstration	Identification of demonstration projects to illustrate the p	x											x												x																														x					
Lessons learned	Unexplored area	RL remains an “unexploited” area				x																																				x					x													
Lessons learned	Lack of empirical evidence	Lack of empirical evidence to support its widespread use of RL				x																																				x																			
Lessons learned	Lack of study	Lack of IFD studies for high-rise buildings								x																																		x																	
Lessons learned	Pilot project effectiveness demonstration	Lack of studies that demonstrate quantitatively the effect	x																							x																																			
Lessons learned	Unexplored area	RL uptake is limited in the construction industry				x																																										x													
Lessons learned	Unexplored area = drivers	The drivers associated with the adoption of RL remain an underst				x																																				x																			
Approach/Methods Training	Specific training, handling, and equipment for	Specific training, handling, and equipment for proper											x																																									x					

3.2 Policies 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		
Slow regulation application	Slow regulation application	National and regional governments are slow to apply C&DW management plans which have been approved																x		
b-Inspectors behaviour						x														
Inspectors behaviour	Building inspectors discourage us	Building inspectors often discourage the use of salvaged materials in new buildin				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
Lack of building standard / guidance	Lack of standard building layout	Lack of standard building layout				x				x				x	x					x
Lack of building standard / guidance	Lack of standards for reclaimed m	Lack of clear information and guidance for designers and owners about the implications of specifying r													x					
Lack of building standard / guidance	Lack of standards and technical gu	Lack of standards and technical guidelines makes the use of salvaged items a sour				x														
Lack of building standard / guidance	Lack of standards & guidelines	Lack of standardised processes and lack of shared understanding of the best pract				x														
Lack of building standard / guidance	Lack of clear information and guic	Lack of clear information and guidance for designers about the design and procurement procedures to													x					
Lack of building standard / guidance	Lack of guidance	Lack of guidance for sustainability in public facilities for FM, operational gaps																		x
Lack of building standard / guidance	Informative RI	Informative regulatory instruments : mandatory labelling																		x
Lack of building standard / guidance	Lack of codes	Lack of standardised processes and lack of shared understanding of the best pract				x														
Lack of building standard / guidance	Normative RI	Normative regulatory instruments: building codes (= time-consuming process)																		x
Lack of building standard / guidance	Lack of Planning policies	Planning policy																		x
Lack of building standard / guidance	Lack of regulatory	Lack of regulatory												x						
Lack of building standard / guidance	Lack of policies framework	Strategic commitments and national policy frameworks which enable local authorities and relevant												x						
2-Lack of standard for recoved materials						x								x						
Lack or unadapted of legislation/Regulatory Fr	Lack of building codes for recover	building codes often do not address the reuse of building components.				x								x						
Lack or unadapted of legislation/Regulatory Fr	Lack of building codes for recover	building codes often do not address the reuse of building components.												x						
Lack or unadapted of legislation/Regulatory Fr	Lack of standards for recovered m	Lack of standards for how to reuse some recovered materials				x														
Lack or unadapted of legislation/Regulatory Fr	Lack of standards for recovered m	Lack of standards for how to reuse some recovered materials												x						
3-Lack of certification and re-certification														x	x					x
Lack of re-certification	Lack of re-certification of used co	Re-certification of used components is not often possible												x	x					x
Lack of re-certification	Lack of re-certification of used co	Re-certification of used components is not often possible												x						
Lack of re-certification	Lack of re-certification of used m	Lack of re-certification of used materials												x						
Lack of Assessment procedures	Certificate schemes	Economic and market-based instruments: certificate schemes																		x
Lack of re-certification	Recertification, legal warranties a	Recertification, legal warranties and residual performance of recovered building materials.													x					
4-Lack of incentives						x														x
Lack of incentives	Lack of economic incentives and f	Lack of economic incentives and fiscal methods				x														x
Lack of incentives	Lack of financial incentives	Lack of financial incentives				x														
Lack of Incentives	Lack of regulatory incentives	Lack of regulatory incentives				x														
Lack of Incentives	Fiscal instruments and incentives	Fiscal instruments and incentives.																		x
Lack of Incentives	Lack of financial and regulatory ir	Lack of financial and regulatory incentives				x														
Lack of Incentives	Lack of financial and regulatory ir	Lack of financial and regulatory incentives				x														
Lack of Incentives	Lack of RI/Innovation incentives	Lack of regulation for existing buildings/C&DW reduction and diversion																		x
Lack of Incentives	Lack of regulation and innovation	Lack of regulation and innovation																		x

	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38	P39	P40	P41
A-Slow regulation application and Inspectors' behaviour																																									
a-Slow regulation application																																									
Slow regulation application																															x										
b-Inspectors behaviour																																									
Inspectors behaviour																												x													
B-Lack of appropriate standards and policies																																									
a-Lack of policies-regulation																																									
1-Lack of standard Building standar / guidance																																									
Lack of building standard / guidance				x	x												x			x								x													
Lack of building standard / guidance																				x																					
Lack of building standard / guidance																												x													
Lack of building standard / guidance					x																																				
Lack of building standard / guidance																				x																					
Lack of building standard / guidance				x																																					
Lack of building standard / guidance				x																																					
Lack of building standard / guidance					x																																				
Lack of building standard / guidance				x																																					
Lack of building standard / guidance				x																																					
Lack of building standard / guidance																									x																
Lack of building standard / guidance																									x																
2-Lack of standard for recoved materials																																									
Lack or unadapted of legislation/Regulatory Fr					x													x						x												x					
Lack or unadapted of legislation/Regulatory Fr																								x																	
Lack or unadapted of legislation/Regulatory Fr					x																																				
Lack or unadapted of legislation/Regulatory Fr																		x																							
3-Lack of certification and re-certification																																									
Lack of re-certification				x																				x						x						x					
Lack of re-certification																								x																	
Lack of re-certification																																				x					
Lack of Assessment procedures				x																																					
Lack of re-certification																														x											
4-Lack of incentives																																									
Lack of incentives				x	x																						x														
Lack of incentives					x																																				
Lack of Incentives					x																																				
Lack of Incentives				x																																					
Lack of Incentives																											x														
Lack of Incentives					x																																				
Lack of Incentives				x																																					
Lack of Incentives				x																																					

			CE-DfCE	CV	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	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38	P39	P40	P41
5-Lack of support						x								x						x																																									
Lack of support	Lack of economic support from th	Lack of economic support from the government.				x								x						x				x	x																				x			x													
Lack of support	Lack of support	Lack of support from professional associations, non-government organisations, et				x																			x																																				
Lack of support	public leadership programmes	Voluntary action: public leadership programmes																		x				x																																					
Lack of support/government	Lack of government support/ince	Lack of government incentives, consistent policies, economic support				x																																										x													
Lack of support/taxation	Lack of taxation and support	Fiscal instruments and incentives: taxation and support																		x				x																																					
6-Lack of assessment procedures																				x																																									
Lack of Assessment procedures	Lack of Assessment procedures	Lack of sustainability criteria into the assessment procedures of architectural competitions																		x				x																																					
Lack of Assessment procedures	Assessment procedures late	Assessement process done late during design phase																		x				x																																					
Lack of Assessment procedures	Lack of labelling/measurement st	Lack of labelling/measurement standard																		x				x																																					
b-Policies weaknesses				x	x									x	x			x																																											
1-Lack of specific constructability requirements				x																																																									
Lack or unadapted of legislation/Regulatory Fr	Lack of specific constructability re	Lack of specific constructability requirements in most building codes.		x																							x																																		
2-Lack of Building code for dissassembly					x																																																								
Lack or unadapted of legislation/Regulatory Fr	Building codes not made for disa:	The connections of building components are defined by building codes to meet			x																																							x																	
3-Lack of standard for DfD														x																																															
Lack or unadapted of legislation/Regulatory Fr	Lack of legislation for DfD	Lack of legislation requiring clients or contractor to consider DfD at the design stage												x																														x																	
4-Lack of legislation for CDW reduction															x			x																																											
Lack or unadapted of legislation/Regulatory Fr	Lack of legislation for C&D waste	Lack of legislation which mandates C&D waste reduction and diversion													x																																									x				
Lack or unadapted of legislation/Regulatory Fr	Lack of waste management legisl	waste management legislation has limited provision for reducng waste through design																x																																			x								
c-Policies absurdity and complexity				x		x								x	x		x	x		x																																										
1-Regulation complexity and strictness				x		x									x					x																																										
Lack or unadapted of legislation/Regulatory Fr	Very strict regulatory	Very strict regulatory support for RL health and safety regulations prevent widesp				x																																										x													
Lack or unadapted of legislation/Regulatory Fr	Normative Rl: Rigid	Rigid normative steering mechanisms may also hinder the adoption of sustainable innovations																		x				x																																					
Complicate processes	Complicate processes	Building regulation and specification that complicate processes													x																																												x	
Lack or unadapted of legislation/Regulatory Fr	Rigid legislation,	Rigid legislation,		x																							x																																		
2-Regulation absurdity and failure						x								x	x		x	x		x																																										
Lack or unadapted of legislation/Regulatory Fr	Lack of consistent policy	Lack of consistent policy												x																															x																
Lack or unadapted of legislation/Regulatory Fr	Lack of proven regulatory framew	Lack of proven legal/regulatory frameworks												x																															x																
Lack or unadapted of legislation/Regulatory Fr	Policies failure	Policies failure															x																												x																
Lack or unadapted of legislation/Regulatory Fr	failure of the waste management	failure of the waste management strategies																x																																			x								
Lack or unadapted of legislation/Regulatory Fr	Inadequate ecological inducemei	Inadequate ecological inducements in the taxation system																		x				x																																					
Lack or unadapted of legislation/Regulatory Fr	Inappropriate governmental regu	Inappropriate governmental regulations				x																			x																																				
Lack or unadapted of legislation/Regulatory Fr	Policies faillure/Regulation weak	Policies failure																x																																	x										
Lack or unadapted of legislation/Regulatory Fr	Weakness of regulations	Weakness of regulations																		x				x																																					
Traditional contracts formats are unadapted	Traditional contracts formats are	Reuse and recycling practices can be less feasible due to traditional contract formats													x																																											x		
3-Liabilities for recovered materials use						x																																																								
Liabilities for recovered materials use		Liabilities associated with using recovered items,				x																			x																																				

