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

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Abstract

Across the world, the use of Building Information Modelling (BIM) and the three-dimensional (3D) model in projects are increasingly frequent for supporting design tasks. The digital data embodied in the BIM model is shared between the project stakeholders from the various disciplines. After giving an overview of the BIM 3D Model data used for planning (4D) and costing (5D), the study assesses the level of clarity or confusion on what the numbers of dimension refer to after the 5th dimension. A systematic review of the different BIM dimensions was conducted associated with an online questionnaire sent to various Architecture, Engineering and Construction stakeholders across Europe. The online questionnaire survey was limited to the 28 European Union (EU) countries. Each of the 28 EU countries was represented by at least one respondent. The research identified 52 papers considering BIM 4D Model, 15 considering 5D modelling, 6 considering the 6D Model and 2 considering the 7D. It was also identified a confusion between academics and practitioners for the 6D and 7D BIM dimensions. Whereas 86% (respectively 85%) of the professionals actually using 6D (respectively 7D), allocate Sustainability to 6D (respectively Facility Management to 7D). The data from the literature enabled to describe the process of the development of the BIM dimensions through time against the current use of BIM dimension in practice.

1. Introduction

Since its origins, around 1978 (Eastman *et al.*, 2011), the Building Information Modelling (BIM) process has been progressively implemented worldwide in the Architecture, Engineering and Construction (AEC) sectors. The use of BIM is now supported by a range of Public Policies trying to improve the efficiency of the construction industry. As an example, the European Union Public Procurement Directive (EUPPD) (Official Journal of the European Union, 2014) defines that "the 28 European Member States may encourage, specify or mandate the use of BIM for publicly funded construction and building projects in the European Union by 2016" (J. Wang *et al.*, 2014; Sacks and Gurevich, 2016). Moreover, the government supports are a critical driver for accelerating BIM adoption (Atkinson, Amoako-Attah and -Jahromi, 2014; Smith, 2014b).

The 3D model is the virtual mock-up model expressing visually, among other ways, the design concepts in the three primary spatial dimensions (width, height and depth). Over the past 20 years, 3D BIM has become ubiquitous in the design and construction field (Li *et al.*, 2014; Arayici *et al.*, 2011), used amongst others for project visualisation, collision detection and model walkthroughs (Yan, Culp and Graf, 2011; Liu *et al.*, 2013; Sattineni and Mead, 2013; Haron *et al.*, 2015; Han, Gao and Shao, 2016; Wu *et al.*, 2016). Indeed, 3D BIM model allows increasing collaboration (Eadie *et al.*, 2013) and improvement in the design and construction processes (Azhar, 2011b) by enabling visual controls during design and construction phase (Schultz *et al.*, 2013; Chong, Preece and Rogers, 2014; Charehzehi *et al.*, 2017).

The visualisation that 3D BIM brought was not enough and to achieve faster delivery; the "time" factor became quickly the 4th dimension of BIM (Zhang and Hu, 2011; Lopez *et al.*, 2016).

Indeed, many others dimensions need to be added for BIM to fulfil its potential. These activities, include sustainability, asset management, accessibility, safety management, energy saving, acoustic among others (Aouad, Lee and Wu, 2005; Fu *et al.*, 2006; Kiviniemi *et al.*, 2011; Ding, Zhou and Akinci, 2014; Yung and Wang, 2014; Yi, Zhang and Calvo, 2015; Nicał and Wodyński, 2016; Davtalab, 2017). These activities linked with 3D BIM model lead to some n-dimensional extensions, recently proposed in the literature (Delgado *et al.*, 2015). According to (Lee *et al.*, 2005), the nD model is an extension of the 3D BIM model that added in it "*multi-aspects of design information required at each stage of the lifecycle of a building facility*" (Aouad, Lee and Wu, 2005). The nD model will provide a dataset for various stakeholders, directly retrievable from the 3D BIM model and will allow them to improve their work during the project (Ding, Zhou and Akinci, 2014). The nD BIM expansion of the 3D BIM model received high interest from researchers trying to link it with various disciplines (Park and Cai, 2017).

The industry has seen excellent gains regarding the 3rd Dimension, such as improving design quality (Chen and Luo, 2014), communication (Fan, Skibniewski and Hung, 2014), and save time and money among others (Joyce, 2014; Candelario Garrido *et al.*, 2017). Although the fourth and fifth dimensions seem to have gained an amount of prominence, they still will be explored in this study to ascertain if there is any consensus or disagreement on what these dimensions represent. The confusion in the industry on BIM dimensions beyond the 5th dimension leads to the risk to lose the benefits brought by these extra BIM dimensions. The construction sector will encounter difficulties to reach the ambitious targets to meet by 2025, "33 percent lower cost, 50 percent faster delivery, 50 percent lower emissions and halving the export trade gap", if the BIM dimensions beyond the 5th is not sorted out and agreed on (Her Majesty Government, 2013).

The study, therefore, aims to assess the level of clarity or confusion on what the numbers of dimension refer to after the 3rd dimension. For example, what the 4^{h}, 5th and above dimensions refer to? The following research objectives will help to achieve the aim:

(i) To investigate what activities are most commonly referred to, like the 4th, 5th and above dimensions in BIM according to academics,

(ii) To investigate what activities are most commonly referred to, like the 4th, 5th and above dimensions in BIM according to European AEC practitioners,

(iii) To compare academics and practitioners views to help for seeing where the key confusions are and what can be done to enhance the consistency of the activities allocated to BIM dimensions beyond 5D.

Before we go on, it will be necessary to define a key term used in this paper as follows. Element: this refers to whatever activity, discipline, data that is associated with a particular dimension of BIM. When used as an element, the following sets will have the same meaning: "scheduling, planning and time" or "Estimating and cost".

Academics and practitioners point of view will be both assessed as done in various papers (Panuwatwanich and Peansupap, 2013; Abdirad, 2016) and recommended by authors (Rynes, Bartunek and Daft, 2001; Rynes, 2007). We will assess the academics point of view because they form a significant driver for BIM in the AEC industry. We also need the stakeholder's perspective because they are the ones implementing it in the industry and working on it directly. The improvement of the consistency between academics and practitioners will go along for helping the construction industry to achieve the benefits of BIM beyond the 3D dimension. Thereby, it will also allow elements like sustainability, asset management, and safety among others to be improved in terms of integration with BIM.

This study will be conducted using systematic review and online questionnaire as will be expatiated under the methods section. The paper is divided into four sections. The next section explains the research method used for this study: the systematic review methodology and the questionnaire method. Section 3 discusses the results of the review and the questionnaire in the form of tables and charts. The data analysis raises the lack of consensus for the 6D onwards. Section 4 gives conclusions and recommendations for future research.

2. Research Method

For the systematic review, the world scale will be considered to give an overview of the view of the academics across the world. Then, the questionnaire will be limited to the European Union to make the scope of the work manageable. We concentrated on the 28 EU countries as defined in the European Commission website. (https://europa.eu/european-union/about-eu/countries_en) Due to its well-known state, the three dimensions investigation will be excluded.

The onion diagram, developed by Saunders et al. (2009), illustrates the different stages to develop a research strategy (Saunders, Lewis and Thornhill, 2007). The first layer of the onion diagram refers to research philosophy. The philosophy of this study is pragmatism which allows the use of any methods that enable the researcher to answer the research question (Doyle, Brady and Byrne, 2009). In this study, the single research question is: what is the level of clarity or confusion on the dimension numbers in BIM after the 3rd dimension?

As BIM has evolved, the people that are dictating the dimensions are predominantly, the foremost practitioners and the academics (Sawyer, 2014b; Abanda, Kamsu-Foguem and Tah, 2017). It is critical for us to assess the academic's view because they have been the major driver in deciding what element is used for a particular BIM dimension. This review will allow us to see where most academics reside in terms of what element should be attached to the 4th dimension and beyond. The professionals also influence what this element of BIM dimension is called. Therefore, it is critical to assess the academics and professional's view to answer the research question. To assess the academic's view, we have investigated the journal papers which are usually the mainstream of academics views. This was done by a systematic review, which is a qualitative study. To assess the professional's view, we have carried out a survey questionnaire, which is a quantitative study. Although qualitative study is generally underpinned by the interpretivism philosophy and quantitative by the positivism philosophy, the use of combined qualitative and quantitative in this study is not contradictory because pragmatism, which is the philosophy of this study, allows the researchers to use whatever method that is required to answer their research questions.

The use of qualitative and quantitative data is a mixed method approach which refers to "*all procedures collecting and analyzing both quantitative and qualitative data in the context of a single study*" (Leech and Onwuegbuzie, 2009 p.19). The mixed method has been established to obtain a solution to complex questions. Due to the lack of a clear list of the design options for the mixed method, researchers should combine quantitative and qualitative approaches for data collection and analysis by using pluralistic approaches (Burke Johnson and Onwuegbuzie, 2004; Morgan, 2007). The use of mixed methods is also enhancing validity and reliability of findings due to the multiplicity of sources of data collection and provide a better understanding of research problems (Creswell and Clark, 2007). A single method approach is usually associated with a low responses rates that can be avoided with mixed methods (Chileshe *et al.*, 2016).

Collecting data in this manner will allow this study to be able to differentiate between academic and practitioner's point of view about dimensions above the third dimension. This will allow us to analyze and try to find the differences, and where they can come together. So, we can have a unanimous front in terms of dimensions above the third dimension. Therefore, BIM can continue to deliver great advancements to the industry, and the construction industry won't lose the benefits of BIM beyond the third dimension due to the divergent view that currently exist.

The following sub-sections explain how the systematic review and the survey questionnaire were carried out. The results of the systematic review influenced the questionnaire design and the type of questions asked to the European practitioners. The data collected was analysed, discussed, and conclusions were drawn. The various BIM dimensions, the 4D, 5D, and beyond will be deeply discussed.

2.1. The Systematic Review

Due to the massive growth of research output in both journal and conference papers, it is hard to establish what work has been done in the area of the study. The systematic review is the "most reliable and comprehensive statement about what works' (Petrosino and Lavenberg, 2007). The systematic review follows the methodology described by Keele and consists of six stages (Keele, 2007). For this systematic review, only journal articles were used because they are thoroughly peer-reviewed and accepted as the highest quality of academic contribution. This will enhance the validity of the study (Schlosser, 2007; Coelho, 2016).

For the systematic review, the main source of information was Scopus, officially named SciVerse Scopus, introduced by Elsevier Science in 2004. Scopus is the largest abstract and citation scientific database of peer-reviewed literature, and it offers the highest reliability in comparison with other databases like Web of Science and Google Scholar among others (Adriaanse Leslie and Rensleigh, 2013; Chadegani *et al.*, 2013). Scopus enables the access above 27 million citations and abstracts going back to 1960s. This database indexes a more significant number of journals in comparison with PubMed, Web of Science (WOS) and Google Scholar (Falagas *et al.*, 2008). Moreover, Scopus offers 20% more coverage than WOS (Vieira and Gomes, 2009). Based on different criteria the search is easy to use. Documents are classified under four subject areas and divided into 27 major thematic categories.

First of all, the research question of this study was set up. Having it in mind, we were able to come up with a number of keywords to be used for the systematic review search. The keywords used were BIM and dimensions, BIM and 4D, 5D. Then, we looked generally at the articles that came up, and we looked at the keywords that have been used in these articles. This preliminary search enabled us to formulate the keywords that will be used for the systematic review. Figure 1 details a diagrammatic framework of the process of the systematic review used. Since it is key to use keywords and Boolean Operators in systematic review (Petticrew and Roberts, 2008), for the stage 0, the combination of the following keywords and Boolean Operators were used: *"BIM AND 4D", "BIM AND 5D", "BIM AND 6D", "BIM AND 7D", "BIM AND 8D", "BIM AND nD"and " BIM AND dimension".* The acronym BIM was also delineated into *"Building Information Modelling" OR "Building Information Management".*

