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A BIM-based theoretical framework for the integration of the asset End-of-Life phase

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Abstract. Due to the migration of industry from the use of traditional 2D CAD tools to Building Information Modelling (BIM) process, and the growing awareness of Construction and Demolition (C&D) waste issues, researchers are interested in compiling the use of BIM for C&D Waste issues. BIM is commonly used for the Design, Construction and Maintenance phases of an asset; however, the use of BIM for the End-of-Life management is still in its infancy. This paper proposes to reconsider the asset lifecycle by incorporating a sustainable End-of-Life, as a phase, in BIM context. Recommendations are given to push the BIM potential up to the asset End-of-Life management. Based on the results of a literature review assessing the current use of BIM for the asset End-of-Life, a conceptual framework was drawn. A set of eleven stakeholders, involved in the asset lifecycle, from inception to deconstruction were interviewed to improve the conceptual framework. The research reveals the impacts and barriers for the integration of the deconstruction phase into the asset lifecycle. Consequently, a theoretical framework for the asset lifecycle from inception to deconstruction in BIM environment is created to change the linear system to a circular economy.

Keywords: Building Information Modelling (BIM), End-of-Life, Deconstruction, Demolition, Barriers, Circular Economy.

1. Introduction

The arrival of Building Information Modelling (BIM) has caused the most significant transformation that the construction sector has experienced since the industrial revolution. This new technology has caused a significant shift in cultural, behavioural, and traditional “ways to work” in Architecture Engineering and Construction (AEC) processes. The use of a multidisciplinary collaboration approach necessitates changes in the roles of the stakeholders involved in the project (clients, architects, contractors among others). They need to move from a “silo process” to collaborative work and share a massive amount of data generated from design to completion. Until now, BIM has been widely used in the design phase but significantly less in the construction and “in use” phases.

In addition to the BIM use growth, the asset End-of-Life (EOL) concern and the waste generated by the construction sector are of increasing interest to academic researchers. Most existing studies focus on



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methods to minimise Construction and Demolition Waste (C&DW) [1], and the potential to use BIM for waste minimisation [2][3]. This interest is due to the continuously growing amount of waste generated by the construction industry [4],[3][5][1]. The environmental impact due to the tremendous amount of C&DW disposed in landfills [6][3][7], and the depletion of natural resources remains a constant concern for government bodies [1] [8][9].

The study aims to address how the End-of-Life phase can be integrated into the BIM environment and in the lifecycle of an asset. The following research objectives will help to achieve the aim: (i) To investigate what the current use of BIM is for EOL issues? (ii) To identify the barriers for integration the sustainable EOL in the asset life cycle?

2. Research method

A literature review was undertaken using Scopus as the main search engine. Owing to the novelty of BIM technology, 8 years were considered, from 2010 to June 2018. Only journal papers were considered. The first search focused on looking for papers addressing the use of BIM for EOL management. A total of 93 documents appeared. After reading the titles and the abstracts, among them, 51 journal papers were excluded due to their improper area. The 42 remained papers were fully read. Finally, seventeen papers were identified as relevant to the topic of the study. These papers were classified into two categories regarding if they focus on Demolition or Deconstruction. The classification was also performed to identify which phase the paper focus on. A second search was performed to identify the papers addressing the barriers and factors for replacing demolition by deconstruction.

Based on these papers, we have designed a BIM-based theoretical framework for the integration of the asset End-of-Life phase and extracted a set of questions to be used for the semi-structured interviews. The aim of the interviews was to identify the barriers for incorporating the asset EOL. For the sampling, the focus was on France.