3.3 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
Belief/Fear/Acceptance	Fear of additional construction cost (W M more expensive than waste landfilling)																x		x
Belief/Fear/Acceptance	Misperception of incurring higher capital costs																		x
Belief/Fear/Acceptance	Perceived cost and time impacts																x		
Belief/Fear/Acceptance	Strong belief = waste management is more expensive																x		
Belief/Fear/Acceptance	Disbelief in the potential utility of a constructability program		x																
Belief/Fear/Acceptance	Waste is inevitable															x			
Culture/waste behaviour	Culture of waste behaviour															x			
Culture/Attitude	Consumer culture and attitude towards the quality of salvaged and used items				x														
Culture/Attitude	Consumer culture and mindset about the lower quality of salvaged and used items				x														
Culture/Attitude	Consumer culture and perceptions				x														
b-Bad image					x				x					x					
Belief/Fear/Acceptance	Bad image of original product				x				x					x					
Belief/Fear/Acceptance	Bad image of salvaged components													x					
Belief/Fear/Acceptance	Poor quality image/Bad image of salvaged components								x										
Belief/Fear/Acceptance	Recovered material poor quality				x														
Belief/Fear/Acceptance	Perception for reuse													x					
B-Lack of awareness and demand		x	x		x								x	x			x		x
a-Deconstruction not a hot topic													x						
Culture/Demolition contractor	Demolition contractor culture												x						
b-Awarness of the decontruction approach													x						
Awareness/Popularity	Lack of popularity												x						
Concern/Engagement/motivation/Effor	Social engagement												x						
Awareness/Popularity	The use of innovative technologies												x						
c-Awarness of the SB approach																			x
Awareness	Lack of awareness																		x
Awareness	Ignorance of existing efficient SB technologies																		x
Awareness/client	Lack of client awareness																		x
d-Lack of concern and awareness					x									x			x		x
Awareness/Popularity	Novel concept				x														
Concern/Engagement/motivation/Effor	Lack of motivation																		x
Awareness	Lack of awareness													x			x		
Awareness	Lack of awareness													x					
Awareness/Initiatives	Lack of awareness initiatives																x		
e-Lack of understanding deconstruction and SB													x						
Awareness/Understanding	Lack of comprehension												x						x
Awareness/Understanding	Lack of understanding												x						
Awareness/Understanding	Lack of common understanding																		x
Awareness/Understanding	The lack of a common language																		x
f-Do not see the benefits os using this approach		x	x		x														
Awareness/Potentials	Lack of awareness in benefits sustainable principles		x		x														
Awareness/Potentials	Lack of awareness of RL's advantage				x														
Awareness/Potentials	Lack of awareness of principles advantages				x														
Awareness/Potentials	Value-added components for Sustainable design		x																
Awareness/Potentials	Lack of awareness in reuse and recycling potentials	x			x														
Awareness/Potentials	Lack of awareness in reuse and recycling potentials				x														
Awareness/Potentials	Lack of awareness in reuse and recycling potentials				x														
Awareness/Understanding	Underestimating the real value of reusing components	x																	

		P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38	P39	P40	P41
A-Societal trend																																										
a-Consumer society																																										
Belief/Fear/Acceptance	Fear of additional construction cost (W M more expensive than waste landfilling)				x																													x								
Belief/Fear/Acceptance	Misperception of incurring higher capital costs				x																																					
Belief/Fear/Acceptance	Perceived cost and time impacts																																	x								
Belief/Fear/Acceptance	Strong belief = waste management is more expensive																																	x								
Belief/Fear/Acceptance	Disbelief in the potential utility of a constructability program							x																																		
Belief/Fear/Acceptance	Waste is inevitable																																	x								
Culture/waste behaviour	Culture of waste behaviour																																	x								
Culture/Attitude	Consumer culture and attitude towards the quality of salvaged and used items					x																						x														
Culture/Attitude	Consumer culture and mindset about the lower quality of salvaged and used items					x																																				
Culture/Attitude	Consumer culture and perceptions					x																																				
b-Bad image																																										
Belief/Fear/Acceptance	Bad image of original product																	x											x													x
Belief/Fear/Acceptance	Bad image of salvaged components																																									x
Belief/Fear/Acceptance	Poor quality image/Bad image of salvaged components																	x																								
Belief/Fear/Acceptance	Recovered material poor quality																												x													
Belief/Fear/Acceptance	Perception for reuse																																									x
B-Lack of awareness and demand																																										
a-Deconstruction not a hot topic																																										
Culture/Demolition contractor	Demolition contractor culture																																				x					
b-Awarness of the decontruction approach																									x	x											x					
Awareness/Popularity	Lack of popularity																									x																
Concern/Engagement/motivation/Effor	Social engagement																									x																
Awareness/Popularity	The use of innovative technologies																								x																	
c-Awarness of the SB approach																									x	x											x					
Awareness	Lack of awareness				x																																					
Awareness	Ignorance of existing efficient SB technologies				x																																					
Awareness/client	Lack of client awareness				x																																					
d-Lack of concern and awareness																																										
Awareness/Popularity	Novel concept																										x															
Concern/Engagement/motivation/Effor	Lack of motivation				x																																					
Awareness	Lack of awareness																																									x
Awareness	Lack of awareness																																					x				
Awareness/Initiatives	Lack of awareness initiatives																															x										
e-Lack of understanding deconstruction and SB																																										
Awareness/Understanding	Lack of comprehension				x																					x																
Awareness/Understanding	Lack of understanding																									x																
Awareness/Understanding	Lack of common understanding				x																																					
Awareness/Understanding	The lack of a common language				x																																					
f-Do not see the benefits os using this approach																																										
Awareness/Potentials	Lack of awareness in benefits sustainable principles					x										x												x														
Awareness/Potentials	Lack of awareness of RL's advantage																											x														
Awareness/Potentials	Lack of awareness of principles advantages					x																																				
Awareness/Potentials	Value-added components for Sustainable design															x																										
Awareness/Potentials	Lack of awareness in reuse and recycling potentials					x	x																					x	x													
Awareness/Potentials	Lack of awareness in reuse and recycling potentials																											x														
Awareness/Potentials	Lack of awareness in reuse and recycling potentials					x																																				
Awareness/Understanding	Underestimating the real value of reusing components						x																																			

		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	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38	P39	P40	P41
D-Human behaviour			x		x				x	x			x	x		x	x		x																																									
a-Cultural believes																x			x																																									
Culture/Thinking	low-risk culture															x																																				x								
Culture/Thinking	Low-risk culture																		x				x																																					
b-Lack of global vision					x					x									x																																									
Culture/Thinking	Lack of lateral thinking				x					x									x				x																								x							x						
Culture/Thinking	Lateral thinking/Linear thinking																		x				x																																					
Culture/Thinking	linear view of the built environment									x																																												x						
Culture/Thinking	Lack of concern = linear thinking				x																																										x													
Culture/Thinking	The ignorance of the life-cycle thinking																		x				x																																					
c-Lack of trust					x								x	x			x																																											
Belief/Fear/Acceptance	Acceptance/Difficult to convince the client												x																											x																				
Belief/Fear/Acceptance	Lack of acceptance of reclaimed components				x									x			x							x																							x					x				x				x
Belief/Fear/Acceptance	Lack of acceptance of reclaimed materials													x																																										x				
Belief/Fear/Acceptance	Reclaimed components risk/trust				x																																										x													
Belief/Fear/Acceptance	Lack of trust hinders reuse													x																																														x
Belief/Fear/Acceptance	Perception low quality of reclaimed materials				x																			x																																				
d-Impatience want a ROI quikly					x																																																							
Culture/Business	Unfavourable business culture				x																			x																																				
e-Resistance to change			x		x				x				x	x					x																																									
Resistance to change	Resistance to change		x		x				x				x	x					x				x	x	x	x										x			x		x		x												x					
Resistance to change	Industry scepticism and tradition													x																									x																					
Resistance to change	Natural resistance to change												x																														x																	
Resistance to change	Manufacture reluctance												x																																										x					
Resistance to change	Builders and owners resistance													x											x																																			
Resistance to change	Resistance to change within the organisation				x																			x																																				
Resistance to change	Resistance to new technologies																		x				x																																					
Resistance to change	Reluctance for innovation		x																							x																																		
Resistance to change	Resistance to change				x																																				x																			
Necessary Effort	Excessive effort necessary,				x																			x																																				

3.4 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 - Profit seeking first				x		x			x		x				x	x				x
a-Market				x		x					x									x
Cost-Affordabi	Affordability	Affordability																		x
Profitability	Uncertainty about the results	Uncertainty about the results				x														
Market	Competitive construction/equipment	A highly competitive construction market,		x							x									
		A highly competitive equipment rental market,		x																
		Difficulty to break into the established markets that are dominated by materials									x									
Market	Current waste market and business cc	Current waste market and business conditions advantage demolition rather than deconstruction									x									
		The inadequate market value																		x
b-Market of recovered materials						x					x				x	x				
Market	Lack of 2nd hand materials market	Lack of established 2nd hand materials markets				x					x									
		Lack of markets for a wide variety of C&D waste products									x									
		Lack of recovery materials markets ⍰				x														
		Lack of material recovery/reprocessing facilities (MRFs)														x				
		Lack of end-use markets for source separated materials														x				
		Availability of established recycling and reuse markets														x				
		Recycled materials' market is not highly developed. Few of the necessary infrastructures for recycling													x					
c-Market supply/demand						x					x				x	x				x
Market	Supply/demand	Lack of demand				x					x				x	x				x
		Principal problems with reuse is to coordinate demand with supply														x				
		Lack of client demand																		x
		Lack of demand														x				
		Low demand for reclaimed materials [24]														x				
		market demand														x				
		Maximizing the resale value of reusable resources and new remade products.									x									
		Barriers imposed by the governing business environment in the industry				x														
d-Marketing plan			x						x											x
Marketing plan	drawbacks in SB marketing processes	drawbacks in SB marketing processes																		x
Marketing plan	Lack of marketing plan	Absence of an appropriate marketing plan.							x											
Commercial	Having strictly commercial objectives	Having strictly commercial objectives, externalities as well as environmental and social	x																	
Commercial	Lack of fully end-customer focused	Lack of fully end-customer focused																		x
Commercial	New ways for trading building	New ways for trading building resources	x																	
B-Sustainable EOL versus demolition						x	x				x			x	x	x				
a-Cost of materials							x				x					x				
Cost non-incen	Low cost of standard construction &	Low cost of construction materials					x									x				
		standard construction and demolition practices focus on the fastest, easiest and most economical way to get the job done.														x				
Cost-Material	Component difficult to recover	Building aluminum scrap is difficult to recover economically														x				
Cost-Material	Recovered material Cost	Quality concern=the price of recycled aggregates be considerably lower than that of the natural materials⍰														x				
Cost-Material	Reuse/recycling uncompetitive	Materials reuse expensive, and sometimes impossible									x					x				
		the low cost of construction materials and the high cost of labour required for the dismantling process which have made the e														x				
		Recycling of building waste must be competitive with natural resources (cost and quality)														x				
b-Low cost of disposal						x					x				x	x				
Cost non-incen	Low costs of waste disposal	Accessibility to landfills which have low tipping fees, such as private facilities, rural sites and landfills l(				x					x				x	x				
		Disposal charges for demolition waste are frequently low									x									
		Low cost to dispose of C&D materials to landfills									x									
		Low costs of disposal of materials in landfill, thus not justifying the RL costs				x														
		Low costs of disposal of materials in landfills which does not justify the costs of RL				x														
		Lower cost per ton disposal charge													x					
		Relative economic advantage of disposal versus recycling.														x				
		The viability of adopting RL depends mainly on landfill levy and labour costs				x														