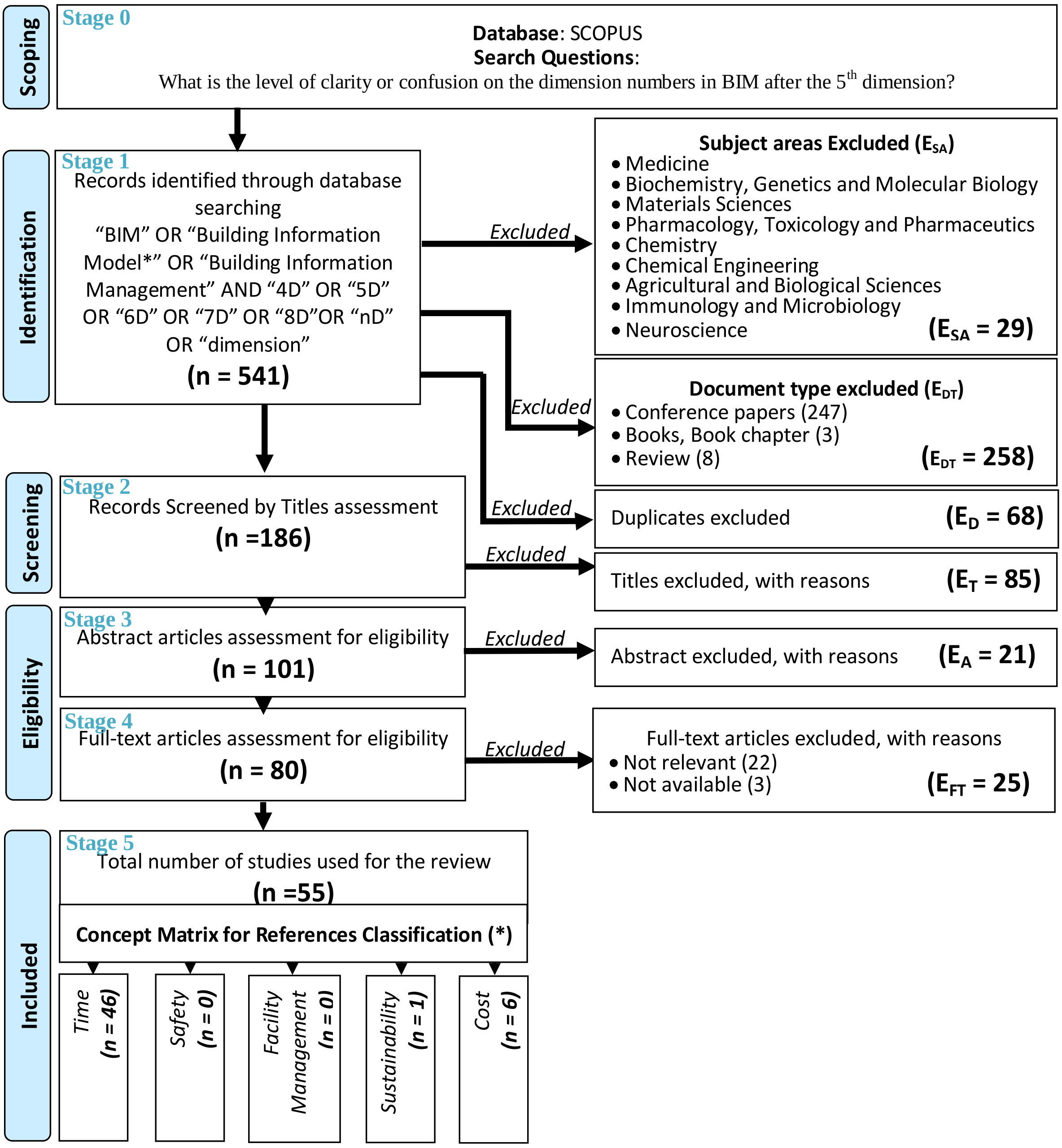
The search with these keywords returned a total of 541 articles. Some of the returned articles were from the medicine or chemistry disciplines leading us to realise that a number of returned articles were not fit for this study. Therefore, three types of exclusion were applied during the stage 1. First, a "subject area" exclusion criterion was used consisting in ticking boxes matching with *Medicine, Biochemistry, Genetics and Molecular Biology among others*, to exclude the documents belonging to these subject areas. This step led to the removal of 29 articles. Secondly, "documents type" exclusion was applied to the 512 left documents by eliminating all books, book chapters, conference papers, and review papers. In total, 258 documents were eliminated, leaving 254 journal papers. Only journal papers will be considered for this systematic review due to their high quality and validity (Schlosser, 2007). Lastly, 68 duplicates were removed.

For the stage 2, the remaining 186 papers were screened by looking at the titles, and those that were not relevant were removed. In total, 85 papers didn't fit with the subject area. For example, the titles "*Application of BIM Techniques to the Construction of the Donggang Station of the Lanzhou Metro*" (Zhang, Zeng and Wang, 2017) or "*Tracking of secondary and temporary objects in structural concrete work*" (Turkan *et al.*, 2014) were removed. Next, during stage 3, the relevance of the 101 papers returned from stage 2 was checked by reading abstracts of the articles. Due to their focus, such as the use of BIM for monitoring fire prevention and disaster relief (Cheng *et al.*, 2017) or to their specific content such as door detection in 3D laser scanning of the indoor environment (Quintana *et al.*, 2018), 21 papers were considered as irrelevant. Finally, 80 papers were selected for the next eligibility step where full-texts were given quick read by skimming through. The skimming was methodologically done by identifying for each document the main goals, the methodology used, the gap identified and the key results.

Despite a wide search for these 80 papers using Coventry University's (first authors' affiliation) extensive subscription to journal articles, and a call for the University library to help, full text of four papers were unavailable but only three of them (Sawyer, 2014a; Yi, Zhang and Calvo, 2015; Hamada *et al.*, 2017) were not included in this review. The abstract of the fourth paper (Behaneck, 2014) was reviewed and included because it was the only paper that focused on the 7^{th} dimension. This type of deviation from the protocol for a valid reason is acceptable in the systematic review (Schlosser, 2007).

Of the available papers, 22 were excluded due to their irrelevance to the research question. For example, Bansal, (2011b) focused on the use of GIS and topology for space conflicts resolution was eliminated and Li *et al.*(2014) focusing on the benefits of building information modelling in the project lifecycle was removed. In the end, 55 papers, including Behaneck,(2014), which didn't have a full-text, were considered in line with the research questions and were reviewed and classified according to a matrix developed for the study, in stage 5. The concept matrix showing what the papers relate to is provided in Figure 1. The matrix was used for setting up questions of the survey designed for collecting primary data. The 55 papers identified detailing the different BIM dimensions will be discussed in section 3.

As essentially done with systematic reviews, a meta-analysis was carried out, and a summary of findings table and charts were used to amalgamate and summarize the data. Khan *et al.*, (2003); Higgins, (2008); Smith *et al.*, (2011) with facts explained directly from the primary studies (i.e. the 55 reviewed studies) and backed up or rebuffed with a wider review of the literature. The table of the summary is provided below (Table 1).



"n"= number of documents
Subject areas Excluded (E_{SA}), Document type excluded (E_{DT}), Duplicates excluded (E_D), Titles excluded (E_T), Abstracts excluded (E_A), Full-texts excluded (E_{FT})
***(*)** The concept Matrix is referring to the key subject the paper focus on*

Figure 1: Flowchart of the systematic review process (PRISMA flow diagram)

Table 1: Summary of findings of the Systematic Review

SN	Author	4D	Paper's focus	5D	Paper's focus	6D	Paper's focus	7D	Journal	Country (ISO 3166)	Methods	Respondent types
1	***Hu et al. (2008)***	T	Safety Analysis for Scaffold						TST	CN		
2	***Duffey et al. (2010)***	T	4D BIM benefits						ME	US		
3	***Popov et al. (2010)***	T		C	5D VPD				AC	LT	CS	
4	***Zhou et al. (2010)***	T				Safety			AC	CN	LR, CS	
5	***Bansal and Pal (2011)***	T	Schedule linked with GIS						IJCM	IN		
6	***Hu and Zhang (2011)***	T	Structural safety						AC	CN	LR, CS	
7	***Kiviniemi et al. (2011)***	T	Management & Communication						VTT	FI	SQ, CS	36/50 people (72% RR)
8	***Zhang and Hu (2011)***	T	Structural safety						AC	CN	LR	
9	***Chavada et al. (2012)***	T	Activity Execution Workspace Management	C					EJITC	GB	LR, CS	
10	***Joannides et al. (2012)***	T		C		FM			IJCER	US	LR, SQ	
11	***Redmond et al. (2012)***	T	Cloud and data exchange	C	C&DE	Sust			AC	GB/IE	SSI	11 experts
12	***Kim et al. (2013)***	T	Automated BIM data extraction		`				AC	US	LR, PS, CS	
13	***Aibinu and Venkatesh (2014)***	T	QS BIM experience	C	QS BIM skills				JPIEEP	AU	LR, OS, I	40/167 QSs (23.9% RR)
14	***Behaneck (2014)***	*						*	CPPT	DE		
15	***Chen and Luo (2014)***	T	Construction quality management						AC	CN	LR, SI, CS	
16	***Choi et al. (2014)***	T	Work-space planing						JCEM	US	CR/CS	
17	***Ding et al. (2014)***	T	Safety management	C					AC	US/CN	LR	
18	***Gelisen and Griffis (2014)***	T	Automated updates schedule						JCEM	US	LR, CS	
19	***Moon et al. (2014a)***	T	Automatic check of Workspace conflicts						AEI	KR/GB	LR, CS, SQ	40 engineers
20	***Moon et al. (2014b)***	T	Automatic check/workspace conflicts						AC	KR	LR, CS	
21	***Stanley and Thurnell (2014)***	T		C	B/B				AJCEB	NZ	LR, SI	8 QSs.
22	***Wang et al. (2014)***	T	Support for site-level operations			Sust			AC	CN/AU	LR, CS	
23	***Yun et al. (2014)***	T	Performance analysis						KSCE	KR	LR, CS	
24	***Yung and Wang (2014)***	T		C		Sust	Auto A		IJARS	AU	LR, M	
25	***Braun et al. (2015)***	T	Automated construction progress						JITC	DE	LS, CS	
26	***Fan et al. (2015)***	T	Automated link Time/cost	C					JASE	US/TW	CS	
27	**Han et al. (2015)**	T	Appearance based material Classification						AC	US	LR, CS	
28	***Harrison and Thurnell (2015)***	T		C	5D Imp	FM		Sust	IJCSCM	NZ	LR, SQ, SSI	5 professional QS
29	**Moon et al. (2015)**	T	Schedule overlap issues						JCCE	KR	LR, CS	
30	***Umar et al. (2015)***	T	4D BIM benefits						RJASET	MY		
31	***Zhang et al. (2015)***	T	Fall hazards						SS	US/FI/DE	LR, CS	
32	***Zhou et al. (2015)***	T	4D for Liquefied Natural Gas project						AC	CN/KR/AU	LR, CS	
33	***Biagini et al. (2016)***	T	4D for historical building						AC	IT	LS, CS	
34	***Ciribini et al. (2016)***	T	Model & Code Checking						AC	IT	LR, CS	
35	***Gledson and Greenwood (2016)***	T	4D BIM implementation						JITC	GB	LR/SQ	136 practitioners
36	***Kang et al. (2016)***	T	4D linked with on-site video	C	5D - video	Resource			AC	KR	LR, CS	
37	***Mallie (2016)***	T	4D BIM benefits	C	B/B				AD	US		
38	***Marzouk and Abubakr (2016)***	T	Tower crane selection						AC	EG	CS	

39	***Lu et al. (2016)***			C	CFA			IJPM	HK	LR,CFA	
40	***Alashwal and Chew (2017)***	T	Cost					BEPAM	MY	LR, Os, I	83 companies
41	***Candelario Garrido et al. (2017a)***	T	4D BIM benefits					ET	ES	OS/CS	65 AEC companies
42	***Candelario Garrido et al. (2017b)***	T	4D comparison/conventional methods					SCS	ES	LR, SQ, CS	65 AEC companies
43	***Abanda et al. (2017)***	T		C	NRM			ESTIJ	GB/FR	M, FGD, CS	6 experts
44	***Choe and Leite (2017)***	T	Construction safety planning process					AC	US/KR	LR, CS	
45	***Gledson and Greenwood (2017)***	T	Consequence of 4D adoption in UK					ECAM	GB	OS	97 planning practitioners
46	***Hamledari et al. (2017)***	T	Automated Updates Schedule					JCCE	CA		
47	***Kehily and Underwood (2017)***	T		C	5D BIM-LCC			JITC	GB/IE	LR, TACE	
48	***Lee and Kim (2017)***	T	Module manufacturing productivity					S	KR	TR, FUI, FTFI, CS	10 project experts
49	***Natephra et al. (2017)***	T	Thermal Performance					BE	JP	LR, TS, CS	
50	***Park and Cai (2017)***	T	Automated As-Built Records	C	Auto ABR	PLI		AC	US		
51	***Park et al. (2017)***	T	Automated updates schedule					JCEM	US	LR, CS	
52	***Son et al. (2017)***	T	Automated Updates Schedule					JME	US	LR, CS	
53	***Kropp et al. (2018)***	T	Automated indoor progress monitoring					AC	DE	LR, CS	
54	***Malacarne et al. (2018)***	T	Construction scheduling process for SMEs					IJSDP	IT	LR, CS	
55	***Park et al. (2018)***	T	Automated registration of daily photo					JCCE	US	LR, CS	

***(*)** This paper is not available*

(FM) *Facility Management,* ***(Sust)*** *Sustainability,* ***(PLI)*** *Project lifecycle information,* ***(RR)*** *Response Rate,* ***(QS)*** *Quantity Surveyor,* ***(GIS)*** *Geographic Information System,* ***(Auto A)*** Automatic Assessment, **(VPD)** Virtual Project Development, **(T)** Time, (**C)** Cost, **(C&DE),** Cloud and data exchange, **(Imp)** Implementation, **(NRM)** New Rules of Measurement, (Auto ABR) Automated As-Built Records, **(CFA)** Cash Flow Analysis, **(B/B)** Benefits/Barriers

Method: ***(LR)****Literature Review,* ***(TR)*** *Technical Review,* ***(CR)*** *Critical Review,* ***(FGD)*** *Focus Group discussion,* ***(M)*** *Methondology,* ***(CFA)*** *cash flow analysis,* ***(CS)*** *Case study,* ***(M)*** *Model,* ***(PS)*** *Prototype System,* ***(OS)*** *Online Survey,* ***(SQ)*** *Survey Questionnaire,* ***(I)*** *Interview,* ***(SSI)*** *Semi-Structured Interview,* ***(SI)*** *Structured Interview,* ***(FUI)*** *follow-up interview,* ***(FTFI)*** *Face to Face Interview,* ***(TACE)****Thinking Aloud Cooperative Evaluation,* ***(SI)*** *Site Investigation,* ***(LS)*** *Laser Scannin,* ***(TS)*** *Thermographic Survey*