3. Results and Analysis

3.1. Literature Review: Results and analysis

A thorough review of the seventeen leads to classifying them into two manners. First, a classification according to the use of BIM for the EOL concern was done: deconstruction or demolition. The results show that, in parallel of the Demolition concern, ten papers address Deconstruction concept. The results also show that publication related to this area started since 2013. Secondly, the classification was done according to the Asset Lifecycle stages, in four categories “(D) Design”, “(C) Construction”, “(I) In use”, and “(E) End-of-Life” (Table 1). The EOL is pointed out in fourteen papers. Seven papers linked the design phase and the EOL phase (Table1). Construction & Demolition Waste has been addressed in several ways. Waste management techniques were tackled by [10] who explored barriers hindering the efficiency of current construction waste management and approaches enabling waste reduction. The authors conducted a Focus-Group Discussion for collecting the data and used a “combination of phenomenological approach with a critical review and analysis of extant literature.” The global purpose of the paper was to explore construction waste management techniques to emphasise the barriers and strategies for enhancing their efficiencies. A framework was developed for improving waste effectiveness. Recently, [11] proposed five BIM-based processes for efficient C&D waste management. Four papers addressed the waste generated during the End-of-Life of the asset exclusively (Table 1). Indeed, they have carried out an investigation of the waste generated during renovation, Demolition and Deconstruction stages. Cheng et al. (2013), using a literature review and survey, identified that no tools are available for the management of C&D Waste. To fill the gap identified, the authors developed a BIM-based system to achieve waste estimation, disposal charging fee calculation and the number of pick-up trucks required to remove the waste. The lack of methodologies and tools for C&DW estimation were also highlighted by other authors. They discuss the construction waste generation concern and some of them have developed frameworks associating BIM technologies for waste estimation, waste

improvement, waste management or for assessing the deconstructability of buildings. Based on a questionnaire survey and face-to-face interviews, these authors developed a design decision-making framework, BIM-aided construction waste (BaW), for improving CWM performance via BIM.

Table 1. The journal papers related to BIM and EOL

SN	Author	Focus of the paper		D	C	I	E	Journal	Country	Method	Respondent
		DEM	DEC								
1	Cheng and Ma (2013)	✓					✓	WM	HK	IE	-
2	Li and Yang (2014)	✓	✓	✓	✓	✓	✓	RCR	AU	SQ	49/120, RR 41%
3	Akbarnezhad et al. (2014)	✓	✓	✓			✓	AC	AU	CS	-
4	Ajayi et al. (2015)	✓		✓				RCR	GB	FGIs	25 Pts
5	Akinade et al. (2015)	✓	✓	✓				RCR	GB	CS	-
6	Bilal et al. (2016)	✓		✓				JOBE	GB	LR	-
7	Akinade et al. (2016)	✓	✓	✓			✓	IJSBTUD	GB	FGIs	24 Pts
8	Won et al. (2016)	✓			✓	✓		WM	HK	CS	-
9	Kim et al. (2017)	✓	✓	✓	✓		✓	WMR	KR	CS	-
10	Ajayi et al. (2017)		✓	✓			✓	RSER	GB	FGIs	24 Pts
11	Akinade et al. (2017)		✓				✓	IJSBE	GB	FGIs	20 Pts
12	Lu et al. (2017)	✓		✓			✓	RSER	HK	CR	-
13	Ge et al. (2017)	✓	✓	✓	✓			VE	AU	CS	-
14	Won and Cheng (2017)	✓		✓	✓		✓	AC	KR	LR	-
15	Volk et al. (2018)	✓		✓			✓	AC	DE	CS	-
16	Akinade et al. (2018)	✓	✓	✓	✓		✓	JCP	GB	FGIs, QS	23 Pts 62/130, RR 47.7%
17	Akanbi et al. (2018)		✓	✓	✓		✓	RCR	GB	CS	-