	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20
A-Economic context - Profit seeking first																				
a-Market																				
Affordability				x																
Uncertainty about the results					x															
A highly competitive construction market,							x													
A highly competitive equipment rental market,							x													
Difficulty to break into the established markets that are dominated by materials																				
Current waste market and business conditions advantage demolition rather than deconstruction																				
The inadequate market value				x																
b-Market of recovered materials																				
Lack of established 2nd hand materials markets																				
Lack of markets for a wide variety of C&D waste products																				
Lack of recovery materials markets ⍰					x															
Lack of material recovery/reprocessing facilities (MRFs)																				
Lack of end-use markets for source separated materials																				
Availability of established recycling and reuse markets																				
Recycled materials' market is not highly developed. Few of the necessary infrastructures for recycling																				
c-Market supply/demand																				
Lack of demand				x	x															x
Principal problems with reuse is to coordinate demand with supply																				x
Lack of client demand				x																
Lack of demand																				
Low demand for reclaimed materials [24]																				
market demand																				x
Maximizing the resale value of reusable resources and new remade products.																				
Barriers imposed by the governing business environment in the industry																				
d-Marketing plan																				
drawbacks in SB marketing processes				x																
Absence of an appropriate marketing plan.																				
Having strictly commercial objectives, externalities as well as environmental and social																				
Lack of fully end-customer focused																				
New ways for trading building resources																				
B-Sustainable EOL versus demolition																				
a-Cost of materials																				
Low cost of construction materials																				x
standard construction and demolition practices focus on the fastest, easiest and most economical way to get the job done.																				x
Building aluminum scrap is difficult to recover economically																				
Quality concern=the price of recycled aggregates be considerably lower than that of the natural materials⍰																				
Materials reuse expensive, and sometimes impossible																		x		x
the low cost of construction materials and the high cost of labour required for the dismantling process which have made the e																				x
Recycling of building waste must be competitive with natural resources (cost and quality)																				
b-Low cost of disposal																				
Accessibility to landfills which have low tipping fees, such as private facilities, rural sites and landfills l(					x															
Disposal charges for demolition waste are frequently low																				
Low cost to dispose of C&D materials to landfills																				
Low costs of disposal of materials in landfill, thus not justifying the RL costs					x															
Low costs of disposal of materials in landfills which does not justify the costs of RL																				
Lower cost per ton disposal charge																				
Relative economic advantage of disposal versus recycling.																				
The viability of adopting RL depends mainly on landfill levy and labour costs																				

	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38	P39	P40	P41
A-Economic context - Profit seeking first																					
a-Market																					
Affordability																					
Uncertainty about the results																					
A highly competitive construction market,									x												
A highly competitive equipment rental market,																					
Difficulty to break into the established markets that are dominated by materials									x												
Current waste market and business conditions advantage demolition rather than deconstruction					x																
The inadequate market value																					
b-Market of recovered materials																					
Lack of established 2nd hand materials markets							x		x												
Lack of markets for a wide variety of C&D waste products									x												
Lack of recovery materials markets ⍰																					
Lack of material recovery/reprocessing facilities (MRFs)																	x				
Lack of end-use markets for source separated materials																	x				
Availability of established recycling and reuse markets																				x	
Recycled materials' market is not highly developed. Few of the necessary infrastructures for recycling											x										
c-Market supply/demand																					
Lack of demand					x		x				x						x		x	x	x
Principal problems with reuse is to coordinate demand with supply																					
Lack of client demand																					
Lack of demand																					x
Low demand for reclaimed materials [24]																			x		
market demand																					
Maximizing the resale value of reusable resources and new remade products.					x																
Barriers imposed by the governing business environment in the industry							x														
d-Marketing plan																					
drawbacks in SB marketing processes																					
Absence of an appropriate marketing plan.				x																	
Having strictly commercial objectives, externalities as well as environmental and social																					
Lack of fully end-customer focused																					
New ways for trading building resources																					
B-Sustainable EOL versus demolition																					
a-Cost of materials																					
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standard construction and demolition practices focus on the fastest, easiest and most economical way to get the job done.																					
Building aluminum scrap is difficult to recover economically																	x				
Quality concern=the price of recycled aggregates be considerably lower than that of the natural materials⍰																	x				
Materials reuse expensive, and sometimes impossible																	x			x	
the low cost of construction materials and the high cost of labour required for the dismantling process which have made the e																					
Recycling of building waste must be competitive with natural resources (cost and quality)																	x				
b-Low cost of disposal																					
Accessibility to landfills which have low tipping fees, such as private facilities, rural sites and landfills l(				x	x		x	x	x								x				
Disposal charges for demolition waste are frequently low				x																	
Low cost to dispose of C&D materials to landfills									x												
Low costs of disposal of materials in landfill, thus not justifying the RL costs																					
Low costs of disposal of materials in landfills which does not justify the costs of RL							x														
Lower cost per ton disposal charge					x																
Relative economic advantage of disposal versus recycling.																	x				
The viability of adopting RL depends mainly on landfill levy and labour costs								x													

			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
c-EOL duration and labor cost						x					x			x		x				
Cost/time	Labor-intensive effort	Deconstruction is a labor-intensive effort				x					x					x				
		Deconstruction process is a labor intensive and costly practice									x									
		Labour costs of deconstruction of a building could be as much as six times higher than conventional demolition of t									x									
		Reuse is considered to be labor-intensive, high labor costs have been seen as the decisive barrier for reuse in the EU														x				
		Specified construction schedules which are too short to allow deconstruction and/or separation to occur														x				
		The viability of adopting RL depends mainly on landfill levy and labour costs				x														
Cost/time	Additional time is required	Additional time is required									x			x		x				
		Deconstruction requires additional time.									x									
		Increase in time for the processing as well as an increase in the processing costs												x						
		The DfD's planning phase requires additional time to develop a comprehensive contractual terms that cover the guidelines of														x				
cost/time	Additional design cost/time	Dismantling buildings requires additional time									x									
		Time									x									
C-Additional cost for SEOL						x	x			x	x	x			x	x		x		x
a-Cost of the approach																				
1-Design phase																				
Cost/time	Additional design cost/time	The additional design costs				x				x						x				
		Required more design time								x										
		RL= demanding and time-consuming				x														
		Requires far more effort and time from the design team.														x				
		Increase of design time								x										
2-New approach adaptation costs						x	x			x	x	x			x	x		x		
1-Attractiveness of conventional recycling																x				
Cost non-incen	Attractiveness of conventional	Attractiveness of conventional recycling														x				
2-Initial cost for principle adoption/True cost of the process						x	x			x	x					x				
Cost-Addition	Initial cost for principle	higher initial cost				x	x			x	x					x				
		at this stage the contractor is often not appointed yet, so the client has to spend money up front purchasing materials, which r														x				
		True cost of the process (perception of planners and developers, time and money, availability of quality informati									x									
		Considerable initial costs of adopting RL				x														
		Cost of disassembly of old buildings				x														
		Deconstruction more expensive									x									
		Deconstruction costs could be 17–25% higher than demolition costs (labor, time, disposal)									x									
		Prefabrication and modular construction more expensive/in-situ construction								x										
		The process would be costly and end up in extracting only a few reusable materials.				x														
		Higher initial cost								x										
		Higher initial cost								x										
3-Additional cost for principle adoption						x	x			x	x	x				x		x		
Cost-Addition	Additional cost for principle	High costs for C&D collection and recovery processes (e.g. additional labor costs)				x	x			x	x	x				x		x		
		High labour costs				x														
		Higher general cost								x										
		Higher price														x				
		it is unlikely that design teams will be willing to take on additional work without increased fees.														x				
		Reused components can be more expensive if there is a need for multiple handling and refabrication.														x				
		Who want to pay for it																x		
		High cost of labour required for the dismantling process = reuse uncompetitive.					x													
		Add cost										x								
		equipment, transportation, disassembly time and labor are costly.														x				
		Transportation and tipping fees														x				
		The barriers hindering reuse is cost														x				
		Cost arising from pre-soaking, extra inspection, and compensating for lower strengh and higher creep, shrinkage and elastic d														x				
		Cost,				x														
		Cost,				x														
		Existing building deconstruction is costly									x									
		Higher costs involved in RL				x														

	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38	P39	P40	P41
c-EOL duration and labor cost																																									
Deconstruction is a labor-intensive effort																									x			x									x	x				x
Deconstruction process is a labor intensive and costly practice																									x																
Labour costs of deconstruction of a building could be as much as six times higher than conventional demolition of t																												x													
Reuse is considered to be labor-intensive, high labor costs have been seen as the decisive barrier for reuse in the EU																																									x
Specified construction schedules which are too short to allow deconstruction and/or separation to occur																																					x				
The viability of adopting RL depends mainly on landfill levy and labour costs																												x													
Additional time is required																				x									x		x					x			x		
Deconstruction requires additional time.																																				x					
Increase in time for the processing as well as an increase in the processing costs																															x										
The DfD's planning phase requires additional time to develop a comprehensive contractual terms that cover the guidelines of																																							x		
Dismantling buildings requires additional time																								x																	
Time																																				x					
C-Additional cost for SEOL																																									
a-Cost of the approach																																									
1-Design phase																																									
The additional design costs																	x			x							x														
Required more design time																	x																								
RL= demanding and time-consuming																											x														
Requires far more effort and time from the design team.																				x																					
Increase of design time																	x																								
2-New approach adaptation costs																																									
1-Attractiveness of conventional recycling																																									
Attractiveness of conventional recycling																																									x
2-Initial cost for principle adoption/True cost of the process																																									
higher initial cost					x												x					x		x	x		x	x					x			x					
at this stage the contractor is often not appointed yet, so the client has to spend money up front purchasing materials, which r																				x																					
True cost of the process (perception of planners and developers, time and money, availability of quality informati																																				x					
Considerable initial costs of adopting RL																											x														
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The process would be costly and end up in extracting only a few reusable materials.																												x													
Higher initial cost																								x																	
Higher initial cost																	x																								
3-Additional cost for principle adoption																																									
High costs for C&D collection and recovery processes (e.g. additional labor costs)			x		x									x			x	x		x	x						x	x	x				x				x			x	x
High labour costs																											x														
Higher general cost																	x																								
Higher price																																									x
it is unlikely that design teams will be willing to take on additional work without increased fees.																				x																					
Reused components can be more expensive if there is a need for multiple handling and refabrication.																				x																					
Who want to pay for it																																	x								
High cost of labour required for the dismantling process = reuse uncompetitive.																				x																					
Add cost														x																											
equipment, transportation, disassembly time and labor are costly.																		x																							
Transportation and tipping fees																																								x	
The barriers hindering reuse is cost																																									x
Cost arising from pre-soaking, extra inspection, and compensating for lower strengh and higher creep, shrinkage and elastic d																																					x				
Cost,			x																																						
Cost,					x																																				
Existing building deconstruction is costly																					x																				
Higher costs involved in RL																												x													