Journals: ***(ESTIJ)*** *Engineering Science and Technology, an International Journal,* ***(JPIEEP)*** *Journal of Professional Issues in Engineering Education and Practice,* ***(BEPAM)*** *Built Environment Project and Asset Management,* ***(IJCM)*** *International Journal of Construction Management,* ***(CPPT)*** *Concrete Plant and Precast Technology,* ***(AC)*** *Automation in Construction,* ***(JITC)*** *Journal of Information Technology in Construction,* ***(ET)*** *Engineering Transactions,* ***(SCS)*** *Sustainable Cities and Society,* ***(JCEM)*** *Journal of Construction Engineering and Management,* ***(ME)*** *Military Engineer,* ***(JASE)*** *Journal of Applied Science and Engineering,* ***(ECAM)*** *Engineering, Construction and Architectural Management,* ***(IJCSCM)*** *International Journal of Construction Supply Chain Management,* ***(IJCER)*** *International Journal of Construction Education and Researc,* ***(ENR)*** *Engineering News-Record,* ***(VTT)*** *Tiedotteita - Valtion Teknillinen Tutkimuskeskus,* ***(IJPM)*** *International Journal of Project Management,* ***(IJSDP)*** *International Journal of Sustainable Development and Plannin,* ***(AD)*** *Architectural Design,* ***(AEI)*** *Advanced Engineering Informatics,* ***(JCCE)*** *Journal of Computing in Civil Engineering,* ***(AJCEB)*** *Australasian Journal of Construction Economics and Building,* ***(RJASET)*** *Research Journal of Applied Sciences, Engineering and Technology,* ***(KSCE)*** *Journal of Civil Engineerin,* ***(IJARS)*** *International Journal of Advanced Robotic Systems,* ***(BE)*** *Building and Environment,* ***(JCCE)*** *Journal of Computing in Civil Engineerin,* ***(JME)*** *Journal of Management in Engineering,* ***(EJITC)*** *Electronic Journal of Information Technology in Construction,* ***(TST)*** *Tsinghua Science and Technology,* ***(SS)****Safety Science,* **(S)** Sustainability

2.2. Questionnaire Survey

Professional practitioners are obviously key actors in the implementation of BIM in the construction industry. This is why their opinion is going to be unravelled in this paper through a questionnaire. To avoid cost, the online questionnaire method was used due to the geographical spread (EU countries) of the study (Oppenheim, 2000). The use of the survey technique for research is relevant because of the low requirement for its organization, its financial cost and timeliness (De Leeuw, Edith Desirée and Don A. Dillman, 2008). The technique is also well known for its flexibility and provision of quality quantitative data (Walliman, 2017). The rest of this subsection covers the survey procedure, the questionnaire structure and the sample selection.

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

To ensure potential respondents from all the 28 EU countries were contacted, the purposive sampling method was used since it is a non-probability sample method that allows respondent selection based on population characteristics and the study's aim (Miles and Huberman, 1984; Merriam, 1998; Palinkas *et al.*, 2015). To avoid bias, authors have decided to have a representative sample composed of 6 BIM professionals per country to send them a request via LinkedIn. Then the aim was to get at least one response per country and 50 respondents in total. The selected sample was purposely targeting position with a high level of responsibilities in the companies, and knowledge in BIM because these people are believed to be well informed in relation to the questions being asked in the questionnaire.

The LinkedIn database was used to search for relevant profiles since it provides readily available contacts of a large pool of professionals, including those that work in construction with expertise in BIM. LinkedIn is not uncommonly used as a database for respondent search (Dusek, Yurova and Ruppel, 2015). The population picked out are, among others architects, engineers, contractors, facility managers, BIM Managers and training providers. A combination of the author's private contacts in the AEC industry and three groups on LinkedIn were used: The international "BIM expert group" (approximately 60,000 members), the International BIM Consultants (approximately 3600 members) and Women in BIM (approximately 500 members) (Rodgers *et al.*, 2015) (Figure 2).

As schemed in Figure 2, for each LinkedIn Group, we clicked on the account of the first 200 members and checked their country of origin. Each relevant profile was subsequently selected based on their BIM expertise according to their profile, and their country of origin. LinkedIn provides this information as part of the profile information of each account that is clicked. We also used the Google search engine by typing "*BIM expert AND the name of the country*". Then the profiles were checked on LinkedIn to make sure that the professionals were working in BIM area and that they had a key role in the company. Once we had six relevant profiles for a particular country, we stopped picking for that country and so on.

About 3000 professional's profiles had been reviewed to assess their profile compliance required by the questionnaire sample, and among them, 168 were selected. The identified relevant profiles were contacted through email to seek their participation consent. Among them, 110 potential respondents gave a positive response. An email with the questionnaire's link was sent to them. After ten days, follow-up emails were sent to the those that had not filled the questionnaire yet in order to increase the response rate (Kittleson, 1997). Table 2 below reports the details of the 168 BIM professionals found with a relevant profile: their current position, their country of origin, and whether they completed the questionnaire or not.

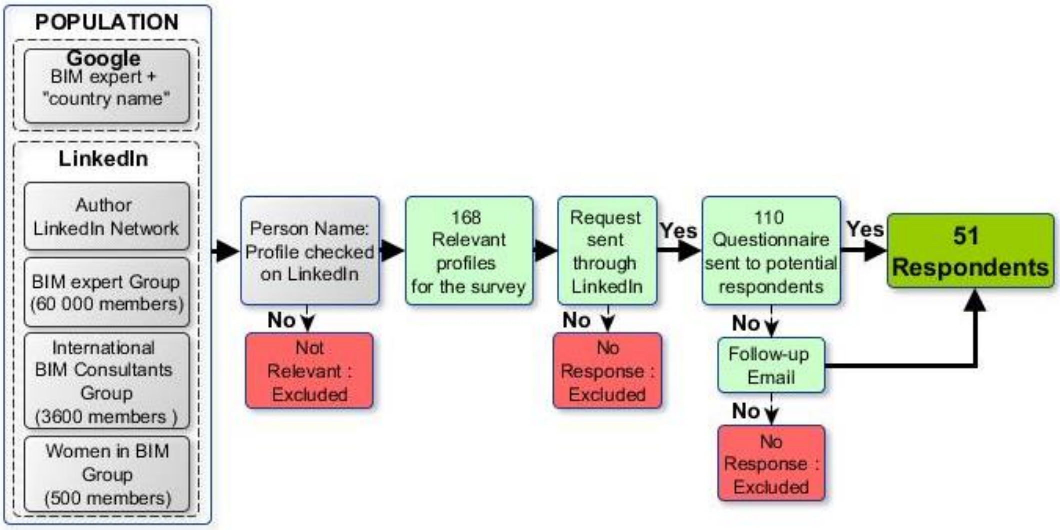


Figure 2: The sampling process for the online survey

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

Table 2: List of all the professionals contacted for the survey

Invitation sent per Country

Countries	Position in the Institution	Survey sent	Survey filled
Lithuania	BIM Manager implementation	✓	X
	CEO/BIM Strategist	✓	
	BIM software Engineer	✓	X
	Director/BIM Specialist		
	CEO/BIM manager/Head of BIM regional development	✓	
	Architect/BIM Consultant	✓	X
Germany	Director/BIM Specialist/Interoperability	✓	
	Smart Building Solution/BIM Developer	✓	X
	Project BIM Coordinator	✓	
	OPEN BIM Consultant	✓	X
	Head of BIM-Lean-Team		
	Managing Director		
Belgium	Architecte et Urbaniste, Enseignant BIM	✓	
	BIM Specialist at Sweco Belgium	✓	
	CAD et BIM Manager - Consultant BIM		
	Consultant/Formateur AEC-BIM et Support Logiciel Revit	✓	
	Chairman of the Technical Committee on BIM & ICT	✓	X
	Secretary General, European Builders Confederation	✓	
Italy	Senior Cad Technician / Bim Manager	✓	
	Senior Technical Sales Specialist	✓	
	BIM Coordinator/MEP Specialist/Director 2Dto6D	✓	X
	Co-Founder & Partner at BIMon		
	Architect/BIM Coordinator		
	Architect/BIM Manager/BIM Consultant		
Spain	Director/BIM Adoption	✓	X
	CEO/Architect Certified International BIM Manager		
	BIM Manager	✓	
	BIM Specialist	✓	
	CEO /Cofounder of CL3VER	✓	
	Projects Director		
France	CEO/BIM Specialist	✓	X
	CEO BIM & Innovation		
	CEO/BIM Specialist/Construction	✓	X
	BIM Facilitator	✓	X
	Responsable Opérations de Formation		
	Senior project manager BIM/VDC/CIM	✓	
Finland	BIM Development Manager	✓	X
	BIM Specialist	✓	
	CEO/BIM Specialist		
	Architect & BIM Coordinator	✓	X
	City Planning Architect	✓	
	Manager for Reality Capture	✓	X
Croatia	BIM Consultant		
	CEO/BIM Management		
	Director/Architect/BIM Services	✓	X
	CEO/BIM Services	✓	
	Architect/BIM consultant	✓	
	BIM manager	✓	X
Poland	Chairman/BIM Services	✓	
	Architect and BIM modeler	✓	
	Architect/ BIM Trainer & Professional Designer		
	Head of BIM / Research & Innovation Centre in Skanska	✓	X
	Head of Digitalization and Smart Equipment Technology	✓	
	Chairman of the Digitisation, Innovation and New	✓	
Hungary	Seniro BIM Consultant		
	BIM Manager		
	Architect, BIM specialist	✓	X
	Scan to BIM and Architecture	✓	
	ArchiCAD Implementation Team Leader at GRAPHISOFT		
	Senior CAD-GIS-BIM engineer		
Latvia	CEO/BIM Consultant	✓	X
	Owner/BIM manager	✓	X
	Founder/Project Leader	✓	
	Head of Construction Unit		
	Finance Manager/BIM Manager	✓	X
	Head of BIM Department	✓	
The UK	BIM Implementation Specialist	✓	
	Learning Services Manager (BIM Specialised) at Cadline	✓	X
	Digital Node	✓	
	Global BIM/IM Consultancy Director		
	Head of BIM Strategy		
	Leads the Ellen MacArthur Foundation		
Greece	Director at EB-Architects		
	BIM Manager - Senior Architect		
	Change Management Manager		
	Senior Engineer/BIM Coordinator	✓	
	Co Owner - Architect - BIM & Visualization Consultant	✓	X
	Architect/BIM Specialist	✓	
Portugal	Site Engineer	✓	
	BIM Consultant / Coordinator- Architect	✓	
	Architect - BIM Consultant	✓	
	BIM Trainer	✓	X
	BIM Manager/Architectural 3D Expert		
	Director at ndBIM Virtual Building	✓	

Invitation sent per Country

Countries	Position in the Institution	Survey sent	Survey filled
Romania	Architect	✓	
	Director/ Head of Architecture	✓	X
	Architect/BIM coordinator	✓	X
	Business Analyst		
	Experienced BIM/Senior Architect	✓	X
	Design Manager/BIM/BREEAM and LEED specialist		
Denmark	Architect/green-BIM specialist	✓	
	Senior BIM Consultant	✓	X
	CEO/BIM Specialist	✓	
	AEC BIM Consultant	✓	
	Risk and Safety Management		
	BIM Manager		
Malta	BIM Manager & Designer	✓	
	Architect & Civil Engineer at ADE Associates		
	Architect	✓	X
	Project Manager , Structural Engineer		
	Immediate Past President European Group of Surveyors		
	Advisor to Minister, MSDEC	✓	
Slovakia	Sales Manager	✓	X
	4D BIM construction Manager		
	CEO, Structural Eng.	✓	
	Architect, BIM specialist		
	President at BIM asociácia Slovensko	✓	X
	Co - Owner ve společnosti iQservices s.r.o	✓	X
Austria	IT consultant at AMOS Austria		
	BIM Project engineer	✓	X
	BIM Consultant		
	BIM Manager	✓	
	BIM Coordinator	✓	X
	CAD/BIM Support Manager	✓	X
Cyprus	Architect	✓	
	Director/Structural BIM Engineer	✓	X
	CEO partner/Architect		
	Managing director at Cyprus Architects		
	Architect /Vice President of Cyprus Youth Council	✓	X
	Architect Engineer/Designer	✓	X
Estonia	BIM specialist	✓	
	BIM-Coordinator		
	BIM software consultant		
	Senior Consultant & Instructor 3D, CAD, BIM / Designer	✓	X
	BIM Modeler	✓	
	CEO/BIM Specialist	✓	X
Sweden	BIM Specialist	✓	X
	Head of BIM Ramboll		
	CTO/ Architect / BIM expert		
	Implementation Manager/5D BIM	✓	
	Architect/ BIM Teacher	✓	
	Director Digital Design/BIM	✓	X
Ireland	BIM Leader	✓	
	Managing Partner/BIM Specialist	✓	X
	Business Data Manager & ISO		
	Architect/BIM Manager		
	BIM Coordinator	✓	
	BIM Specialist/Electrical Design Engineer	✓	
Slovenia	CEO/Co-founder/BIM Services	✓	
	BIM Manager		
	Head of Chair and BIM Technology Transfer	✓	
	CEO/Co-founder/BIM Modeler	✓	X
	BIM Director	✓	
	Chairman/Association for BIM implementation	✓	X
Bulgaria	BIM Implementation Consultant/BIM Manager	✓	X
	Senior Project Manager/BIM Consulting	✓	
	Principal Architect/BIM Manager		
	Expert European programs & projects/BIM Consulting	✓	
	BIM Expert		
	Head of International Relations and Mobility Center	✓	
Luxemourg	Consultant BIM chez BIM Consult	✓	
	BIM Specialist presso Tase Solutions	✓	X
	BIM Manager		
	BIM Manager		
	BIM manager	✓	
	BIM, Building & Facility Manager Trainee	✓	X
Netherland	Director Construsoft	✓	
	Architect / BIM-coordinator	✓	X
	BIM Specialist		
	Director		
	Senior BIM Specialist		
	Director	✓	
C-Republic	BIM Consultant	✓	X
	BIM Coordinator		
	Chairman of the board/BIM Council		
	BIM Coordinator		
	Director BIM Manager		
	Vice President BIM World MUNICH	✓	X
Total relevant profiles respondents contacted		168	
Total potential respondents		110	
Total questionnaire filled		51	