SN	Authors	Approach for sustainable EOL	Journal	Country	Method	Respondent
1	Chieleshe et al. (2015)	Design for Reverse logistic (DfRL)	SCM	AU	SQ	49/539, RR 9%
2	Tingley et al. (2017)	Steel reuse-barriers & benefits	JCP	GB	SSIs	13 Pts
3	Akinade et al. (2017)	Design for Deconstruction (DfD)	WM	GB	FGIs	24 Pts
4	Hakkinen & Belloni (2011)	Sustainable buildings, Barriers& Drivers	BRI	FI	SQ, SSIs, CS	158/350, 20 Pts
5	Akinade et al. (2018)	Designing out Construction Waste	JCP	GB	FGIs	23 Pts
6	Akanbi et al. (2018)	Salvage of structural components	RCR	GB	CS	-
7	Hosseini et al. (2015)	Reverse Logistic- Advantages & barriers	WMR	AU	LR	-
8	Jaillon & Poon (2010)	Prefabrication - Design issues	CME	HK	SQ, SSIs, CS	84/354, RR 24%, 35 Pts
9	Chikeshe et Al. (2014)	Reverse Logistic implementation Analysis	IJOPM	AU	SQ, SSIs	49/539, RR 9%, 6 Pts
10	Chikeshe et Al. (2014)	Reverse Logistic: Drivers for adoption	ECAM	AU	SSIs	8 Pts
11	Chini (2003)	Barriers for Deconstruction	FSC	US	CS	8 Cases Study
12	Jaillon et al. (2009)	Prefabrication - waste reduction	WM	HK	SQ, CS	84/354, RR 24%
13	Bilal et al. (2016)	Factors for designing out waste	IJSBTUD	GB	FGIs	24 Pts
14	Ajayi et al. (2015)	AEC Waste effectiveness	RCR	GB	FGIs	25 Pts

Method
 (DEM) Demolition, (DEC) Deconstruction, (D) Design, (C) Construction, (I) In Use, (E) End-of-Life
 (RR) Response Rate, (LR) Literature Review, (CR) Critical Review, (FGI) Focus Group Interviews, (CS) Case study, (IE) Illustrative Example, (SQ) Survey Questionnaire, (SSIs) Semi-Structured Interviews

Journal
 (WM) Waste Management, (RCR) Resources, Conservation and Recycling, (AC) Automation in Construction, (JOBE) Journal of Building Engineering, (IJSBTUD) International Journal of Sustainable Building Technology and Urban Development, (RSER) Renewable and Sustainable Energy Reviews, (IJSBE) International Journal of Sustainable Built Environment, (VE) Visualization in Engineering, (JCP) Journal of Cleaner Production, (SCM) Supply Chain Management: An International Journal, (BRI) Building Research Information, (IJOPM) International Journal of Operations & Production Management, (ECAM) Engineering Construction & Architectural Management, (FSC) The Future of Sustainable (Pts) Participants, Country ISO 3166

The link between the design phase and the End-of-Life was introduced in 2001 by [12], [13] with the notion “Design for Disassembly”. In 2003, the concept of “Design for Deconstruction” was proposed [13], followed in 2004 by [14]. This opens a new vision of design with the end of life in mind to reduce waste and enable material reusability. In fact, the concepts of “Design for Deconstruction” and “Design out Waste” are explored by various authors with the aim to minimize construction waste by using BIM technology [4], [15]–[19]. [10] mentioned that proper design coordination could be a real preventive measure for reducing the volume of waste generated during construction activities.