			CE-DfCE	Cv	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	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38	P39	P40	P41
4-Cost for hazardous components						x									x	x																																													
Cost-Addition	Cost for hazardous components	The existence of lead and asbestos in old buildings makes the process costly and time consuming				x									x	x																																x			x						x				
		High cost for hazardous components lead to that the obligation are not fulfilled													x																																				x										
		The cost of separating the material to be recycled from contaminating materials														x																																									x				
3-Insurance cost																x																																													
Cost-Addition	Insurance cost	Higher insurance fees														x																																													x
4-for new roles, missions, tasks																x				x																																									
Cost-benefits	Benefits are not well established	Economic benefits are not well established								x																																		x																	
Cost-benefits	Lack of business case understanding	Lack of business case understanding																		x				x																																					
Cost-benefits	Lack of ROI evidence	Economic and environmental benefits from the C&D waste management are not well established								x																																							x												
Cost-allocation	Different construction budget	The distribution of the construction budget was completely different														x										x																																			
b-Client readiness to pay the new concept						x								x																																															
Cost-allocation	Willingness to pay up front	At this stage the contractor is often not appointed yet, so the client has to spend money up front purchasing materials, wl												x																										x																					
Cost-Investmei	Not a priority investment	RL is not a priority in the organisations investment				x																			x																																				

3.5 Technical barriers

			CE-DfCE	CV	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	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38	P39	P40	P41
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																																															
Building: Building system	Building long lifetime	Buildings can have a very long lifetime exceeding those of the industrial pro		|x|																																						|x|																		
Building: Building system	Long life cycle of buildings	Long life cycle of buildings				x																																									x																
Building: Building system	Long life cycle of buildings, Different owners	Long life cycle of buildings with differents owners				x																			x																																				
Building Type Lifespan	Long lifespan of buildings & changing ownership	The very long lifespan of buildings with changing ownership.				x																																										x														
2-Building composition - several layers- finishes			x												x																																															
Finishes drawbacks	Drawbacks of the use of finishes on building materi	The use of finishes on building materials reduces the possibility of reus	x												x																																				x											
b-Building type and size as a barrier						x								x	x																																																
Building Type Uniqueness	The unique and one-off nature of buildings	Owing to the unique and one-off nature of buildings, differences in deteriorat				x																																										x														
Building Type Uniqueness	Uniqueless of each buildings	Uniqueless of each buildings			|x|																																																									
Building Type Nature/Design	Building's nature & design	The nature and design of the building												x																																										x					
Building Type Uniqueness	Buildings are heterogeneous	The development of unique products (buildings are heterogeneous)				x									x							x																											x														
Building Type Complexity	Size and complexity	The size and complexity of a construction													x							x																																								
Building: Building type	The nature of construction products	Barriers due to the nature of construction products (e.g. buildings) and its activ				x																																									x															
Building: Building type	The type of building materials	Technical aspects such as the type of building materials				x									x																									x		x																					
Building: Building type	Deconstruction & material reutilization potentials d	The potential of deconstruction & material reutilization depend on the buildings type													x																									x																						
c-Project phases adaptation					x	x		x	x	x	x			x	x																																															
1-Design phase adaptation					x	x			x		x			x	x																																															
Unsuitable foundation					x																																																									
Building: Building system	Foundations are the most challenging for CLMC	The main problematic building items in terms of achieving a CLMC construct			x																												x																													
Unsuitable design for current assets					x	x			x		x			x	x																																															
Building: Building system	Buildings are not designed for disassembly	buildings are not designed for such ease of disassembly			x	x			x		x			x	x							x			x									x						x				x				x	x							x					x
Building: Building system	Not designed for that	Existing buildings have not been designed for dismantling												x																																			x												
Building: Building system	Not designed for that	Existing buildings or building components have not been designed for disassembly												x																														x																	
Building: Building system	Not designed for that	Historically, building products have not been designed for disassembly and			x																																								x																	
Building: Building system	Not designed for that	If the existing buildings are not designed for deconstruction and easy dismant				x																																										x														
Building: Building system	Not designed for that	Lack of design. Products are not designed with deconstruction in mind.												x																																										x					
Building: Building system	Not designed for that	Most of the existing building stock was not designed for relocation or dismantling.													x																									x																						
Building: Building system	Lack of buildings designed under DfD guidelines	Lack of buildings designed under DfD guidelines												x								x																																									
Building: Building system	Joints designed to be hidden	Joints between components are often designed to be hidden (and therefore inaccessible) and p												x																																										x					
Building: Building system	Joints design	Design of joints to facilitate deconstruction												x																																										x					
Building: Building system	Buildings are not designed for deconstruction	Components not designed for deconstruction													x																																														x
Building: Building system	Buildings' Design not compatible with deconstructi	Design of buildings not compatible with deconstruction				x																			x																																				
Building: Building system	Existing building stock not designed for	Existing building stock= not designed for relocation or dismantling.							x																															x																						
Building: Building system	Buliding not designed for disassembly = unattractiv	Existing buildings are not designed for easy disassembly. Thus, the necessary t				x																			x																																				
2-Construction methods adaptation								x							x																																															
Project complexity	Use of reclaimed materials = complexity addition	Using reclaimed materials adds a whole new level of complexity to the project													x																									x																						
Building: Building system	Use of in-site connection	Use of in-sit connection between precast concrete elements						x																																				x																	
3-In use					x	x								x																																																
Building: Building system	Building systems lifetime are different	Building systems are updated or replaced at intervals during the building's li			x	x																																						x			x														
Building: Building system	Lack of maintenance = impact on connections	Lack of maintenance impacts mechanical connections												x								x																																									

			CE-DfCE	Cv	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
4-Deconstruction processes implemetation (storage facilities)						x		x		x				x	x					
Space issues: Itinerant	Itinerant construction site	Itinerant construction site													x					
Space issues: Site access	Site access	Site access						x												
Space issues: Site access	Site access	Site storage, access and transportation issues						x												
Space issues: Site dimensions	Site dimensiosns	Site dimensions						x												
Space issues: Site dimensions	Site dimensiosns	Site dimensions (narrow site)						x												
Space issues: Sorting/Separat	Labour required	Labour required for sorting and separating the salvaged materials				x														
Product size	Immobility and huge size of extracted materials	Immobility and huge size of extracted materials; the difference in their deteri				x														
Space issues: Storage	On-site space for storage	Necessity of providing on-site space				x		x						x						
Recovered facilities	Lack of technologies	Lack of infrastructure, specifically recovery facilities, infrastructure, technolog				x														
Recovered facilities	Lack of recovery facilities, infrastructure	Lack of recovery facilities, infrastructure				x														
Cost-Recovered materials	Reused/recycled material cost	Materials reuse expensive, and sometimes impossible												x						
Risk & Safety	Deconstruction risks	Deconstruction risks,				x								x	x					
Risk & Safety	Increased risk	key issue for designers is the increased risk involved													x					
Risk & Safety	Safety	Safety												x						
Pilot projects	Lack of applications and examples	Lack of applications and examples													x					
Deconstruction Complexity	Deconstruction more complex than demolition	Deconstruction more complex than demolition (construction)												x						
Building: Building system	Lack of drawings and specifications.	Lack of drawings for the connection between the building components								x										
Building: Building system	Demountable connection issues	Demountable connections do not always ensure the possibility of deconstruction						x						x						
Building: Building system	Poor connections	Poor connection with others elements						x												
Building: Building system	The deconstruction of non-prefabricated componer	The deconstruction of non-prefabricated components is more laborious.												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		
Product quality	Vast variety of quality of materials extracted	The difference in the vast variety in the quality of materials extracted from bu				x								x	x		x	x		
Product quality	Loss of quality	loss of quality													x					
Product quality	Reuse dimensional lumber	Major technical barriers: reusing dimensional lumber												x						
Product quality	Quality of recovered materials	The barriers hindering reuse is, quality													x					
Product quality	Material damaged	Inadequate material properties or damage													x					
Product quality	Product strengh	Its use is a slightly lower compressive strength compared with a control mix made with the original													x					
Product quality	Quality control: critical element	Quality control: critical element												x						
Product quality	Lack of Technical standards for CDW Management	Technical standards for CDW Management not fully developed																x		
Material/Product quality	Quality control: critical element	Quality control: critical element												x						
Material/Product Damage	Damage of materials on-site	Damage of materials on-site during deconstruction													x					
Product composition	Poor materials behaviour during all phases	Poor materials behaviour during all phases															x			
2-Uncertain product composition						x									x					
Product quality	Variety & uncertainaty	Wide variety and uncertainty of the location of points of origin				x														
Product composition	Reclaimed materials uncertainties	Uncertainties in the properties of reclaimed wood													x					
Product composition	Material composition	material composition is not well known													x					
3-Location of collection points						x									x		x			
Facilities	Lack of recovery facilities	Lack of recovery facilities, infrastructure				x											x			
		Lack of infrastructure, specifically recovery facilities, infrastructure, technolog				x														
		Lack of recovery facilities				x														
		Provision of adequate recycling services															x			
Material/Product Location	Location of collection points	Location of collection points				x														
Material/Product Location	Difficulty to source the reused components	Reused components are identified on demolition sites by salvage contractors and may be difficult t													x					
Material/Product Location	Product's location	Wide variety and uncertainty of the location of origin points				x														