The questionnaire was structured in four sections (Table 3). (i) First, the respect for persons was tackled by including the informed consent section to address the ethical requirement for questionnaires and explaining the terms and conditions of the survey (De Leeuw, Edith Desirée and Don A. Dillman, 2008). Authors mentioned the objectives of the research project. It was specified why the participant was chosen and that they incur no risk by being involved in the survey. The respondents were also assured of the confidentiality of their identity. This section must be read and agreed to be able to pursue the survey (ii) Secondly, the next section developed a set of 4 questions on the respondent identification (Table 3). This part of the survey was structured to identify who are the respondents and their role in the company. (iii) Thirdly, the company description section contained 2 questions aiming to identify the type and size of the company where the respondents were working in. (iv) Lastly, a set of 3 questions regarding BIM dimensions was set up (Table 3). The aim of this part was to determine the awareness, understanding and utilisation of BIM dimensions by the practitioners, across Europe. The three closed questions were designed according to the matrix obtained by the systematic review (Figure 1). Sampling

Table 3: Questions asked in the online questionnaire

Questions of 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 size of your company?	0-5 Employees, 6-20 Employees, 21-50 Employees, 51-100 Employees, 100+ Employees	
4- BIM dimensions		

Are you aware of the various BIM Dimension?				
	Strongly Agree	Agree	Disagree	Strongly Disagree
BIM 4D	▢	▢	▢	▢
BIM 5D	▢	▢	▢	▢
BIM 6D	▢	▢	▢	▢
BIM 7D	▢	▢	▢	▢

Which BIM dimension do you use?					
	The most frequently	Frequently	Less frequently	Rare	Nether
BIM 4D	▢	▢	▢	▢	▢
BIM 5D	▢	▢	▢	▢	▢
BIM 6D	▢	▢	▢	▢	▢
BIM 7D	▢	▢	▢	▢	▢

what does BIM dimension refer to?					
	Scheduling	Estimating	Facility Management	Sustainability	Safety
BIM 4D	▢	▢	▢	▢	▢
BIM 5D	▢	▢	▢	▢	▢
BIM 6D	▢	▢	▢	▢	▢
BIM 7D	▢	▢	▢	▢	▢

3. Results and discussion

3.1. *Systematic Review*

3.1.1.Descriptive analysis

The obtained journal papers are classified by country in Figure 3. The greatest number of publications related to BIM dimensions is provided by the US (Figure 3a) which shows that the US is taking the lead at the world level, whereas, the UK is leading on the European scale, followed by Germany and Italy respectively (Figure 3b). The number of outputs from the US is close to the total of the 28 EU countries and approximately one-fourth of the total world number of publications within the period search.

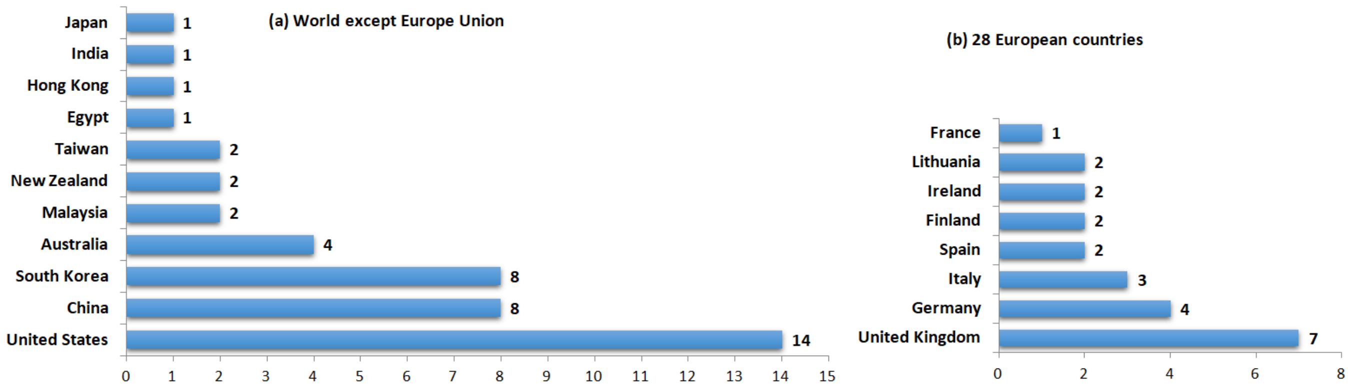
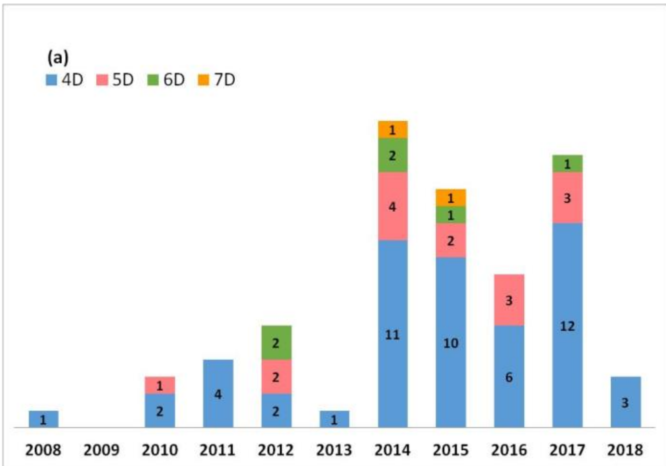


Figure 3: Number of publications according to Country, (a) World except European Union, (b) 28 European Union countries

Figure 4a gives the number of journal papers per year and the number of papers that focuses, each year, on various BIM dimensions from 2006 to 2017. The thought behind the reviewing of the 55 selected publications (stage 5 of the PRISMA flowchart in Figure 1) was to make sure that it would provide an insight into any discrepancy on what element academics assign to 4D and 5D; and what academics generally think about 6D and beyond in the BIM environment. The systematic review showed that BIM 4D first appeared in a journal article in (Hu, Zhang and Deng, 2008). Two years later, in 2010, BIM 5D first appeared in the Automation in Construction journal (Popov *et al.*, 2010). The first consideration of 6D was in

2012 by (Redmond *et al.*, 2012). The first journal paper found to be addressing 7D in this review was published in 2014. The paper was selected despite its full text was not available (Behaneck, 2014). The sixth and the seventh dimensions have still remained under-researched. This is evident in Figure 4b where it is showed that only 8% of the papers reviewed were covering 6D, while 7D covering paper represented only 2% of the total number of papers.

There are also authors using BIM for various elements without allocating a dimension yet. For instance, some authors have performed energy analysis in BIM environment without linking it to any dimension in particular (Lee *et al.*, 2005; Abanda and Byers, 2016). In order to enhance the accuracy of manual methods for embodied energy and CO_2 assessment, Abanda et al. (2014) explored the possibility to use BIM tools and later some authors also proposed a system for embodied energy/CO_2 automation (Abanda, Oti and Tah, 2017) without allocating a dimension. The expansion of BIM dimension beyond 3D has received high interest from researchers, trying to link various dimension to elements as can be seen in this study with over 55 papers detailed in Table 1.



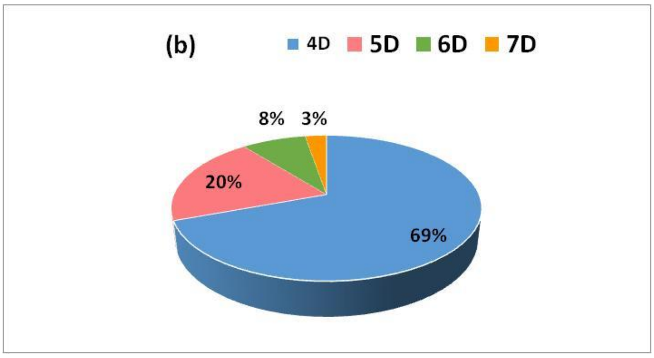


Figure 4: Publications related to BIM dimensions, through Scopus and keywords (a) by year, (b) in percentage of the total number of paper of (a)

3.1.2.Discussion

- <u>The 4D activities other the years</u>

The advanced BIM 4D is now widely used, and its increasing adoption is due to the general acceptance that 4D relates to planning at large. This is confirmed by Table 1 (planning is labelled by "Time"), where it is clear that BIM 4D relation to planning represents a consensus. This means that most professionals already understand when they are talking about 4D. However, most of the publications have developed specific activities embedded in 4D without linking them to a particular dimension. The first journal paper addressing 4D BIM in Table 1 was published by Hu et al. (2008) who used 4D for safety analysis for scaffold management. The word « safety » was therefore early associated with 4D planning. Moreover, various authors have discussed the use of BIM 4D for Safety management. Safety plans can be reviewed virtually before the real on-site application and issues can be anticipated by using simulation (Bansal and Pal, 2011; Eastman *et al.*, 2011; Ding, Zhou and Akinci, 2014; Choe and Leite, 2017). In fact, between 2010 and 2011, some authors linked the BIM 4D with safety planning (Hu, Zhang and Zhang, 2010; Hu and Zhang, 2011). Bansal (2011a) linked the schedule with GIS and explored the use of 4D GIS in construction safety planning.This is backed by the systematic review of Martínez-Aires et al. (2018) addressing the BIM for safety management in the construction sector. They have highlighted the advantages of using BIM for potential hazard identification via 4th BIM dimension.

Then Duffey et al.(2010) was the first author of Table 1 to address the benefits obtained by the use of 4D BIM then followed by (Mallie 2016; Umar et al. 2015). BIM 4D has since given a lot of benefits to the construction industry including avoidance of the direct and indirect cost due to inefficient schedules and updates issues (Duffey *et al.*, 2010), facilitation of the management of changes occurring during the construction phase (Choi *et al.*, 2014), tackle of errors associated with the construction phase and to have a better control and measurement of project progress (Gelisen & Griffis 2014; Candelario-Garrido et al. 2017; Yun et al. 2014).

The next development of 4D was proposed by Kiviniemi et al. (2011) (Table 1) about the management and communication improvement, and on-site practice enhancement, also addressed later by (Yi, Zhang and Calvo, 2015; Ganah and John, 2017). Two authors have also explored the real-time management of Activities Execution Workspace (AEW) in the 4D environment, (Chavada, Dawood and Kassem, 2012; Choi *et al.*, 2014) and environmental management and planning (Hu, Zhang and Zhang, 2010; Zhang and Hu, 2011; Ding, Zhou and Akinci, 2014; Zhang *et al.*, 2015; Marzouk and Abubakr, 2016).

Then, the academics have had an increasing interest in the use of BIM for 4D with the highest number of journal paper publications in 2014, as depicted in Figure 5. The expanding of the 3D BIM to a 4D BIM referred later to quality control (Elbeltagi and Dawood, 2011; Chen and Luo, 2014; Ding, Zhou and Akinci, 2014; Hu C. *et al.*, 2014; Ciribini, Mastrolembo Ventura and Paneroni, 2016). In the same way, Fan (2013) discussed and explored the 4D BIM utilisation for a quality application based on construction codes (Fan, 2013). According to other authors, the 4D can also refer to the combination of 3D BIM and Carbon emission (Ding, Zhou and Akinci, 2014) and module manufacturing productivity (Lee and Kim, 2017).

The automation of tasks was also a great centre of interest for the researchers, such as automated BIM data extraction (Kim *et al.*, 2013) and automated updates schedules monitoring (Kim, Kim and Son, 2013; Gelisen and Griffis, 2014; Park *et al.*, 2017; Son, Kim and Kwon Cho, 2017). Golparvar-Fard *et al.(*2011) suggested generating a 4D BIM As-Built automatically, by using point clouds and photos.

During the last decade, authors started using BIM 4D (time planning) to solve different problems. This is because it was realised that one of the key problems that construction has is the case of planning as it was stated by Azhar, (2011a). This author has reported the result of a survey conducted in 2007 amongst professionals. The aim was to check what the key areas where BIM was successfully contributing. The survey showed that the project planning was the key area that BIM was successfully used and where the company really wanted to be used. No wonder the planning quickly became the 4th D in term of general consensus.