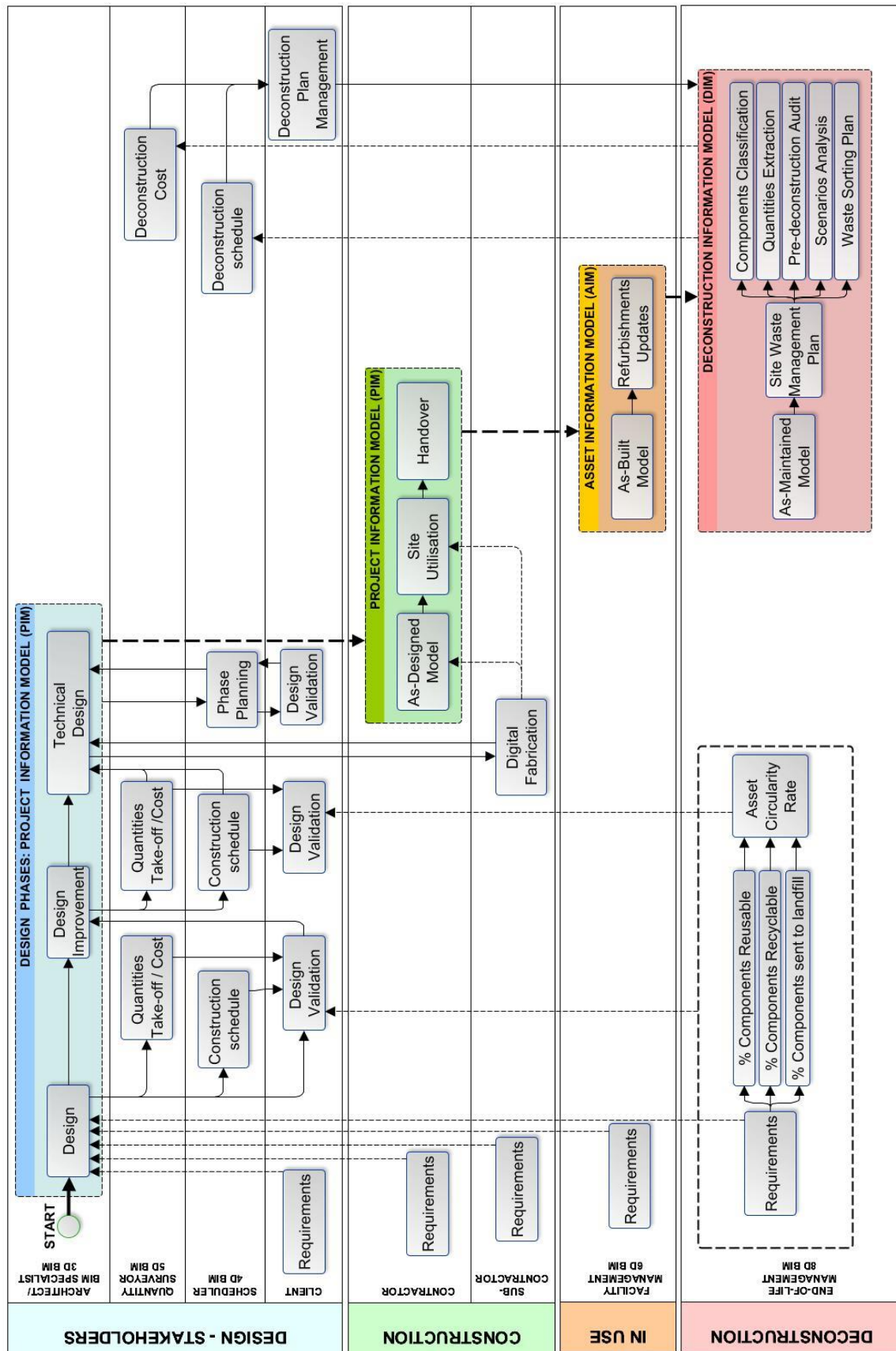


Figure 1. The conceptual framework based on the Literature Review and Messner et al. [20]

Akinade et al., for their part, developed an interest in the design and EOL phases [4]. They focused on an asset's deconstructability capabilities by using a "mathematical modelling approach based on building design's bill of quantities." The gap identified by the authors was that existing BIM software did not have the capabilities for EOL waste performance analysis. [4] developed a BIM-based Deconstructability Assessment Score (BIM-DAS) enabling designers to assess the deconstructability of their projects, adapt their design to improve the Deconstruction capabilities and thus reduce the volume of construction waste sent to landfill. They highlighted the importance to link the asset Deconstruction with the design phase to minimise waste production.

Akbarnezhad et al., proposed a potential application of BIM for building Deconstruction. Based on a case study, three common Deconstruction strategies were conducted (landfilling, recycling and design for disassembly). The developed conceptual framework was used to evaluate the best Deconstruction strategies and compare the effects of the Deconstruction strategies according to cost, energy consumption and carbon footprint. Finally, none of the relevant articles discussed above has addressed how to integrate the EOL (whatever demolition or deconstruction), as a phase of the asset lifecycle. Based on this literature review and on Messner et al. [20], we have designed a BIM-based theoretical framework for the integration of the asset EOL phase (Figure 1). To assess the obstacle against the practical use of this theoretical framework, we have performed interviews that will be discussed below.

