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A SYSTEMATIC REVIEW OF INFORMATION MODELLING OF INDIVIDUAL RESIDENTIAL BUILDINGS

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Abstract. Rapidly growing building information modelling (BIM) in construction offers a number of advantages and new opportunities of improving efficiency and effectiveness of the construction process and enhancing the use of emerging technology throughout the project's lifecycle, not only in new buildings, but also in existing ones, including overall infrastructure. Recently, there has been a great number of publications discussing BIM advantages in construction. A number of review papers summarising BIM usage cases have been published. However, as the preliminary research shows, not all organizations use BIM because of its disadvantages. Therefore, the main aim of this research is to study the extent of available literature on BIM, to determine the current situation of BIM usage, and summarise publications related to the application of BIM. The current study is limited solely to papers available in SpringerLink, ScienceDirect and Thomson Reuters Web of Sciences scientific databases. The obtained results make it clear that BIM case studies and research in academic journals show high level of BIM implementation in practice, and advantages of BIM. However, there are some limitations of BIM usage in practice. Moreover, new trends in the evolving BIM are presented and discussed in this paper.

Keywords: BIM, building information model, construction, literature review.

Introduction

Building information modelling (BIM) is one of the most promising recent developments in the architecture, engineering, and construction (AEC) industry (Azhar, 2011). With BIM technology, an accurate virtual model of a building, called a building information model, is digitally constructed. It can be used for planning, design, actual construction, and operation of the facility. It helps architects, engineers, and constructors visualize what is to be built in a simulated environment to identify any potential design, construction, or operational issues (Azhar, 2011).

However, as the preliminary research shows, there is a number of disadvantages interfering with the usage and popularising BIM in the industry. Therefore, the main aim of this research is to study the extent of available literature on BIM, and clarify why some companies choose this technology while others do not. Consequently, this research presents a systematic review of literature in SpringerLink, ScienceDirect and Thomson Reuters Web of Sciences scientific databases.

The paper is organized as follows. Section 1 briefly introduces the concept of BIM used in related works. Section 2 describes methodology of the review. Section 3 describes the results of the review, and Section 4 presents a discussion. Finally, last Section concludes the review.

1. Related works

In this section, the concept of building information modelling (BIM) is briefly introduced, and the overview some important publications is presented.

As recently proposed by (Wang & Song, 2016), BIM is becoming increasingly popular in the Architecture, Engineering and Construction (AEC) industry. Many researchers and practitioners have verified the benefits of BIM as compared to traditional information technologies, such as Autodesk CAD. According to the authors (Wang & Song, 2016; Aranda-Mena, Crawford, Chevez, & Froese, 2009) BIM incorporates software, information of a process

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for designing and documenting a building, new policies, standards and regulations, etc. According to the United States (U.S.) National BIM standard, BIM is defined as "a digital representation of physical and functional characteristics of a facility", which serves as "a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition".

There is a number of papers presenting BIM's origins, its history and future trends. This paper summarizes future trends presented in other publications.

Turk (2016) defines three main categories or directions of BIM development. They are as follows: BIM *structure*, which defines parts, their organization and how the parts work together; BIM *functionality*, which describes how it can be made useful; and BIM *behaviour*, which describes how it responds to its environment. The author defines future BIM trends in the scope of these three categories. However, they are very broad. The more detailed BIM directions (in whole 12) are presented in (Merschbrock & Munkvold, 2012) and adapted from (Isikdag & Underwood, 2010).

Anumba (2016) defines BIM's emerging directions as well. However, they are mainly related to information technology (IT). Authors (Jung & Joo, 2011) present a detailed BIM practical implementation framework, which can be used as such and for analysis of future trends. Their analysed framework consists of three main directions, namely construction business function, BIM perspective and BIM technology. After the analysis, the authors stated that knowledge (in within the property level variable) and reasoning (within the ontology variable) are promising areas for advanced BIM, and cost-effective approaches, using structured BIM properties, found in literature and in actual industry experience.

Saoud, Omran, Hassan, Vilutienė, and Kiaulakis (2017) describe the developed method to predict the propagation of change through BIM, and provide the concept of visual technology to help designers to predict the change in the construction industry. The developed method includes the use of parameter-based Design Structure Matrix (DSM) as a tool for predicting change propagation. Their case study demonstrates the possibilities of the method in BIM environment. Matthews et al. (2015), Matthews, Love, Mewburn, Stobaus, and Ramanayaka (2018) also analyse real time progress management and a change in management perspectives.