As 4D was developed in different directions (listed in the 4th column of Table 1), other authors started to link the 3D with cost, named 5D. Some authors explored the possibility to link BIM elements with cost and schedule data automatically. This is feasible due to the close interconnection that existed between costs and schedules. In fact, they share common data such as budgeted cost, resources, and quantities (Fan, Wu and Hun, 2015). The 5th BIM dimension appeared with Popov et al. (2010) and had increased significantly since 2012 (Figure 5).

- <u>The 5D activities other the years</u>

As for 4D, the Table 1 shows a clear consensus about 5D to be related to cost in the first instance. And similarly, authors have linked different specific tasks to 5D cost. The first authors in Table 1, are Popov et al. (2010) who have analysed the applications of BIM for simulation of construction processes based on Virtual Project Development concept (VPD).
The second paper deals with the 5D as the link between cost and the Project Information Model (PIM) developed by designers (Joannides, Olbina and Issa, 2012) and enables lifecycle costs, scenario analysis, quantities extraction and real-time modelling & cost planning.
Various authors highlighted 5D BIM benefits and barriers (Stanley and Thurnell, 2014; Mallie, 2016) and its implementation. Harrison and Thurnell, (2015) concluded that the use of 5D BIM greatly facilitates the management and identification of design changes. Moreover, it enables Quantity Surveyors to streamline their workflows and increase the provision of quality service. The main benefits are the productions of quantities in real time for cost estimating, and the ability to visualise the project and its variants. In fact, the data embodied in the Project Information Model can be extracted easily at an early stage, for estimation. Aibinu and Venkatesh, (2014) tried to understand the BIM experience of the Australian Quantity Surveyors (QS) and concluded that the QS does not hugely use BIM features due to the uncertainties and incompleteness of the data embedded in the 3D BIM model delivered by designers. In the same way, the UK National BIM Survey in 2013 revealed that only 14% of BIM users thought that BIM makes traditional bills of quantities (BOQs) redundant (Stanley and Thurnell, 2014). The parametric modelling creates a relationship between elements and their properties. This accurate and comprehensive data can then be extracted from the model for costing (Stanley and Thurnell, 2014). The 5D BIM is related to estimation in BIM environment by using new technologies for more competitive cost management. In fact, Cost management can take benefits on 5D BIM use by enabling simulation and scenarios exploration (Russell *et al.*, 2009; Smith, 2014a). Later a methodology based on BIM 4D was proposed for cash flow analysis by (Lu, Won and Cheng, 2016) as a support for decision-making.

As discussed beforehand, the 4th and 5th BIM dimensions are well established, and BIM has really been able to help in term of cost and planning. In fact, multiple authors agreed on the consensus of what the 4D and 5D refer to; there exists no agreement between the 6D and onwards (Yung and Wang, 2014; Abanda, Kamsu-Foguem and Tah, 2017; Park and Cai, 2017).

- <u>The sixth and seventh dimension elements</u>

In Table 1, the 6D is first allocated to safety by Zhou et al.(2010) in a case study of a metro construction. This shows that these authors wish to develop the safety as a dimension on its own instead of being embedded in 4D. Other authors have allocated BIM 6D to "the construction records such as quality information, health and safety information, and contract information" (Ding *et al.*, 2012; Wu and Hsieh, 2012; Park and Cai, 2017).

Then, (Redmond *et al.*, 2012) defined 6D as the representation of the As-Built model, the extension of the BIM model for Facilities Management by using information embodied in the rich Project Information Model (PIM) and incorporating specific data required for the Operation & Maintenance (O&M) stage (Joannides, Olbina and Issa, 2012; Moya and Pons, 2014; Smith, 2014a; Chew and Riley, 2013; Harrison and Thurnell, 2015). The 6D BIM can embed O&M manuals, plan and technical support. This is an "As-Built" model that needs to be updated during the asset lifecycle. Fuchs and Scherer, (2017) proposed that in BIM environment; all project lifecycle information is integrated into the 6D BIM. The National Building Specification (NBS) also defines the 6D as a dimension including information to support the facility management and operation activities (McPartland, 2017).

The third different allocation to 6D was made by Yung and Wang, (2014) and W. C. Wang *et al.(* 2014) who attributed the sixth dimension to sustainability information. They developed a model that can automatically evaluate the sustainability performance of a project enabling thus designers to select the best design option.

To summarise, the sixth dimension is still in its infancy. Only eight journal papers were considered as relevant (Table 1). Because we are far from the agreement in what 6th dimension relates to, BIM has not been able to achieve anything tangible in terms of safety, sustainability and all other activities that have been tried attached to BIM. Therefore, professional bodies should take the lead in order to give a consistent approach to professionals by designing appropriate standards. The seven D is going to follow a similar pattern. In fact, the Seventh Dimension (7D) appearing in 2014 is also still in its early stage (Figure 4a). Two journal papers are citing the 7D. For Behaneck, (2014) none information was specified in the title and the abstract to enable to allocate a specific element to 7D. As explained previously, the full text of this paper was not accessible. In the second paper Harrison and Thurnell, (2015), allocated the 6D to Facility Management and the 7D to sustainability, without giving more information.

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

3.2. ***Online survey***

3.2.1.Descriptive analysis of the survey

We had 51 respondents to our survey which makes a response rate of 46%. We obtained a maximum of 3 responses per country and a minimum of one response per country. Figure 5a shows the proportion of the respondent position. The proportion of the number of responses per country is given in Figure 5b. A majority of respondents were either BIM manager (39%), company directors or CEO (31%) or architects (16%). The Company Size is mainly 0-5 and

6-20 Employees. The third highest rate is for the more 100 Employees company which represents 20% of the respondents. A minor proportion of respondents is from a Company Size between 21-50 and 51-100 Employees.

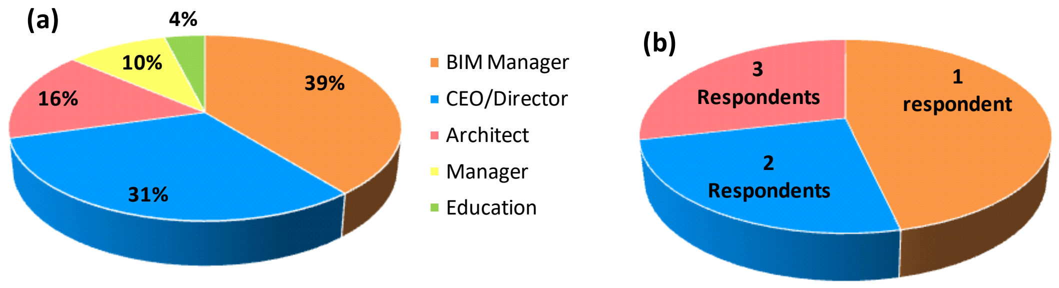


Figure 5: (a) Profiles of the 51 respondents, (b) Proportion of the number of response per country

The survey showed that the majority of the respondent Companies are from the architecture sector with 63%, followed by Project management (55%) and training sectors (53%), (Figure 6). Most of the companies are specialised in more than one sector so that the total is more than 100%.

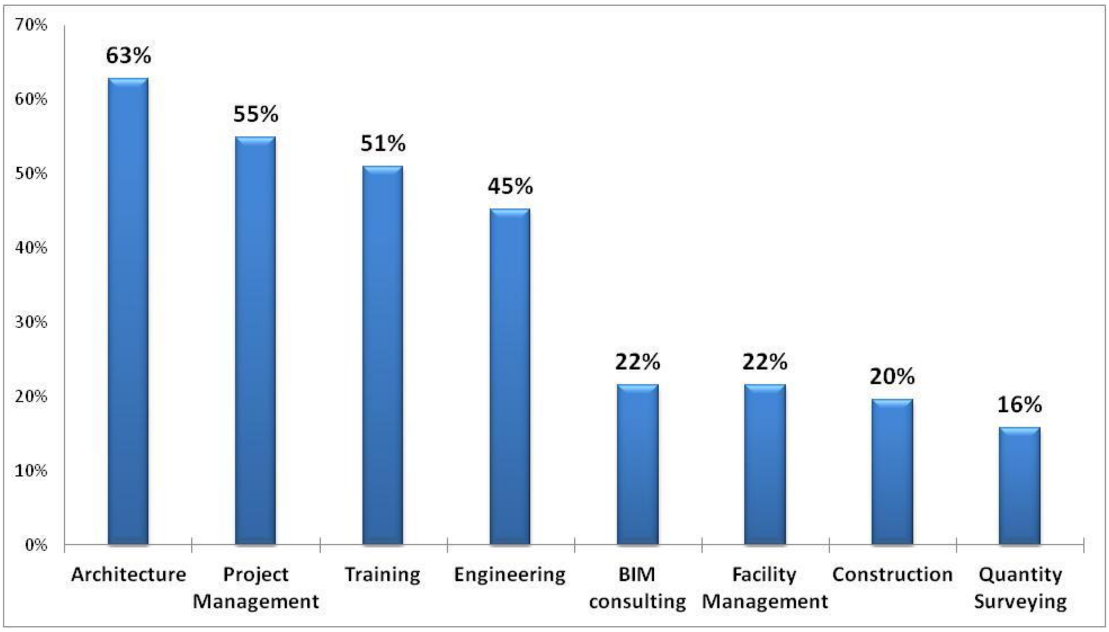


Figure 6: Responses by company Sector

Regarding the BIM Dimensions awareness and use, three questions were asked. The first question was "*Are you aware of the various BIM Dimension?*" 98% of the respondents knew about BIM 3D modelling (Figure 7a). Similarly, BIM 4D and 5D are familiar to 96% of the respondents. On the other hand, the awareness of BIM Dimension for 6D and 7D respectively decreases but is still well-known by three-quarter of the respondents (78% and 72% respectively).

The second question asked was “*What does BIM Dimension refer to?”* Figure 7b highlighted that the 4D and 5D are well known because 86% of the respondents assigned the 4D to schedule tasks and 84% to Cost Estimating activities. The fact that we have a few professional that don’t link 4D to planning again highlights the fact there is not a general consensus on planning.

On the other hand, the two other dimensions awareness (6D and 7D) are less significant with a demarcation of 68% for the 6D and 56% for the 7D. The last question was “*Which BIM dimension do you use?*” (Figure 7c). The 3D is the dimension the most utilized by the respondents (88%). The 4D is frequently used or most frequently by 58% of the practitioners. The 5D is commonly used or most frequently by 34% of the respondents. The proportion of respondents using BIM Dimension decreases significantly for the 6D and 7D, becoming 6%.

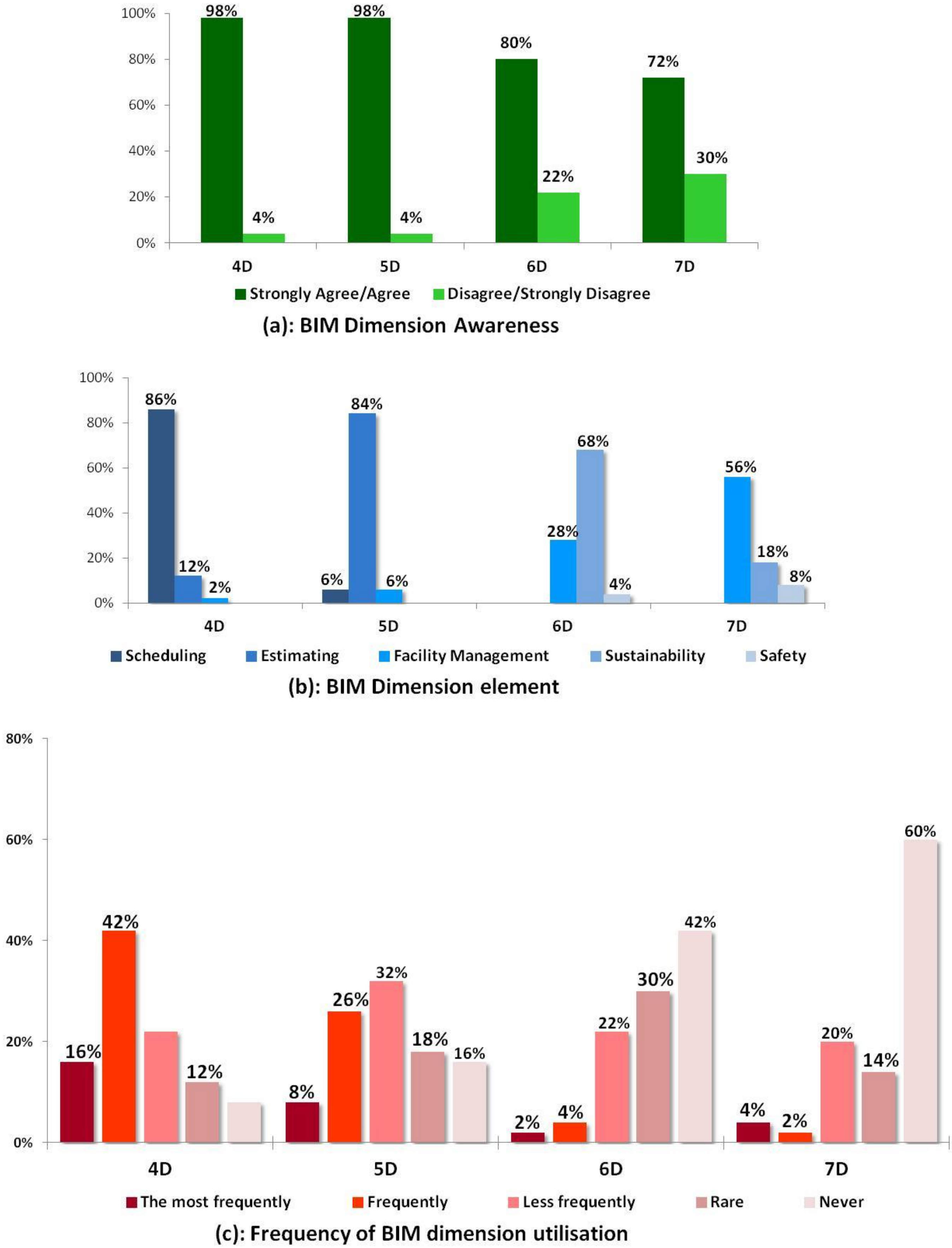


Figure 7: BIM dimensions awareness (a), dimension element (b) and utilisation (c)

3.2.2. Discussion on the survey results

As all the BIM Dimension are not used by all the repondents, it is interesting to separate the respondents that are actually using the BIM dimensions (4D, 5D, 6D or 7D) from the ones who do not use them. A priori, the users should give a more reliable information on the actual assigment of the BIM dimension. The Table 4 gives the related data of “Users” (the ones who responded using the n BIM Dimension most frequently, frequently and less frequently) and the “Non Users” (who responded rarely or never using the n BIM Dimension). The 4D was assigned to time by 83% of the respondents “users”. The 5D was assigned to cost by 88% of the respondents “users”.This is confirming an agreement but not a consensus. The responses given by the users, which are not in agreement with majority of the respondents will be discussed now.