3.2. Interviews: Results and analysis

According to (Creswell, 2013), in-depth interviews or Focus Group Interviews (FGIs) could be used for collecting qualitative data. This kind of approaches are pertinent for exploratory research because of that it enables the emersion of new concepts [21]. Interviews can be used for qualitative and quantitative data collection. It depends if the questions are open-ended (qualitative) or closed-ended (quantitative) [22]. In this study, individual semi-structured face-to-face interviews were used.

Table 2. Structured interviews' sampling

SN	Stakeholder ROLE	Company Size	Phases	Project types	Exp.	EOL	APPROCHES								
							BIM	CW	RMU	FWR	RB&C	DOW	DWM		
1	BIM Manager	Expert Strategic Deployment BIM	21-50	D-C	H-E-R	10	BIM	✓	✓						
2	BIM Manager	Head of BIM & Innovation	21-50	O&M	C - I	37	BIM	✓	✓	✓					✓
3	BIM Manager	Head of the Engineering Office	20	D-C	C - I	20	BIM/DEM	✓	✓	✓					✓
4	BE/Owner	Engineering Office/Client	0-5	D-C	R	20	DEC					✓			
5	R&D	Research & Development	0-5	D	R	10	DEC					✓			
6	Designer	CEO/Architect	0-5	D	R - O	30	DEC			✓	✓	✓	✓	✓	✓
7	Designer	Architect (France & India)	21-50	D	R - H&L-O	15	DEC		✓	✓	✓	✓	✓	✓	✓
8	Control Officer	Head of Control Office	+100	D-C	All types	30	DEC	✓	✓			✓			✓
9	BIM Manager	Digital project manager	+100	O&M	All types	15	DEC/BIM	✓	✓	✓					
10	QSS	Quantity Surveyor/BIM manager	0-5	D-C	All types	8	BIM/DEM	✓	✓						
11	Designer	CEO - Architect	0-5	D	R-O-E	30	BIM/DEC	✓	✓	✓	✓	✓	✓	✓	✓

Project type: (R) Residential Buildings, (C) Commercial Buildings, (I) Industrial Buildings, (O) Office Buildings, (H) Health Buildings, (E) Education Buildings, (H&L) Hospitality and Leisure

Phase: (EOL) End-of-Life, (O&M) Operation & Maintenance (D) Design, (C) Construction, (DEC) Deconstruction, (DEM) Demolition

Approaches: (CW) Collaborative Work, (RMU) Recyclable Materials Users, (FWR) Finishing works Reduction, (RB&C) Reuse Buildings & Component, (DOW) Design out waste, (DWM) Design waste minimisation

(Exp.) Experience in years

Company size: (0-5) Employees, (6-20) Employees, (21-50) Employees, (51-100) Employees, (+100) Employees

Table 2 reported the interviewees selected for this study. The target population for the study are the stakeholders involved during the asset lifecycle from inception to the End-of-Life asset management. The interviewees should work with consideration for asset EOL and /or with the Building Information Modelling process. Another parameter that matter to the researcher is the years of experience. A delimiting factor of 10 years as a minimum was selected to make sure that all the interviewees have

robust experience in the construction industry. The sampling was done by using the purposive technique and the personal researcher network (Table 2).

Table 3. The barriers for adding the sustainable End-of-life phase into the asset lifecycle

BARRIERS		Interviewees References	ROLES			
Categories	Sub-categories		BIM Manager (x4)	Designer (x2)	Controller (x1)	Owner/R&D (x1)
ECONOMIC 76 References 7 Respondents	Activity sector	2 4	3	1		
	Financial cost	7 42	31	5		6
	Market-structure	3 9	5		3	1
	Space for storage	2 3	1			2
	Time-complexity	6 18	9	8		1
POLITIC 43 References 8 Respondents	Contracts-tender	1 1		1		
	centive for reclaimed materials	1 1	1			
	Insurance	3 3		1	1	1
	Regulations	8 38	14	5	2	17
SOCIOLOGIC 78 References 8 Respondents	Aesthetic trend	1 1			1	
	Awareness	4 6	5			1
	Construction = durability	3 7	1	2		4
	Human behaviour	8 32	15	7		5
	Lack of information	3 3	2	1		
	Lack of understanding-interest	2 3	1	2		
	Responsibilities	5 10	6	3		1
	Training-skills	6 12	8	3		1
TECHNOLOGIC 61 References 7 Respondents	Unrealistic	3 4	2			2
	Building type & size	6 12	10		1	1
	Material	7 30	15	5	1	9
	Method adaptation	3 7	1	2		4
	Software - New tools	3 4	3	1		
	Work-task	4 8	8			