	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38	P39	P40	P41
4-Deconstruction processes implemetation (storage facilities)																																									
Space issues: Itinerant		x																																							
Space issues: Site access																	x																								
Space issues: Site access																	x																								
Space issues: Site dimensions																	x							x																	
Space issues: Site dimensions																	x																								
Space issues: Sorting/Separat																												x													
Product size					x																																				
Space issues: Storage					x																			x	x		x	x	x												
Recovered facilities																												x													
Recovered facilities					x																																				
Cost-Recovered materials																		x																							
Risk & Safety					x															x																x					
Risk & Safety																				x																					
Risk & Safety																																				x					
Pilot projects																																									x
Deconstruction Complexity		x																																							
Building: Building system																								x																	
Building: Building system		x															x							x												x					
Building: Building system																	x																								
Building: Building system		x																																							
B-Material related barriers																																									
a-Material composition-knowledge & reliability																																									
1-Product quality																																									
Product quality					x						x	x	x												x		x				x						x				x
Product quality													x																												
Product quality																									x																
Product quality																																									x
Product quality																																									x
Product quality																																					x				
Product quality																									x																
Product quality																															x										
Material/Product quality																									x																
Material/Product Damage																																							x		
Product composition												x																													
2-Uncertain product composition																																									
Product quality																											x														
Product composition											x																														
Product composition																																						x			
3-Location of collection points																																									
Facilities				x			x																			x	x														
																											x														
																										x															
							x																																		
Material/Product Location					x																							x													
Material/Product Location																				x																					
Material/Product Location					x																																				

			CE-DfCE	Cv	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	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38	P39	P40	P41
4-Material availability															x	x																																													
Building components	Under-estimation of the building components	The under-estimation of the embedded resources in the building components and materials														x										x																																			
Material/Product Quantities	Quantity of materials	The barriers hindering reuse is quantity													x																																														x
Material/Product Availability	Availaility & clear specifications	Reclaimed components are often not readily available from stock and their specifications may not													x																									x																						
Material/Product Availability	Timing and availability	A limited availability of such components makes it difficult for designers who wish to specify them													x																									x																						
Material/Product Availability	Timing and availability	Issue of timing and availability													x																									x																						
Material/Product Availability	Timing and availability	Reclaimed materials do not show up at the right time, in the right amount or the right dimension.													x																									x																						
Material/Product Availability	Timing and availability	The design team should do additional research at the front end of the project to identify, locate, in													x																									x																						
Material/Product Availability	Timing and availability	Timing and availability													x																									x																						
Material/Product Availability	Timing and availability	When proceeding to construction, the required size or type of component may not be readily avail													x																									x																						
b-Material recoverability			x			x								x	x																																															
1-Difficulty to recover materials						x								x	x																																															
Building component	Building component difficult to separate	Building components are difficult to separate without damaging them				x								x	x										x													x			x			x													x			x	
Building component	Component damaged by demolition machines	Damage to timber by machine demolition													x																																												x	
Building component	On-site separation difficulties	Extra time, practical difficulties and adverse attitudes to onsite separation													x																																												x	
Building component	Difficulties for separate	It is "bound" into building assemblies that are difficult to separate or disassemble													x																																								x				
Building component	Difficulty for component separation	Preplanned and careful deconstruction techniques to separate the aluminium demolition waste												x																																									x				
Building component	Composite products.	Composite products.												x																																							x					
Building: Building system	Concrete removal of rebar surface	Difficulty of removing concrete debris adhering to the surface of the rebar													x																																								x				
Building: Building system	Difficulty to dismantle without its destruction	In-situ concrete structure = difficult to dismantle without its destruction												x																												x																	
2-Damage during deconstruction						x								x	x																																															
Cost-Recovered materials	Damage salvaged materials	Existing building deconstruction damage salvaged materials												x																										x																				
Product size	Deterioration rate	The difference in their deterioration rates and the vast variety in the quality o				x																			x																																			
3-Hazardous components						x								x	x																																															
Building component hazardou	Component contamination	Contamination brought about by paint coatings and treated timber				x									x										x													x									x								x					x	
Building component hazardou	Buildings are rife with hazardous materials	buildings are rife with hazardous materials													x																							x																							
Building component hazardou	Materials durability improvement: use of toxic mat	Use of more toxic materials due to their improved durability												x																																						x						
Building component hazardou	Material issues: asbestos and lead	Material issues: asbestos and lead												x																								x																							
Building component hazardou	Existence of hazardous substances	Existence of hazardous substances				x																			x																																			
Building component hazardou	Hazardous component	Immobility, huge size, existence of hazardous substances, difference in deteri				x																																									x														
4-Building component lifespan														x	x																																															
Building component	Duration period of products	duration period of products													x							x																																								
Building component	Components fate	Fate of the components												x																																							x					
C-Data related barriers			x			x								x	x		x		x	x																																											
a-Data management																x																																												
Data	Poor data collection and reporting	National data collection and reporting remains poor														x																												x																
b-Data availability-accessibility						x								x	x				x	x																																											
Data	Lack of accessibility to data	Access to data																	x				x																																						
Data	Lack of data in design stage for LCA	Lack of data in design stage to carry a LCA towards the EOL												x	x				x			x									x																							x							
Data	Lack of information on deconstruction projects and	Lack of information on deconstruction projects and process												x								x																																							
Data	Lack of C&D waste data	Lack of national data on C&D waste													x																x																														
Data	Data Reliability	Lack of reliable data and methodological limitations.				x									x		x			x				x																						x			x										x				
Data	Lack of data	More information on the behaviour of recycled concrete is required is its durability													x																																										x				
Data	Lack of data of the building composition	The composition of buildings at the end of their life are generally not known				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																																																						
Tools & procedures	Lack for adapted BIM tools for prefabricated buildin	Lack for adapted BIM tools for prefabricated building design					x																												x																									
b-Lack of technologies and technologies evolution			x			x								x	x	x	x	x		x																																											
1-Lack of technology for deconstruction														x	x																																															
Tools specialized	Lack of tools	Lack of specialized tools designed for deconstructing buildings												x																																							x					
Reclaimed material	Recovered material process	Cleaning, denailing and resizing timber													x																																												x	
Tools & procedures	Lack of tools for deconstruction	Tools for deconstruction of existing buildings often do not exist												x																												x																	
Tools & procedures	Suitable tools development	Development suitable tools for safe & economic removal of structural elements												x																																							x					

			CE-DfCE	Cv	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	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38	P39	P40	P41
2-Lack of R&D			x											x	x	x				x																																									
Tools & procedures	Lack of innovation	Innovation																		x				x																																					
Product Innovation	Product innovation	Product innovation and depreciation													x																									x																					
Research	Lack of peer-reviewed scientific research	Deficit in New Zealand based peer-reviewed scientific research in the sphere of C&D waste mini												x																															x																
Tools & procedures	Inclusion of new techniques for construction	Inclusion of new techniques for construction	x													x				x				x		x																																			
Tools & procedures	Lack of development of science-based user-friendly	Lack of development of science-based user-friendly tools	x											x						x				x		x																														x					
3-Lack of tools technology for recovered materials						x								x	x					x																																									
Reclaimed material	Lack of techniques for reusing reclaimed materials	Development of techniques for reusing such elements.				x								x	x										x																							x								x				x	
Tools & procedures	Lack of technical support	lack of technical support in favour of using recovered items				x																			x																																				
Tools & procedures	Absence of a common framework	absence of a common framework																		x				x																																					
Tools & procedures	Complicate processes	adaptive reuse for a building project is a complex process														x										x																																			
Tools & procedures	Lack of desing practices for efficient deconstruction	Design and construction practices which preclude efficient and effective deconstruction and / or sc													x																																										x				
Tools & procedures	Lack of guidance	intuition and experience are the only guides														x										x																																			
Tools & procedures	Lack of information and tools	Lack of information, skills and tools												x																																										x					
Tools & procedures	Lack of mobilization of sustainable building tools	Lack of mobilization of sustainable building tools																		x				x																																					
Tools & procedures	Lack of technical support	Lack of technical support (i.e. building standards, codes and guidelines) for rec				x																			x																																				
4-Lack of tools to manage CDW														x	x																																														
Lack of prediction tools																	x	x		X																																									
Tools & procedures	Lack of tools for designers	existing waste management tools are not helpful to designers															x																						x																						
Tools & procedures	Lack of tools for various caracteristics of DW genera	DW generation rate estimation method doesn't reflect the various caracteristics of DW generation																			x																																								
Tools effectiveness	Construction Waste Prediction Tools effectiveness	Construction Waste Prediction Tools effectivness and not compatible with design tools															x	x																																			x								
Tools effectiveness	Waste prediction tools	waste prediction tools don't offer little or no solution to waste reduction															x																																				x								
Tools & procedures	Lack of availability of automatic calculation procedu	availability of automatic calculation procedures																		x				x																																					
Lack of alternative technologies-downcycling															x					x																																									
Tools & procedures	Lack of proven alternative technologies	Lack of proven alternative technologies																		x				x																																					
Downcycling	Downcyclig is not a CLC process	Downcycling can not be regarded as a CLC process= excessive loss of material value													x																		x																												

3.6 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	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38	P39	P40	P41
A-Site constraints for SEOL implementation						x		x																																																					
Space issues: Site access	Site access	Site access						x																													x																								
Space issues: Site access	Site access	Site storage, access and transportation issues						x																													x																								
Space issues: Site dimensions	Site dimensiosns	Site dimensions						x																													x							x																	
Space issues: Site dimensions	Site dimensiosns	Site dimensions (narrow site)						x																													x																								
Space issues: Storage	On-site space for storage	Necessity of providing on-site space				x		x						x											x																			x	x		x	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																																											
Cost-Addition	Cost for hazardous components	The existence of lead and asbestos in old buildings makes the process costly and time consuming				x									x			x																				x										x			x						x				
b-Awareness of impacts on the environment														x	x	x				x																																									
Awareness/benefits/Impacts	Lack of strong environmental and economic outcomes	Lack of strong environmental and economic outcomes associated with well-designed C&D waste minimization												x	x	x				x				x		x																			x	x																	x
Awareness/benefits/Impacts	Benefits not well-established	Environmental benefits are not well established												x																															x																	
Awareness/benefits/Impacts	Unclear environmental benefit	Unclear environmental benefit													x																																														x
Sustainability Assessment	Lack of sustainability criteria into the assessment procedures	Lack of sustainability criteria into the assessment procedures of architectural competitions																		x				x																																						
Awareness/benefits/Impacts	Undervaluing environmental impacts	Undervaluing and thus not including social and environmental impacts														x										x																																			
C-Pollution						x		x			x				x																																														
Emission from transport	Emissions from transport and reconditioning	Emissions from transport and reconditioning						x							x																						x																						x		x
Emission from transport	Emissions from transport and reconditioning	The transportation of the salvaged materials for reuse and recycling would consume additional energy (Time & money)													x																																											x		
Emission from transport	Transportation	Transportation						x																													x																								
Environmental issues	Environmental issues.	Environmental issues.				x																	x																																						
Risk/Contamination	Contaminated components	Exposure to health and safety risks and the possibilities of encountering contaminated.				x																																									x													
Cost-Addition	Environmental cost	Potential environmental costs									x																																											x						
Use of virgin feedstock	Recycling process requires additional virgin feedstock	recycling process= loss of material mass requiring additional virgin feedstock to be added													x																		x																												