Table 4: Data for users and no users of BIM dimensions, the cells highlighted in blue are developed in Table 5.

	BIM awareness, understanding and utilisation									
	Awareness				USERS			NON USERS		
	Agree/ Strongly Agree		Disagree/ Strongly Disagree							
BIM DIMENSION	Number	%	Number	%	Element referring to	Number of Respondents	%	Element referring to	Number of Respondents	%
4D	49	96%	2	4%	Time	34	83%	Time	10	100%
					Facility Management	1	2%	Facility Management	?	?
					Cost	6	15%	Cost	?	?
					Total Respondent	41	80%	Total Respondent	10	20%
5D	49	96%	2	4%	Time	2	6%	Time	1	6%
					Facility Management	2	6%	Facility Management	1	6%
					Cost	29	88%	Cost	14	78%
					Total Respondent	33	65%	Total Respondent	18	35%
6D	40	78%	11	22%	Sustainability	12	86%	Facility Management	13	35%
					Facility Management	2	14%	Safety	2	5%
						?	?	Sustainability	22	59%
					Total Respondent	14	27%	Total Respondent	37	73%
7D	36	71%	15	29%	Sustainability	1	8%	Facility Management	17	45%
					Facility Management	11	85%	Safety	4	11%
					no response	1	8%	Sustainability	8	21%
						?	?	no response	9	24%
					Total Respondent	13	25%	Total Respondent	38	75%

The Table 5 gives the details of responses assigning 4D or 5D or 6D or 7D to other element than the majority. We have highlighted in red the responses showing the discrepancy and in green the responses compliant with the majority. The other cells are not consistent due the fact that the respondent was not a user or was not aware. The Table 5 shows that logically the 3 respondents (R16, R29 and R40) that assigned cost to 4D, assigned Time to 5D. The two respondents R30 and R26 are compliant with the majority for the 4D and 5D but then disagree for the 6D and 7D. The other responses are difficult to discuss, however there is no obvious correlation with a given country of the respondent because the 9 respondents come from 9 different countries.

Table 5: Details of the responses not in agreement with the majority

Respondent		use the dimension for other element than the majority	4D			5D			6D			7D		
Country	S/N		Aware	Refer to	Use	Aware	Refer to	Use	Aware	Refer to	Use	Aware	Refer to	Use
Czech Republic	R1	4D	Aware	FM	User	Aware	Cost	User	Aware	Safety	Non User	Aware	Sustainability	Non User
Latvia	R16	4D/5D	Aware	Cost	User	Aware	Time	User	Aware	Sustainability	User	Aware	FM	Non User
The Netherlands	R29	4D	Aware	Cost	User	Aware	Time	Non User	Non Aware	Sustainability	Non User	Non Aware	?	Non User
Lithuania	R40	4D/5D/7D	Aware	Cost	User	Aware	Time	User	Aware	Sustainability	User	Aware	?	User
Croatia	R24	4D/5D	Aware	Cost	User	Aware	FM	User	Aware	Sustainability	Non User	Aware	?	Non User
Finland	R35	4D/5D	Aware	Cost	User	Aware	FM	User	Non Aware	Sustainability	Non User	Non Aware	Safety	Non User
Luxembourg	R38	4D	Aware	Cost	User	Aware	?	Non User	Aware	Sustainability	Non User	Aware	FM	User
Sweden	R30	6D/7D	Aware	Time	User	Aware	Cost	User	Aware	FM	User	Non Aware	Sustainability	User
The UK	R26	6D	Aware	Time	User	Aware	Cost	User	Non Aware	FM	User	Non Aware	?	Non User

User = Less frequently, Frequently, the most frequent
Aware = Strongly Agree, Agree
Non User = Rare, Neither
Non Aware = Disagree, Strongly Disagree
(FM) = Facility Mangement

In Table 6, the 6D was assigned to sustainability by 86% of the respondents "users". The 7D was assigned to Facility Management by 85% of the respondents "users". This is also confirming an agreement but not a consensus.

The Table 6 presents the comparison with the systematic literature review. Therefore, the confusion depicted in the systematic review for 6D and 7D is not in agreement with the results of the questionnaire which shows that in Europe, the attribution of the 6D, respectively 7D is more clearly attributed to sustainability, respectively Facility Management.

Table 6: Comparison between Academics and Practitioners for the BIM dimensions

Dimensions	Systematic literature review	Practitioners	Practitioners using the selected Dimensions
4D	Consensus on Time	86% Time	83% Time
5D	Consensus on Cost	84% Cost	88% Cost
6D	2 papers assigning FM	28% FM	14% FM
	1 paper assigning Safety		
	1 paper assigning Resource		
	1 paper assigning Project Lifecycle Information	68% Sustainability	86% Sustainability
	3 papers assigning Sustainability		
7D	1 paper assigning Sustainability	18% Sustainability	18% Sustainability
		56% FM	85% FM

4. Conclusion and recommendations

The aim of this study was to assess the level of clarity or confusion on what the numbers of dimension refer to after the 5^{th} dimension. To achieve the aim, three objectives were set up. The two first objectives were to investigate what activities are most commonly referred to, like the 4th, 5th and above dimensions in BIM according to academics and practitioners. Then academics and practitioners' views were compared to highlight where consensuses are, and the confusion exists. A systematic review was conducted to collect the academics state of the art, and an online survey enabled to figure out the practitioners' point of views.

The results showed a clear agreement on what the 4th and 5th dimensions refer to. Academics and practitioners agreed that in BIM environment, the 4D is related to time (or planning or scheduling) and the 5D to cost. The systematic review and the online survey conducted across the 28 European countries raised up discrepancies for the 6D and 7D, related to Sustainability, Facility Management or Safety. Indeed, the practitioners actually using these dimensions usually refer to Sustainability for the 6D (86%) and Facility Management activities for the 7D (by 85%).

This lack of clarity on BIM dimensions beyond the 5th dimension leads to the risk to lose the benefits brought by these extra BIM dimensions. In fact, the industry has seen excellent gains regarding the 4th and 5th dimensions mainly because there is a broad agreement on what these "n" dimensions refer to. So as to gain clarity for the 6th and 7th BIM dimension, professional bodies should take the lead to give a consistent approach to professionals by designing appropriate standards. Without that, BIM wouldn't be able to achieve anything tangible in terms of safety, sustainability and all other activities that have been tried attached to BIM. Moreover, the potential of BIM could be expanded, as a dimension, to new activities not yet found in the literature. For example, the willingness to take advantages of the data embodied in the 3D model also exists in the area of construction and demolition waste issues. The End of Life (EOL) BIM would refer to an additional dimension of data that can be used to support decision-making for component selection during the design process, but also to facilitate the deconstruction process, once the asset cannot be used anymore. The EOL Dimension would contain data related to demolition or deconstruction activities and could be an area for future research.

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References

Abanda, F. H. and Byers, L. (2016) 'An investigation of the impact of building orientation on energy consumption in a domestic building using emerging BIM (Building Information Modelling)', *Energy*, 97, pp. 517–527.

Abanda, F. H., Kamsu-Foguem, B. and Tah, J. H. M. (2017) 'BIM - New rules of measurement ontology for construction cost estimation', *Engineering Science and Technology, an International Journal*, 20, pp. 443–459.

Abanda, F. H., Oti, A. H. and Tah, J. H. M. (2017) 'Integrating BIM and new rules of measurement for embodied energy and CO2assessment', *Journal of Building Engineering*. Elsevier Ltd, 12(June), pp. 288–305. doi: 10.1016/j.jobe.2017.06.017.

Abanda, F. H., Tah, J. H. M. and Manjia, M. B. (2014) 'Embodied Energy and CO2 Analyses of Mud-brick and Cement-block Houses', *AIMS Energy*, 2(1), pp. 18–40. doi: 10.3934/energy.2014.1.18.

Abdirad, H. (2016) 'Metric-based BIM implementation assessment: a review of research and practice', *Architectural Engineering and Design Management*, 2007(June), pp. 1–27. doi: 10.1080/17452007.2016.1183474.

Adriaanse Leslie, S. and Rensleigh, C. (2013) 'Web of Science, Scopus and Google Scholar: A content comprehensiveness comparison', *The Electronic Library*, 31(6), pp. 727–744. Available at: https://doi.org/10.1108/EL-12-2011-0174 (Accessed: 22 January 2018).

Aibinu, A. and Venkatesh, S. (2014) 'Status of BIM Adoption and the BIM Experience of Cost Consultants in Australia', *Journal of Professional Issues in Engineering Education Practice*, 140, pp. 1–10.

Aouad, G., Lee, A. and Wu, S. (2005) 'From 3D to nD Modelling', *Journal of Information Technology in Construction (ITcon)*, 10(2), pp. 15–16.

Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C. and O 'reilly, K. (2011) 'BIM adoption and implementation for architectural practices', *Emerald insight Group*, 29, pp. 7–25. doi: 10.1108/02630801111118377.

Atkinson, L., Amoako-Attah, J. and -Jahromi, A. B. (2014) 'Government's influence on the implementation of BIM', in *Computing in Civil and Building Engineering ASCE 2014*, pp. 520–527.

Azhar, S. (2011a) 'Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry', *Leadership and Management in Engineering*, 11(3), pp. 241–252. doi: 10.1061/(ASCE)LM.1943-5630.0000127.

Azhar, S. (2011b) 'Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry', *Leadership and Management in Engineering*, 11(Bazjanac 2006), pp. 241–252.

Bansal, V. K. (2011a) 'Application of geographic information systems in construction safety planning', *Project Management*, 29(1), pp. 66–77.

Bansal, V. K. (2011b) 'Use of GIS and Topology in the Identification and Resolution of Space Conflicts', *Journal of Computing in Civil Engineering*, 25(2), pp. 159–171.

Bansal, V. K. and Pal, M. (2011) 'Construction projects scheduling using GIS tools', *International Journal of Construction Management*, 11(1), pp. 1–18.

Behaneck, M. (2014) 'Little or big, closed or open, 3D or 7D?', *Betonwerk und Fertigteil-Technik/Concrete Plant and Precast Technology*, 80(6), pp. 46–55.

Burke Johnson, R. and Onwuegbuzie, A. J. (2004) 'Mixed Methods Research: A Research Paradigm Whose Time Has Come', *Educational Researcher*, 33(7), pp. 14–26.

Candelario-Garrido, A., García-Sanz-Calcedo, J. and Reyes Rodríguez, A. M. (2017) 'A quantitative analysis on the feasibility of 4D Planning Graphic Systems versus Conventional Systems in building projects', *Sustainable Cities and Society*, 35, pp. 378–384.

Candelario Garrido, A., Garcia-Sanz-Calcedo, J., Salgado, D. R. and Gonzalez, A. G. (2017) 'Planning, Monitoring and Control of Mechanics Projects by the BIM', *Engineering Transactions*, 65(1), pp. 25–30.

Chadegani, A. A., Salehi, H., Yunus, M. M., Farhadi, H., Fooladi, M., Farhadi, M. and Ebrahim, N. A. (2013) 'A Comparison between Two Main Academic Literature Collections: Web of Science and Scopus Databases', *Asian Social Science*, 9(5), pp. 18–26. doi: 10.5539/ass.v9n5p18.

Charehzehi, A., Chai, C., Md Yusof, A., Chong, H.-Y. and Loo, S. C. (2017) 'Building information modeling in construction conflict management', *International Journal of Engineering Business Management*, 9. doi: 10.1177/1847979017746257.

Chavada, R., Dawood, N. and Kassem, M. (2012) 'Construction workspace management : the development and application of a novel nD planning approach and tool', *Journal of Information Technology in Construction (ITcon)*, 17(17), pp. 213–236.

Chen, L. and Luo, H. (2014) 'A BIM-based construction quality management model and its applications', *Automation in Construction*, 46, pp. 64–73.