A thematic analysis was conducted by using a coding scheme to classify the barriers, shown in Table 3. The barriers were classified into four categories and split into twenty sub-categories. The economical and sociological barriers are the one that appears most frequently, followed by the technological and political barriers.

Adding a sustainable End-of-life, such as deconstruction or dismantling as a phase into the asset lifecycle has a huge impact on the various project phases and the stakeholders involved throughout the asset lifespan. According to the 8 interviewees, the sociological barriers are the one that are the most pointed out by the interviewees. Human behaviour such as, resistance to change, acceptance of a new concept is crucial. The lack of awareness generate false believes that are a barrier for the implementation of the new asset lifecycle concept. In a collaborative work perspective, trust between stakeholders involved in a project is crucial. Lack of trust become an obstacle leading them to re-do the work, wasting time and extending the total duration of studies. Regarding the economic barriers, the most important are related to time and cost. Some respondents raised the need to create new roles to support the design team and the owner for implementing a sustainable EOL. The cost of material transport, specific treatment and process to make the reclaimed component reusable is also an important obstacle. The storage space needed for reclaimed materials will have an important impact on the project cost and schedule. Sustainable End-of-life activities are time-consuming and labour-intensive impacting hugely the project's schedule and cost. Seven interviewees listed also some technological barriers associated

with materials, methods and building types and size. For example, the transparency on the material composition seems to be capital if we want to increase the materials' reusability. Three interviewees raised the issues related to the complexity of construction materials that make them unsuitable for reuse or recycling. Two interviewees insisted on the negative side of finishing work and their extend use of material that are hardly recyclable. The materials' lifespan looks also to be a key factor for virgin resources reduction used by the construction sector. Some interviewees achieve a sustainable approach by avoiding the use of finishing materials. In fact, new approaches should be used to increase buildings' deconstructability or dismantling. Designer should adapt their design and manufacturers should revise their product to make them more reusable or proper for recycling. Political and regulations barriers were also raised by all the interviewees. Construction contracts and tender should be adapted to incorporate the EOL phase, from a responsibility' point of view. Inevitably, insurances must change their clause and create new clauses considering the use of reclaimed materials. The most cited political barrier is related to regulation. In fact, lack of regulations and their complexity were raised by more than half interviewees. Regulation dysfunction was pointed out by five interviewees.

The next step of this study is to put together the twenty barriers into an online questionnaire to collect construction experts' point of view to validate the results given by the interviews.

4. Conclusion

It is being acknowledged that the BIM process improves a project from its inception to completion. In fact, the data embodied in the Model generated during the design process represents real value for researchers wanting to explore the waste management area.

The aim of this investigation was to fill the gap of EOL incorporation in the Asset Lifecycle by considering the asset sustainable EOL as a phase. Based on a literature review, we have designed a BIM-based theoretical framework for the integration of the asset EOL phase. Then, to assess the obstacles against the practical use of this theoretical framework, we have performed interviews.

The integration of the End-of-Life as a stage in the lifecycle of the building requires various adaptation. In fact, the impact of this new concept is tremendous and affects various sectors. Based on the literature review, questions were designed for Structured Interviews. Interviews' analysis gave a set of twenty barriers classified into four categories, economic, political, sociological and technological barrier.

By redefining the Asset Lifecycle, the construction industry will be able to move toward the circular economy concept. As a matter of fact, designing with the end in mind, on purpose to reuse or recycle asset components reinforces the holistic aspect of the construction process. The new asset lifecycle concept will have implications for society and policies by shifting architect attitudes towards more responsible design and reduced environmental impact.

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