3.7 List of references

N/p	Ref	Titles
P01	Kim et al, (2017)	An estimation framework for building information modeling (BIM)-based demolition waste by type
P02	Carvalho Machado et al., (2018)	Analysis of Guidelines and Identification of Characteristics Influencing the Deconstruction Potential of Buildings
P03	Chileshe et al., (2015)	Analysis of reverse logistics implementation practices by South Australian construction organisations
P04	Hakkinen and Belloni (2011)	Barriers and drivers for sustainable building
P05	Chileshe et al., (2015)	Barriers to implementing reverse logistics in South Australian construction organisations
P06	Sanchez and Haas (2018)	Capital project planning for a circular economy
P07	Kifokeris and Xenidis (2017)	Constructability: Outline of Past, Present, and Future Research
P08	Inglis, M. (2007)	Construcion and Demolition waste- Best practice and cost saving
P09	Green Leigh and Patterson (2006)	Deconstructing to Redevelop
P10	Chini and Bruening (2003)	Deconstruction and materials reuse in the United States
P11	Diyamandoglu and Fortuna (2015)	Deconstruction of wood-framed houses: Material recovery and environmental impact
P12	Kibert, C. J. (2003)	Deconstruction: the start of a sustainable materials strategy for the built environment
P13	Sassi P. (2008)	Defining closed-loop material cycle construction
P14	Crowther P. (2002)	Design for buildability and the deconstruction consequences
P15	Pulaski et al., (2004)	Design for Deconstruction
P16	Yuan et al., (2018)	Design for Manufacture and Assembly-oriented parametric design of prefabricated buildings
P17	Jaillon and Poon (2010)	Design issues of using prefabrication in Hong Kong building construction
P18	Knecht B. (2004)	Designing for Disassembly and Deconstruction
P19	Akinade et al., (2018)	Designing out construction waste using BIM technology: Stakeholders' expectations for industry deployment
P20	Gorgolewski M. (2008)	Designing with reused building components: some challenges
P21	Tingley and Davison (2012)	Developing an LCA methodology to account for the environmental benefits of design for deconstruction
P22	Chileshe et al., (2015)	Drivers for adopting reverse logistics in the construction industry: a qualitative study
P23	Akinade et al., (2016)	Evaluation criteria for construction waste management tools: towards a holistic BIM framework
P24	Jaillon and Poon (2014)	Life cycle design and prefabrication in buildings: A review and case studies in Hong Kong
P25	Zaman et al., (2018)	Resource Harvesting through a Systematic Deconstruction of the Residential House: A Case Study of the 'Whole House Reuse' Project in Christchurch, New Zealand
P26	Bouzon et al., (2015)	Reverse logistics drivers: empirical evidence from a case study in an emerging economy
P27	Hosseini et al., (2014)	Reverse Logistics for the Construction Industry: Lessons from the Manufacturing Context
P28	Hosseini et al., (2015)	Reverse logistics in the construction industry
P29	Xanthopoulos et al., (2009)	Reverse logistics processes of multi-type end-of-life buildings/construction sites: An integrated optimization framework
P30	Akanbi et al., (2018)	Salvaging building materials in a circular economy: A BIM-based whole-life
P31	Río Merino and Gracia (2010)	Sustainable construction: construction and demolition waste reconsidered
P32	Brancart et al., (2017)	Transformable structures: Materialising design for change
P33	Ajayi et al., (2015)	Waste effectiveness of the construction industry: Understanding the impediments and requisites for improvements
P34	Akinade et al., (2015)	Waste minimisation through deconstruction: A BIM based Deconstructability Assessment Score (BIM-DAS)
P35	Crowther P. (2005)	Design for Disassembly - themes and principles
P36	Couto and Couto (2010)	Analysis of Barriers and the Potential for Exploration of Deconstruction Techniques in Portuguese Construction Sites
P37	Nisbet et al. (2012)	Demolition and Deconstruction: Review of the Current Status of Reuse and Recycling of Building Materials.
P38	Kohler, N., & Yang, W. (2007)	Long-term management of building stocks.
P39	Cruz Rios et al. (2015)	Design for Disassembly and Deconstruction - Challenges and Opportunities
P40	Perry Forsythe (2011)	Drivers of Housing Demolition Decision Making and the Impact on Timber Waste Management
P41	Huuhka and Hakanen (2015)	Potential and barriers for reusing load-bearing building components in Finland

4 Appendix 4

Participant Information Sheet for interviews

1. Information about the project/Purpose of the project

Project title: *A Framework to integrate the sustainable End-of-Life phase into the Asset Lifecycle in BIM - Towards the Circular Economy*

Project summary:

The interviews are part of a PhD research and it is designed to study the impact of the incorporation of the sustainable End-of-Life (EOL) phase into the asset lifecycle in BIM environment. The aim of the research is to develop a framework for integrating the sustainable End-of-Life phase into the asset lifecycle (from programming phase to EOL management) in BIM environment.

The main objectives of this research are to:

- Assess the impact of the incorporation of the sustainable End-of-Life phase into the asset lifecycle.
- What would be the stakeholder's interplays in this new asset lifecycle (from programming to EOL phase)?
- Assess the social, economic and environmental barriers of the Design for a sustainable EOL (Deconstruction, Design for disassembly, DFMA principle among others)
- Assess the social, economic and environmental barriers for using reclaimed materials

Please be assured that the interview is strictly for research purpose, and individual responses will remain confidential. As such, you are encouraged to discuss your expectation on the incorporation of a sustainable EOL phase as part of the asset lifecycle in BIM environment. The data from the research will be used, stored, and destroyed in a safe way. The interview will take about 60-90 minutes to complete. The discussion will be recorded on a digital device. Please let me know if you have any concern about this.

2. Why have I been chosen?

Because you are involved in Building Information Modelling (BIM) and or in EOL management (deconstruction, disassembly, DFMA…) in your country.

3. Do I have to take part?

Taking part is 100% voluntarily. However, your participation can support the aims of this project which is developing a framework that can be used for integrating the sustainable EOL phase into the asset lifecycle, in BIM environment.

4. What do I have to do?

This is a semi-structured interview followed by a set of questions. Few days before the interview an email will be send to you containing:

- A questionnaire that you are asked to fill before the Face-to-Face interview. You can fill it online by clicking here : https://coventry.onlinesurveys.ac.uk/interview-21june-2018
- A sheet with the questions that will be asked to you during the interview that you are invited to read to prepare the interview. This sheet will also contain a **Framework** for the incorporation of the sustainable EOL phase in BIM environment.

I will be grateful if you complete the assigned questionnaire, as much detail as possible. I will ask you to give your comments on the **Framework.** Please, feel free to add, remove, correct whatever you want.

Please, note that the documents given to you are part of my research work and are **strictly confidential**.

5. **What are the risks associated with this project?**

No risks are envisaged associated with this project. The desired outcome of this project is to develop a framework for incorporating the sustainable EOL phase into the asset lifecycle.

6. **What are the benefits of taking part?**

As a professional, your perspective will help to improve the understanding of the impacts and barriers of the incorporation of the sustainable EOL phase into the asset lifecycle in BIM environment. Your contribution will help reaching the EU commitment to be able to recycle 70% of the C&D waste by 2050.

7. **Withdrawal options**

You can withdraw anytime during and after the interview/questionnaire.

8. **Data protection & confidentiality**

All data are confidential. All the records (audio and notes) will be stored on a dedicated safe location advised by Coventry University (OneDrive). The details of the participants will be destroyed safely by the end of the PhD. Coventry University data protection and confidentiality policy will adhere fully, personal or business data will not be mentioned in the final thesis.

9. **What if things go wrong? Who to complain to**

You may complain to the head of the Centre for the Built and Natural Environment, Professor Mark Tyrer through email: ac5015@coventry.ac.uk

10. **What will happen with the results of the study?**

The results of the study will be summarised and analysed in the thesis. They also will be published in scientific journals and conferences in an open-access format.

11. **Who has reviewed this study?**

Pr. Eshmaiel Ganjian cbx111@coventry.ac.uk
Dr. Hafiz Alaka ac7485@coventry.ac.uk
Pr. Jean-Claude Morel ac0969@coventry.ac.uk

12. **Further information**

Please, contact Rabia Charef charefr@uni.coventry.ac.uk

I have read and agreed to the terms and conditions

- ○ Yes
- ○ No

Date | Signature

5 Appendix 5 : Certificates of Ethical Approval

Certificate of Ethical Approval

Applicant:

Rabia Charef

Project Title:

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

This is to certify that the above named applicant has completed the Coventry University Ethical Approval process and their project has been confirmed and approved as Medium Risk

Date of approval:

04 July 2018

Project Reference Number:

P72584

Certificate of Ethical Approval

Applicant:

Rabia Charef

Project Title:

A conceptual BIM-Based Framework to integrate the Sustainable End-of-Life phase into the Asset Lifecycle in the context of the Circular Economy

This is to certify that the above named applicant has completed the Coventry University Ethical Approval process and their project has been confirmed and approved as Medium Risk

Date of approval:

30 July 2019

Project Reference Number:

P93523

6 Appendix 6: Methods choice

A. Mono Method: qualitative or quantitative

The collection of data and data analysis are crucial steps during the research process. The researcher must select between a qualitative or quantitative approach. According to Bryman, some research questions cannot be answered without using the combination of both approaches (Bryman 2006). When qualitative and quantitative data are required to be able to answer the research question, the method used is called “Mixed Methods”. There are multiples strategies or methods to collect the data, mentioned in Chapter 3, Figure 3-1.

a. *Quantitative method*

Definition: According to Aliaga and Gunderson (2002), quantitative research is ‘*Explaining phenomena by collecting numerical data that are analysed using mathematically based methods (in particular statistics)*.’ (Aliaga and Gunderson 2002). A very close definition was also done by Bryman and Bell (2007), “*Quantitative research develops and uses mathematical models, theories and hypothesis to describe relevant natural phenomena*”. The key specificity of quantitative research is that the data collected to answer to a research question or explain a phenomena is numerical. Even if the phenomena don’t naturally exist in a quantitative form, researchers use instruments to convert phenomena. The data collection instruments used for quantitative research are questionnaires or tests. According to Muijs (2004) quantitative research is flexible and can be used on an almost unlimited phenomena (Muijs 2004). While the advantages of quantitative are numerous.