Cheng, M.-Y., Chiu, K.-C., Hsieh, Y.-M., Yang, I.-T., Chou, J.-S. and Wu, Y.-W. (2017) 'BIM integrated smart monitoring technique for building fire prevention and disaster relief', *Automation in Construction*, 84, pp. 14–30. doi: 10.1016/j.autcon.2017.08.027.

Chew, A. and Riley, M. (2013) 'What is going on with BIM? On the way to 6D', *The International Construction Law Review*.

Chileshe, N., Rameezdeen, R., Hosseini, R. M., Lehmann, S. and Udeaja, C. (2016) 'Analysis of reverse logistics implementation practices by South Australian construction organisations', *International Journal of Operations & Production Management*, 36(3), pp. 332–356. doi: 10.1108/IJOPM-01-2014-0024.

Choe, S. and Leite, F. (2017) 'Construction safety planning: Site-specific temporal and spatial information integration', *Automation in Construction*, 84, pp. 335–344. doi: 10.1016/j.autcon.2017.09.007.

Choi, B., Lee, H.-S., Park, M., Cho, Y. K. and Kim, H. (2014) 'Framework for Work-Space Planning Using Four-Dimensional BIM in Construction Projects', *Journal of Construction Engineering and Management (ASCE)*, 140(9), pp. 1–13.

Chong, H.-Y., Preece, C. and Rogers, J. (2014) 'BIM update 2013: A mixed review approach from Academia and Industry', *Trends and Development in Management Studies*, 3(1), pp. 1–21.

Ciribini, A. L. C., Mastrolembo Ventura, S. and Paneroni, M. (2016) 'Implementation of an interoperable process to optimise design and construction phases of a residential building: A BIM Pilot Project', *Automation in Construction*, 71, pp. 62–73.

Coelho, L. M. G. (2016) 'Multi-criteria decision making to support waste management : A critical review of current practices and methods', *Waste Management & Research*, pp. 1–26. doi: 10.1177/0734242X16664024.

Cook, C., Heath, F. and Thompson, R. L. (2000) 'A meta-analysis of response rates in web-or internet-based surveys', *Educational and psychological measurement*, 60(6), pp. 821–836. doi: 10.1177/00131640021970934.

Creswell, J. W. and Clark, V. L. P. (2007) 'Designing and conducting mixed methods research', in *Australian and New Zealand Journal of Public Health*. Blackwell Publishing Ltd, pp. 388–389. doi: 10.1111/j.1753-6405.2007.00097.x.

Davies, K. (2010) 'IT Barometer New Zealand – A survey of computer use and attitudes in the New Zealand Construction Industry', in *Proceedings of the CIB W78 2010: 27th International Conference*. Cairo, Egypt. Available at: http://itc.scix.net/data/works/att/w78-2010-48.pdf (Accessed: 11 July 2017).

Davtalab, O. (2017) 'Benefits of real-time data driven BIM for FM departments in operations control and maintenance', in *Congress on Computing in Civil Engineering*, pp. 202–210.

Delgado, F., Martínez, R., Puche, J. and Finat, J. (2015) 'Towards a client-oriented integration of construction processes and building GIS systems', *Computers in Industry*, 73, pp. 51–68.

Ding, L. Y., Zhou, Y., Luo, H. B. and Wu, X. G. (2012) 'Using nD technology to develop an integrated construction management system for city rail transit construction', *Automation in Construction*, 21, pp. 64–73.

Ding, L., Zhou, Y. and Akinci, B. (2014) 'Building Information Modeling (BIM) application framework: The process of expanding from 3D to computable nD', *Automation in Construction*. Elsevier B.V., 46(82–93), pp. 82–93. doi: 10.1016/j.autcon.2014.04.009.

Doyle, L., Brady, A. M. and Byrne, G. (2009) 'An overview of mixed methods research', *Journal of Research in Nursing*, 14(2), pp. 175–185. doi: 10.1177/1744987108093962.

Duffey, M., DiProfi, V., Semproch, D., DiPofi, V. and Semproch, D. (2010) 'The next dimension', *Military Engineer*, 102(668), pp. 75–76.

Dulaimi, M. F., Ling, F. Y. Y. and Bajracharya, A. (2003) 'Organizational motivation and inter-organizational interaction in construction innovation in Singapore', *Construction Management and Economics*, 21, pp. 307–318.

Dusek, G. A., Yurova, Y. V. and Ruppel, C. P. (2015) 'Using Social Media and Targeted Snowball Sampling to Survey a Hard-to-reach Population: A Case Study', *International Journal of Doctoral Studies*, 10, pp. 279--299. doi: 10.28945/2296.

Eadie, R., Browne, M., Odeyinka, H., McKeown, C. and McNiff, S. (2013) 'BIM implementation throughout the UK construction project lifecycle: An analysis', *Automation in Construction*. Elsevier B.V., 36, pp. 145–151.

Eastman, C., Teicholz, P., Sacks, R. and Liston, K. (2011) *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors, BIM Handbook*. John Wiley & Sons, Inc. doi: 1.

Elbeltagi, E. and Dawood, M. (2011) 'Integrated visualized time control system for repetitive construction projects', *Automation in Construction*, 20, pp. 940–953.

Falagas, M. E., Pitsouni, E. I., Malietzis, G. A. and Pappas, G. (2008) 'Comparison of PubMed, Scopus, web of science, and Google scholar: Strengths and weaknesses', *FASEB*

Journal, 22, pp. 338–342.

Fan, S.-L., Skibniewski, M. J. and Hung, T. W. (2014) ‘Effects of building information modeling during construction’, *Journal of Applied Science and Engineering*, 17(2), pp. 157–166. doi: 10.6180/jase.2014.17.2.06.

Fan, S. L. (2013) ‘Study on buidling information modeling to construction disputes - Coventry University’, *Journal of the Chinese Institute of Civil and Hydraulic Engineering*, 25(3), pp. 257–264.

Fan, S. L., Wu, C. H. and Hun, C. C. (2015) ‘Integration of cost and schedule using BIM’, *Journal of Applied Science and Engineering*, 18(3), pp. 223–232.

Fu, C., Aouad, G., Lee, A., Mashall-Ponting, A. and Wu, S. (2006) ‘IFC model viewer to support nD model application’, *Automation in Construction*, pp. 178–185.

Fuchs, S. and Scherer, R. J. (2017) ‘Multimodels — Instant nD-modeling using original data’, *Automation in Construction*, 75, pp. 22–32.

Ganah, A. A. and John, G. A. (2017) ‘BIM and project planning integration for on-site safety induction’, *Journal of Engineering, Design and Technology*, 15(3), pp. 341–354. Available at: https://doi.org/10.1108/JEDT-02-2016-0012 (Accessed: 23 August 2017).

Gelisen, G. and Griffis, F. (2014) ‘Automated Productivity-Based Schedule Animation: Simulation-Based Approach to Time-Cost Trade-Off Analysis’, *Journal of Construction Engineering and Management (ASCE)*, 140(4), pp. 1–10.

Golparvar-Fard, M., Asce, M., Peña-Mora, F., Savarese, S., Asce, M., Peña-Mora, F. and Savarese, S. (2011) ‘Integrated Sequential As-Built and As-Planned Representation with D4AR Tools in Support of Decision-Making Tasks in the AEC/FM Industry’, *Journal of Construction Engineering and Management (ASCE)*, 137(December), pp. 1099–1116.

Gustavsson, T. K., Samuelson, O. and Wikforss, Ö. (2012) ‘Organizing IT in construction: Present state and future challenges in SWEDEN’, *Journal of Information Technology in Construction (ITcon)*, 17(17), pp. 520–534. Available at: http://www.itcon.org/2012/33 (Accessed: 6 July 2017).

Hadzaman, N. A. H., Takim, R. and Nawawi, A. H. (2015) ‘Building Information Modelling (BIM): the impact of project attributes towards clients’ demand in BIM-based project’, *WIT Transactions on The Built Environment*, 149. doi: 10.2495/BIM150061.

Hamada, H. M., Haron, A. T., Zahrizan, Z. Z. and Humada, A. M. (2017) ‘Implementation of 4D/BIM in the Iraqi construction industry’, *International Journal of Engineering Systems Modelling and Simulation*, 9(4), pp. 227–236. doi: 10.1504/IJESMS.2017.087556.

Han, R., Gao, Y. and Shao, D. (2016) ‘Research on the application of building information model technology in the design of Urban residential buildings in cold region’, *International Journal of Smart Home*, 10(5), pp. 183–194. doi: 10.14257/ijsh.2016.10.5.17.

Haron, A. T., Marshall-ponting, A., Zakaria, Z., Nawi, M. N. M., Hamid, Z. A. and Kamar, K. A. M. (2015) ‘An industrial report on the Malaysian building information modelling (BIM) taskforce : Issues and recommendations’, *Malaysia Construction Research Journal (MCRJ)*, 17(January), pp. 21–36.

Harrison, C. and Thurnell, D. (2015) ‘BIM Implementation in a New Zealand consulting quantity surveying practice’, *International Journal of Construction Supply Chain Management*, 5(1), pp. 1–15.

Her Majesty Government (2013) *Industrial Strategy: government and industry in partnership. Construction 2025*, *UK Government*. London: Her Majesty Government. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/210099/bis-13-955-construction-2025-industrial-strategy.pdf (Accessed: 17 March 2018).

Higgins, J. P. T. (2008) *Cochrane handbook for systematic reviews of interventions*. Cochrane C, *Systematic reviews of interventions*. Cochrane C. Edited by Julian PT Higgins and Sally Green. John Wiley & Sons Ltd.

Hu, Z. Z., Zhang, J. P. and Zhang, X. L. (2010) '4D construction safety information model-based safety analysis approach for scaffold system during construction', *Gongcheng Lixue/Engineering Mechanics*, 27(12), pp. 192–200.

Hu, Z. and Zhang, J. (2011) 'BIM- and 4D-based integrated solution of analysis and management for conflicts and structural safety problems during construction: 2. Development and site trials', *Automation in Construction*, 20(2), pp. 155–166. doi: 10.1016/j.autcon.2010.09.014.

Hu, Z., Zhang, J. and Deng, Z. (2008) 'Construction Process Simulation and Safety Analysis Based on Building Information Model and 4D Technology', *Tsinghua Science and Technology*, 13, pp. 266–272.

Hu C., Xiong H., Long H. and Wang X. (2014) 'Study on cost and schedule combined control of 4D model based on building information modelling (BIM)', *Journal of Xi'an University of Architecture and Technology*, 46(4), pp. 474–478.

Joannides, M. M., Olbina, S. and Issa, R. R. A. (2012) 'Implementation of Building Information Modeling into Accredited Programs in Architecture and Construction Education', *International Journal of Construction Education and Research*, 8(2), pp. 83–100.

Joyce, E. (2014) 'Show me the money: 5D-cost estimating tools taking off', *Engineering News Record*. McGraw-Hill Companies, 273(10). Available at: www.enr-com.

Keele, S. (2007) *Guidelines for performing Systematic Literature reviews in Software Engineering Version 2.3*, *EBSE Technical Report*. Durham, UK.

Khan, K. S., Msc, M., Kunz, R., Msc, M., Kleijnen, J., Phd, M. and Antes, G. (2003) 'Five steps to conducting a systematic review', *Journal of the Royal Society of Medicine*, 96, pp. 118–121.

Kim, C., Kim, C. and Son, H. (2013) 'Automated construction progress measurement using a 4D building information model and 3D data', *Automation in Construction*, 31, pp. 75–82.

Kim, H., Anderson, K., Lee, S. and Hildreth, J. (2013) 'Generating construction schedules through automatic data extraction using open BIM (building information modeling) technology', *Automation in Construction*. Elsevier B.V., 35, pp. 285–295.

Kittleson, M. J. (1997) 'Determining effective follow-up of e-mail surveys', *American Journal of Health Behavior*, 21(3), pp. 193–196.

Kiviniemi, M., Sulankivi, K., Kähkönen, K., Mäkelä, T. and Merivirta, M. L. (2011) 'BIM-based safety management and communication for building construction', *VTT Tiedotteita - Research Notes*, (2597).

Kviz, F. J. (1977) 'Toward a standard definition of response rate', *Public Opinion Quarterly*, 41, pp. 265–267.

Lee, A., Wu, S., Marshall-Ponting, A., Aouad, G., Cooper, R., Tah, J., Abbott, C. and Barrett,

P. (2005) *nD modelling road map : A vision for nD- Enabled construction*. Manchester.

Lee, J. and Kim, J. (2017) 'BIM-Based 4d simulation to improve module manufacturing productivity for sustainable building projects', *Sustainability*, 9(3), p. 426.

Leech, N. L. and Onwuegbuzie, A. J. (2009) 'A typology of mixed methods research designs', *Quality & Quantity*, 43(2), pp. 265–275. doi: 10.1007/s11135-007-9105-3.

De Leeuw, Edith Desirée and Don A. Dillman (2008) *International Handbook of Survey Methodology*. Taylor & Francis. Available at: http://joophox.net/papers/SurveyHandbookCRC.pdf (Accessed: 1 March 2018).

Li, J., Wang, Y., Wang, X., Luo, H., Kang, S.-C., Wang, J., Guo, J. and Jiao, Y. (2014) 'Benefits of building information modelling in the project lifecycle: Construction projects in asia', *International Journal of Advanced Robotic Systems*, 11(1). doi: 10.5772/58447.

Liu, H. L., Wang, G. B., Zhang, L., Hou, H. and Tian, L. (2013) 'Research on BIM-based Construction Project Organization Interface Management', *Applied Mechanics and Materials*, 357–360, pp. 2781–2784.

Lopez, R., Chong, H.-Y., Wang, X. and Graham, J. (2016) 'Technical Review : Analysis and Appraisal of Four-Dimensional Building Information Modeling Usability in Construction and Engineering Projects', *Journal of Construction Engineering and Management (ASCE)*, 142(5), pp. 1–6. doi: 10.1061/(ASCE)CO.1943-7862.0001094.

Lu, Q., Won, J. and Cheng, J. C. P. (2016) 'A financial decision making framework for construction projects based on 5D Building Information Modeling (BIM)', *Project Management*, 34, pp. 3–21.

Mallie, J. (2016) 'Ever faster but still very good', *Architectural Design*, 86(1), pp. 114–119. doi: 10.1002/ad.2009.

Manfreda, K. L., Bosnjak, M., Berzelak, J., Hass, I. and Vehovar, V. (2008) 'Web surveys versus other survey modes: A meta-analysis comparing response rates', *International Journal of Market Research*, 50(1), pp. 79–104. doi: 10.2501/IJMR-53-1-075-094.

Martínez-Aires, M. D., López-Alonso, M. and Martínez-Rojas, M. (2018) 'Building information modeling and safety management: A systematic review', *Safety Science*. Elsevier, 101(October 2015), pp. 11–18. doi: 10.1016/j.ssci.2017.08.015.

Marzouk, M. and Abubakr, A. (2016) 'Decision support for tower crane selection with building information models and genetic algorithms', *Automation in Construction*, 61, pp. 1–15. doi: 10.1016/j.autcon.2015.09.008.

McPartland, R. (2017) *BIM dimensions - 3D, 4D, 5D, 6D BIM explained | NBS*, *NBS*. Available at: https://www.thenbs.com/knowledge/bim-dimensions-3d-4d-5d-6d-bim-explained (Accessed: 28 February 2018).

Merriam, S. B. (1998) *Qualitative research and case study applications in education. Revised and expanded from" case study research in education*. San Francisco, CA: Jossey-Bass Publishers.

Miles, M. B. and Huberman, A. M. (1984) *Qualitative Data Analysis: a Source Book of New Methods*. Sage. Beverly Hills, CA.

Morgan, D. L. (2007) 'Paradigms Lost and Pragmatism Regained: Methodological Implications of Combining Qualitative and Quantitative Methods', *Journal of Mixed Methods Research*, 1(1), pp. 48–76. doi: 10.1177/2345678906292462.

Moya, Q. and Pons, O. (2014) ‘Improving the design and production data flow of a complex curvilinear geometric Glass Reinforced Concrete facade’, *Automation in Construction*. Elsevier B.V., 38, pp. 46–58.

Nicał, A. K. and Wodyński, W. (2016) ‘Enhancing Facility Management through BIM 6D’, in *Procedia Engineering*, pp. 299–306. doi: 10.1016/j.proeng.2016.11.623.

Official Journal of the European Union (2014) ‘Directive 2014/24/UE of the European Parliament and of the Council’, pp. 1–178.

Oppenheim, A. N. (2000) *Questionnaire design, interviewing and attitude measurement*. Bloomsbury Publishing.

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N. and Hoagwood, K. (2015) ‘Purposeful Sampling for Qualitative Data Collection and Analysis in Mixed Method Implementation Research’, *Administration and Policy in Mental Health and Mental Health Services Research*. Springer US, 42(5), pp. 533–544. doi: 10.1007/s10488-013-0528-y.

Panuwatwanich, K. and Peansupap, V. (2013) ‘Factors affecting the current diffusion of BIM: A qualitative study of online professional network’, in *Creative Construction Conference 2013*. Budapest, Hungary, pp. 6–9.

Park, J. and Cai, H. (2017) ‘WBS-based dynamic multi-dimensional BIM database for total construction as-built documentation’, *Automation in Construction*, 77, pp. 15–23.

Park, J., Cai, H., Dunston, P. S. and Ghasemkhani, H. (2017) ‘Database-Supported and Web-Based Visualization for Daily 4D BIM’, *Journal of Construction Engineering and Management (ASCE)*, 143(10), pp. 1–12.

Petrosino, A. and Lavenberg, J. (2007) ‘Systematic Reviews and Meta-Analyses : Best Evidence on “ What Works ” for Criminal Justice Decision Makers’, *Western Criminology Review*, 8(1), pp. 1–15.

Petticrew, M. and Roberts, H. (2008) *Systematic reviews in the social sciences: a practical guide*. John Wiley.

Popov, V., Juocevicius, V., Migilinskas, D., Ustinovichius, L. and Mikalauskas, S. (2010) ‘The use of a virtual building design and construction model for developing an effective project concept in 5D environment’, *Automation in Construction*, 19(3), pp. 357–367. doi: 10.1016/j.autcon.2009.12.005.

Quintana, B., Prieto, S. A., Adán, A. and Bosché, F. (2018) ‘Door detection in 3D coloured point clouds of indoor environments’, *Automation in Construction*, 85, pp. 146–166. doi: 10.1016/j.autcon.2017.10.016.

Redmond, A., Hore, A., Alshawi, M. and West, R. (2012) ‘Exploring how information exchanges can be enhanced through Cloud BIM’, *Automation in Construction*, 24, pp. 175–183.

Rodgers, C., Hosseini, M. R., Chileshe, N. and Rameezdeen, R. (2015) ‘Building Information Modelling (BIM) within the Australian construction Related small and Medium Sized Entreprises: Awareness, Practices and Frivers’, in *Procs 31st Annual ARCOM Conference*. London UK, pp. 691–700.

Russell, A., Staub-French, S., Tran, N. and Wong, W. (2009) ‘Visualizing high-rise building construction strategies using linear scheduling and 4D CAD’, *Automation in Construction*, 18, pp. 219–236.

Rynes, S. L. (2007) ‘Let’s create a tipping point : What Academics and Practitioners can do alone and together’, *Academy of Management Journal*, 50(5), pp. 1046–1054.

Rynes, S. L., Bartunek, J. M. and Daft, R. L. (2001) ‘Across the great divide: Knowledge creation and transfer between practitioners and academics’, *Academy of Management Journal*, 44(2), pp. 340–355.

Sacks, R. and Gurevich, U. (2016) ‘A Review of Building Information Modeling protocols, guides and standards for large construction clients’, *Journal of Information Technology in Construction (ITcon)*, 21(21), pp. 479–503. Available at: http://www.itcon.org/2016/29 (Accessed: 20 December 2016).

Sattineni, A. and Mead, &kyle (2013) ‘Coordination Guidelines for Virtual Design and Construction’, in *SARC 2013 - 30th International Symposium on Automation and Robotics in Construction and Mining, Held in Conjunction with the 23rd World Mining Congress*, pp. 1508–1516.

Saunders, M. N. K., Lewis, P. and Thornhill, A. (2007) *Research methods for business students*. Prentice Hall.

Sawyer, T. (2014a) ‘Collaboration technology for construction sees rapid improvements’, *ENR*. McGraw-Hill Companies, 273(22).

Sawyer, T. (2014b) ‘Construction managers embrace 4D BIM for safety’, *ENR (Engineering News-Record)*, 272(22).

Schlosser, R. W. (2007) ‘Appraising the quality of systematic reviews’, *Focus*, 17, pp. 1–8. Available at: http://ktdrr.org/ktlibrary/articles_pubs/ncddrwork/focus/focus17/Focus17.pdf (Accessed: 27 February 2018).

Schultz, A., Essiet, U. M., Souza de souza, D. V., Kapogiannis, G. and Ruddock, L. (2013) *The Economics of BIM and added Value of BIM to the Construction Sector and Society, CIB Publication 395*.

Shih, T. H. and Xitao, F. (2008) ‘Comparing response rates from web and mail surveys: A meta-analysis’, *Field Methods*, 20(3), pp. 249–271. doi: 10.1177/1525822X08317085.

Smith, P. (2014a) ‘BIM & the 5D Project Cost Manager’, in *Procedia - Social and Behavioral Sciences*. Peter Smith, pp. 475–484. doi: 10.1016/j.sbspro.2014.03.053.

Smith, P. (2014b) ‘BIM Implementation – Global Strategies’, in *Procedia Engineering*, pp. 482–492. doi: 10.1016/j.proeng.2014.10.575.

Smith, V., Devane, D., Begley, C. M. and Clarke, M. (2011) ‘Methodology in conducting a systematic review of systematic reviews of healthcare interventions’, *BMC Medical Research Methodology*, 11(1), p. 15. doi: 10.1186/1471-2288-11-15.

Son, H., Kim, C. and Kwon Cho, Y. (2017) ‘Automated Schedule Updates Using As-Built Data and a 4D Building Information Model’, *Journal of Management in Engineering*, 33(4), p. 4017012.

Stanley, R. and Thurnell, D. (2014) ‘The benefits of, and barriers to, implementation of 5d BIM for quantity surveymg in new zealand’, *Australasian Journal of Construction Economics and Building*, 14(l), pp. 105–117.

Turkan, Y., Bosché, F., Haas, C. T. and Haas, R. (2014) ‘Tracking of secondary and temporary objects in structural concrete work - ProQuest’, *Construction Innovation*, 14(2), pp. 145–167.

Umar, U. A., Shafiq, N., Malakahmad, A., Nuruddin, M. F., Khamidi, M. F., Farhan, S. A. and Gardezi, S. S. S. (2015) '4D BIM Application in AEC Industry : Impact on Integrated Project Delivery', *Research Journal of Applied Sciences, Engineering and Technology*, 10(5), pp. 547–552.

Vieira, E. S. and Gomes, J. A. N. F. (2009) 'A comparison of Scopus and Web of Science for a typical university', *Scientometrics*, 81(2), pp. 587–600. doi: 10.1007/s11192-009-2178-0.

Walliman, N. (2017) *Research Methods - The Basics*. Edited by T. & Francis. Routledge. doi: 10.3794/johlste.41.res.

Wang, J., Ding, Z., Zou, L., Zhang, L., Wang, G. and Liu, H. (2014) 'The Development Trend and Government Policies of Open BIM in China', in *Proceedings of the 17th International Symposium on Advancement of Construction Management and Real Estate*, pp. 981–993.

Wang, W. C., Weng, S. W., Wang, S. H. and Chen, C. Y. (2014) 'Integrating building information models with construction process simulations for project scheduling support', *Automation in Construction*. Elsevier B.V., 37, pp. 68–80.

Wu, I.-C. and Hsieh, S.-H. (2012) 'A framework for facilitating multi-dimensional information integration, management and visualization in engineering projects', *Automation in Construction*, 23, pp. 71–86.

Wu, W., Professor, A., Luo, Y. and Professor, A. (2016) 'Pedagogy and Assessment of Student Learning in Bim and Sustainable Design and Construction', *Journal of Information Technology in Construction (ITcon)*, 21(21), pp. 218–232. Available at: http://www.itcon.org/2016/15.

Yan, W., Culp, C. and Graf, R. (2011) 'Integrating BIM and gaming for real-time interactive architectural visualization', *Automation in Construction*, 20, pp. 446–458. doi: 10.1016/j.autcon.2010.11.013.

Yi, S. L., Zhang, X. and Calvo, M. H. (2015) 'Construction safety management of building project based on BIM', *Journal of Mechanical Engineering Research and Developments*, 38(1), pp. 97–104.

Yu, A. T. W., Poon, C. S., Wong, A., Yip, R. and Jaillon, L. (2013) 'Impact of Construction Waste Disposal Charging Scheme on work practices at construction sites in Hong Kong', *Waste Management*. Elsevier Ltd, 33(1), pp. 138–146. doi: 10.1016/j.wasman.2012.09.023.

Yun, S. heon, Jun, K. hyun, Son, C. baek and Kim, S. chul (2014) 'Preliminary study for performance analysis of BIM-based building construction simulation system', *KSCE Journal of Civil Engineering*, 18(2), pp. 531–540.

Yung, P. and Wang, X. (2014) 'A 6D CAD model for the automatic assessment of building sustainability', *International Journal of Advanced Robotic Systems*, 11(1), pp. 1–8. doi: 10.5772/58446.

Zhang, J. P. and Hu, Z. Z. (2011) 'BIM- and 4D-based integrated solution of analysis and management for conflicts and structural safety problems during construction: 1. Principles and methodologies', *Automation in construction*, 20(2), pp. 167–180.

Zhang, S., Sulankivi, K., Kiviniemi, M., Romo, I., Eastman, C. M. and Teizer, J. (2015) 'BIM-based fall hazard identification and prevention in construction safety planning', *Safety Science*, 72, pp. 31–45.

Zhang, X., Zeng, S. and Wang, P. (2017) 'Application of BIM Techniques to the Construction of the Donggang Station of the Lanzhou Metro', *Modern Tunnelling Technology*. Editorial By Modern Tunnelling Technology, 54(2), pp. 46–54. doi: 10.13807/j.cnki.mtt.2017.02.007.

Zhou, Y., Ding, L., Luo, H. and Chen, L. (2010) 'Research and Application on 6D Integrated System in Metro Construction Based on BIM', *Applied Mechanics and Materials*, 26–28, pp. 241–245.