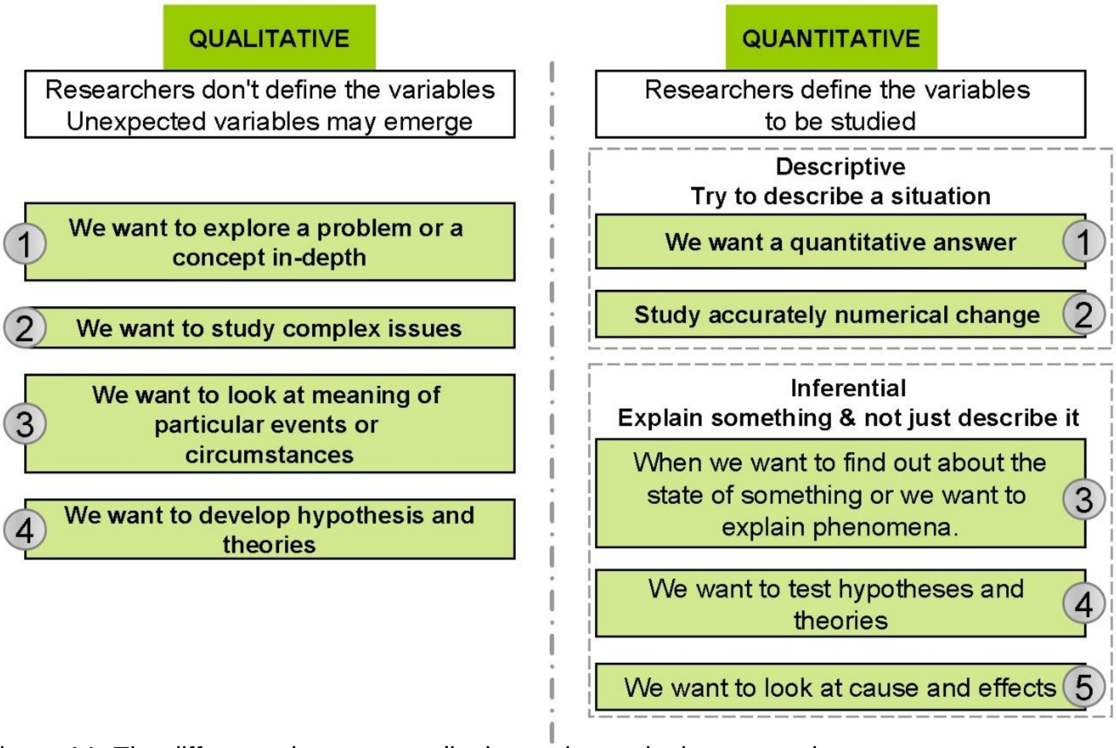

Figure A1: The difference between qualitative and quantitative research

b. Qualitative method

Quantitative research is usually contrasted against qualitative methods that use non-numerical data. According to Muijs (2004) qualitative research term encompasses "*a wide range of range of methods, such as inter- views, case studies, ethnographic research and discourse analysis, to name just a few examples*" (Muijs 2004).

People usually consider that there are "paradigm wars" between quantitative and qualitative research due to their difference. This idea come from the worldviews and underlying philosophies of quantitative and qualitative researchers. Indeed, qualitative research is described as "subjectivist" and opposed to realist for quantitative research. The key differences between quantitative and qualitative research are summarized in Figure A1.

At first glance, the two approaches may seem incompatible but in reality, they can combine and complement each other.

B. **Mixed Methods: Several types of mixed methods design**

One of the first definition of Mixed Methods, given by Creswell et al., is that Mixed Methods are "the collection or analysis of both quantitative and qualitative data in a single study in which the data are collected concurrently or sequentially, are given a priority, and involve the integration of the data at one or more stages in the process of research" (Creswell et al. 2003) p. 212.

A few years later, Creswell and Clark define Mixed Methods research as "a research methodology with philosophical assumptions as well as methods of inquiry. As a methodology, it involves philosophical assumptions that guide the direction of the collection and analysis of data and the mixture of qualitative and quantitative approaches in many phases in the research process. As a method, it focuses on collecting, analyzing, and mixing both quantitative and qualitative data in a single study or series of studies. Its central premise is that the use of quantitative and qualitative approaches, in combination, provides a better understanding of research problems than either approach alone" (Creswell and Clark 2007).

Several authors tried to classify the various mixed methods in types. Hanson et al. and Creswell and Plano consider that the Mixed Methods can be classified into six types: three sequential and three concurrent. The three concurrent Mixed Methods are Triangulation, Nested or Embedded and Transformative. The three sequential Mixed Methods designs are Explanatory, Exploratory and Multiphase or Sequential Embedded Design or Transformative Mixed Methods Design(Hanson et al. 2005)(Creswell 2014). According to Creswell and Plano, the major Mixed Methods types of design are Convergent design, explanatory design, exploratory design, embedded design, transformative design and multiphase design(Creswell and Plano Clark 2011). The following sub-sections will explain the six major Mixed Methods.

a. Concurrent mixed methods

Convergent Parallel Mixed Methods Design**:** This is the most familiar. The researcher collects two types of data, quantitative and qualitative data, analyses the data separately and then compare the results (confirm/disconfirm). The sample size that is usually different for qualitative and quantitative data is considered by some researchers as an issue. To work around the issue, some researcher will increase or use the same sample for the qualitative data. The qualitative sample (S2) can be taken from the quantitative sample (S1), (Figure A2). For this type of design, the key idea is to use the same variables or concept that will be assessed quantitatively and qualitatively (Creswell 2014). The data convergence or merging is a real challenge. During the interpretation phase, the data from qualitative and quantitative will be compared and discussed. The comparison can be done, side by side, data transformation or merging the data in tables or graph before the discussion (Figure A2). This type of Mixed Methods design cannot be used for this study because the variables are not the same for the quantitative and qualitative data.

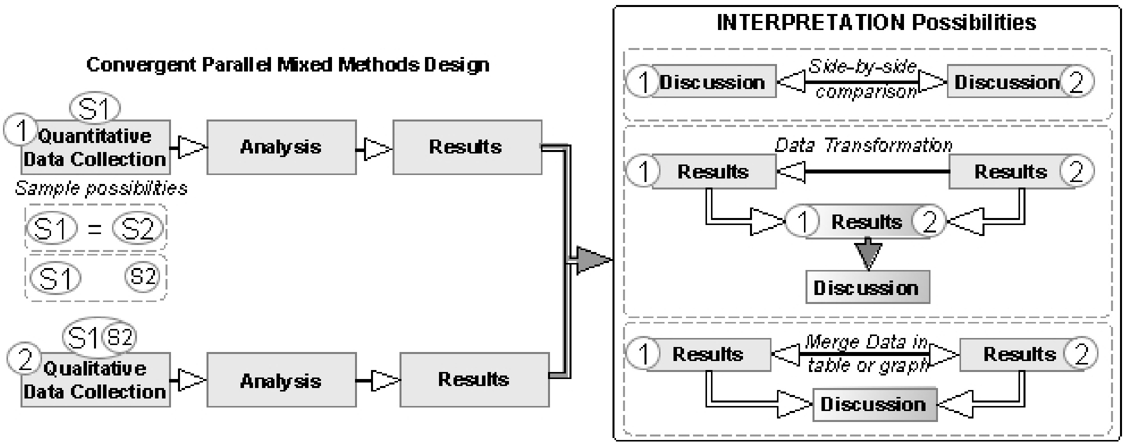

Figure A2: The Convergent Parallel Mixed Methods Design (based on Creswell (2014))

Explanatory Sequential Mixed Methods**:** The researcher collects two types of data in two phases: During the first phase, the quantitative data is collected and analysed. Then, the results are used to plan or build on the second phase of qualitative data collection. The results from the quantitative phase will inform the types of interviewees selected by the researcher purposefully. "*A typical procedure might involve collecting survey data in the first phase, analyzing the data, and then following up with qualitative interviews to help explain the survey responses*" (Creswell 2014). The sampling for the qualitative data collection (S2) will be selected purposefully from the quantitative sampling (S1). Indeed the key strength of the explanatory sequential method is to follow-up the quantitative data and explore the results deeply by conducting the qualitative phase. The qualitative and quantitative data are analysed separately. The results of the first quantitative phase will inform and help the researcher to design the questions and select the participant for the second phase. (Figure A3)

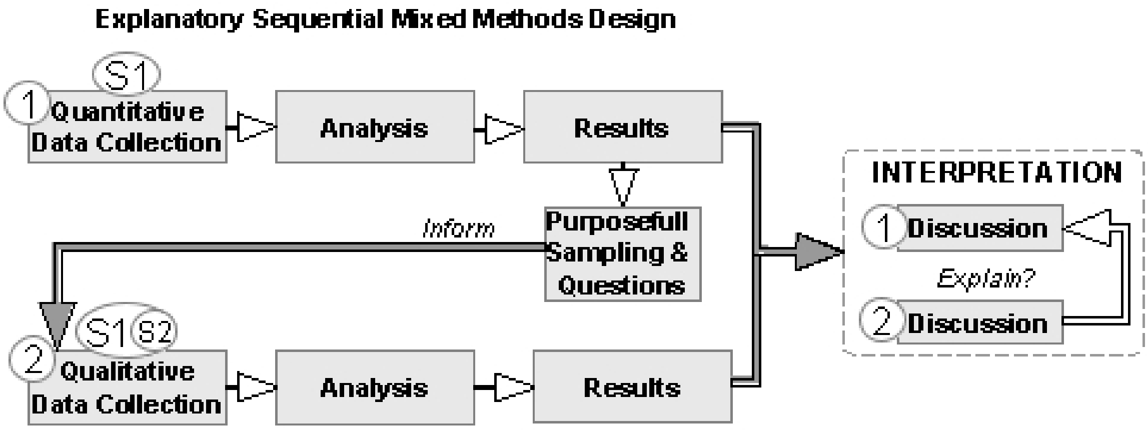

Figure A3: The Explanatory Sequential Mixed Methods Design (based on Creswell (2014))

Exploratory Sequential Mixed Methods**:** The exploratory sequential type of mixed methods is simply the reverse of the explanatory sequential approach (Creswell 2014), (Figure A4). The intent of the exploratory sequential approach is to explore by using the qualitative approach first, on a small sample and then, to see if the results can be generalized to a larger sample. For a good procedure, the qualitative sample (S2) cannot be taken from the quantitative sample (S1).

According to Creswell, the 3 previous mixed methods types (Convergent parallel, Explanatory sequential, Exploratory sequential), are the basic strategies. The three following strategies are more advanced, containing the three basic forms.

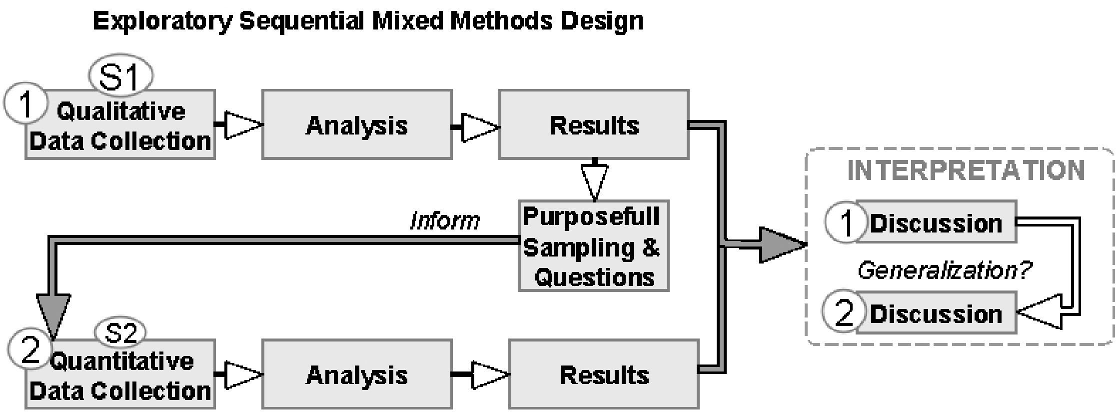

Figure A4: The Exploratory Sequential Mixed Methods Design (based on Creswell

b. Embedded Mixed Methods design

The embedded Mixed Methods nests one or more type of data, whether qualitative or quantitative or both within a quantitative or qualitative procedure (Figure A5). Creswell gave an example within an experiment. He said that qualitative data could be collected at several time during the project research. When the data is collected during the experiment, the approach is convergent. However, when the data is collected before or after the experiment, the approach is sequential. Two types of data answer different research questions. The second data set is collected and analysed before, during or after the first data collection. This method is common for research necessitating to test “an intervention or program in an applied setting” (Creswell 2014).

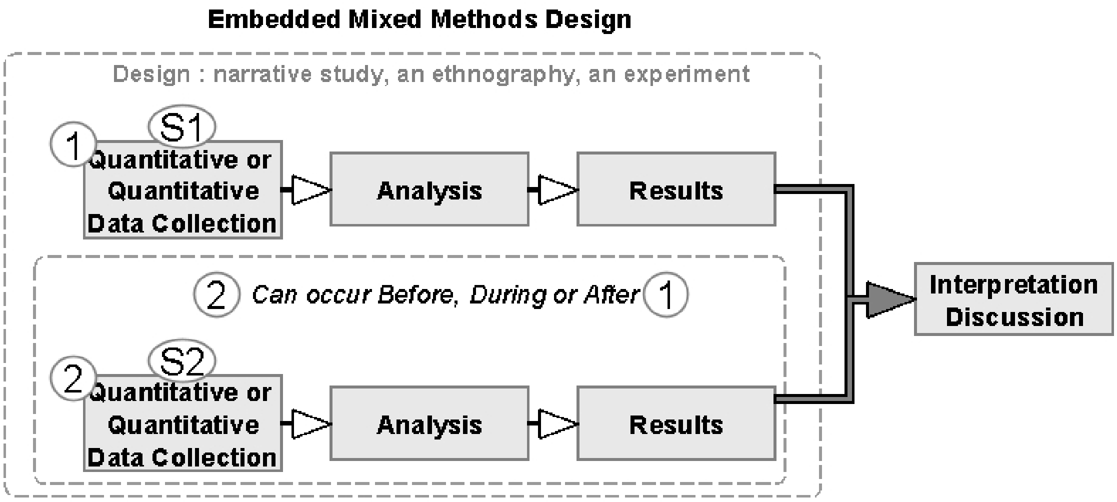

Figure A5: Embedded Mixed Methods Design (based on Creswell (2014))

Transformative Mixed Methods design**:** In the transformative mixed methods, the research is conducted within the social justice theory, used by the researcher as a framework. Figure A6 gives an example of the implementation of the explanatory Mixed Methods design within the Framework. The Researcher can implement any of the four basic mixed methods discussed previously (Convergent, Explanatory, exploratory and Embedded). According to Creswell and Plano Clark, the transformative mixed methods design is the use of one of the four designs, encased within a transformative Framework used as an orienting lens. The aim of the transformative framework is to conduct research that brings change. The Framework informs the research question, the way the data is collected and the results of the study (Creswell and Plano Clark 2011).

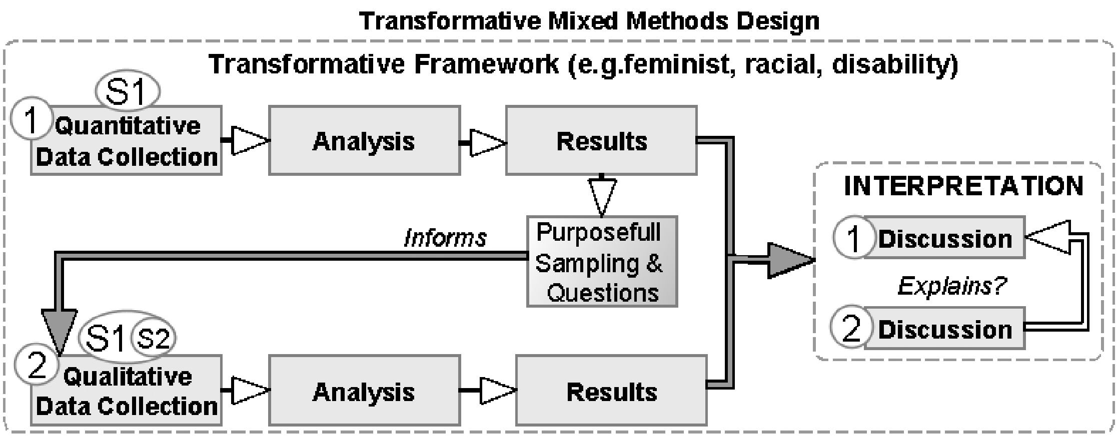

Figure A6: Transformative Mixed Methods Design (based on Creswell (2014))

Multiphase Mixed Methods design: The last type of Mixed Methods design is Multiphase Mixed Methods, (Figure A7). The use of these methods is adapted when several mixed methods projects are conducted in a longitudinal study with a common objective. According to Creswell, "*the researchers conduct several mixed methods projects, sometimes including mixed methods convergent or sequential approaches, sometimes including only quantitative or qualitative designs in a longitudinal study* "(p.278) (Creswell 2014). The projects conducted with the multiphase mixed methods must address a common objective and build on each other. A multiphase design is a "*flexible large-scale enterprise, where quantitative and qualitative methods are combined within and between several phases, and where the phases depend on each other and on an overall objective for the enterprise*" (Lund 2012). This type of mixed method design is a combination of sequential and concurrent aspects. It is common in large projects. For some authors, the multiphase Mixed Methods design is named "sandwich design", an alternation of the quantitative and qualitative methods, across three phases (Sandelowski 2003).

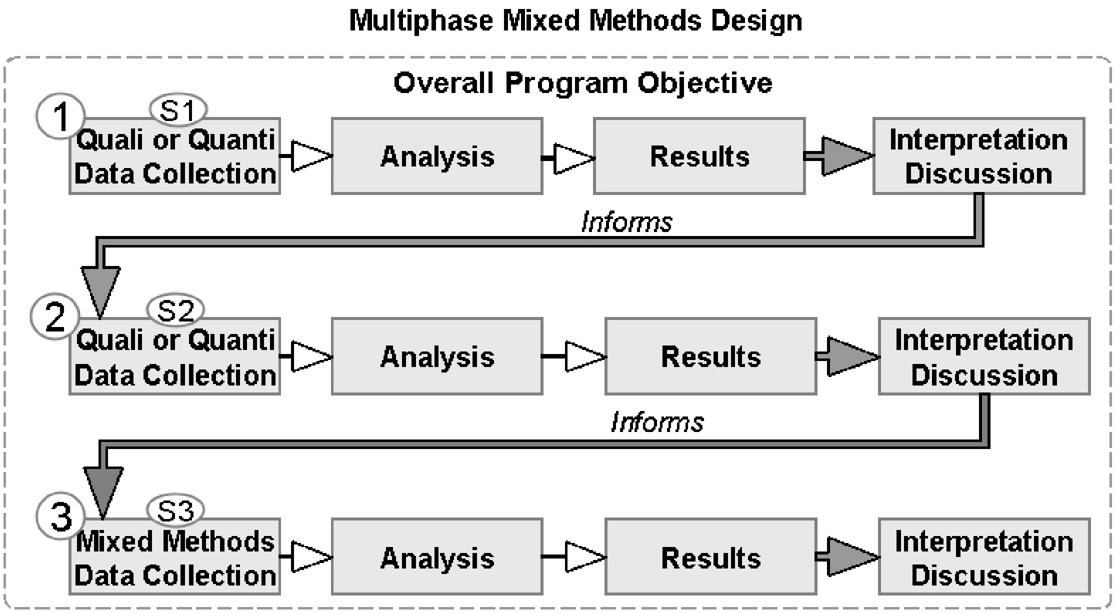

Figure A7: The Multiphase Mixed Methods Design (based on Creswell (2014))

It was concluded that the most appropriate for the study was the sequential Embedded Mixed Method. Indeed, two types of data (quantitative and qualitative) were collected sequentially within a traditional qualitative design. The embedded design was used to add a quantitative strand to the study within a qualitative design. The process was deeply explained by Creswell and Plano Clark (Creswell and Plano Clark 2011).

Regarding the procedural notations used in Figures A2 to A7, (S1) and (S2) refer to the sample of the first, second and third steps (circled number),