Also a number of papers present different applications of BIM, like in (Liao & Teo, 2017) the authors identify 15 success factors of applying BIM, in (Ustinovichius, Peckienė, & Popov, 2017) the authors have used BIM for spatial planning of the site, in (Juan, Lai, & Shih, 2017), investigated the current status of BIM adoption in 224 Taiwanese architectural firms and created a predictive model that can be used by decision makers who are considering adopting BIM. The results revealed that approximately one third of the firms surveyed had already adopted BIM-based tools (Juan et al., 2017). More than half of the firms were willing to use BIM-based tools to streamline the building permit review process; however, their willingness was strongly influenced by governmental policies, competitor motivation, financial incentives, and technological support.

The next section presents the methodology of a systematic literature review on BIM.

2. Methodology

In this section, literature review process is presented. The research begins with a brief literature review of published papers on BIM in the selected databases and search engines. A well-structured and solid literature review enables researchers to identify under-researched topics and research gaps (Merschbrock & Munkvold, 2012).

The review process is presented in Figure 1, and is based on (Pautasso, 2013).

1. ***Define research questions***. In this step, brief research questions were defined, pertinent to the papers about BIM. They are as follows:

The review in this study can be considered a scoping study (Merschbrock & Munkvold, 2012; Arksey & O'Malley, 2005) and designed *to cover the extent of available literature, allowing for the identification of journal articles and other publications across several research disciplines*. Some possible previous studies focused on journal articles or conference proceedings originating within the construction informatics (CI) field are presented in (Amor, Betts, Coetzee, & Sexton, 2002; Björk, 1999).

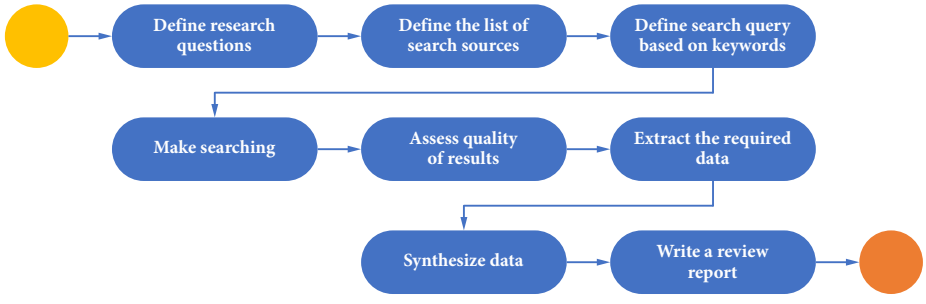

Figure 1. A systematic literature review process

2. ***Define the list of search sources***. In this step, the list of search sources was defined. In order to review a certain amount of papers on BIM, several digital databases and search engines naming sources were chosen. Due to the technical limitations, only free access[1] and limited number of sources were chosen. Therefore, only three sources were used (see Table 1). However, the initial study of sources shows that they contain significant number of books, journals, peer-reviewed conferences and workshops relevant to the research field.

Table 1. List of sources

Data source	Website
SpringerLink	http://link.springer.com/
ScienceDirect	http://www.sciencedirect.com/
Thomson Reuters Web of Science	https://apps.webofknowledge.com/

3. ***Define search query based on keywords***. In this step, synonyms, related terms and their meaningful combinations are defined. The following search query has been defined:

(("BIM") OR ("Building Information Modelling") OR ("BIM technology") OR ("Building Information Model")) AND ("construction" OR "building")

Note that other terms, like "digital model", "3D modelling", etc., can also be used in the search. However, adding such terms increases the number of results, but doe not make it more specific. Therefore, they were excluded from the search.

4. ***Make searching***. In this step, the searching process is performed according to the defined terms in step 4.
5. ***Assess quality of results***. In this step, quality of results is assessed. According to (Kitchenham, Mendes, & Travassos, 2007) there is no commonly agreed definition of study "quality". Therefore, quality issues presented in (Zhang, Kitchenham, & Pfahl, 2008) were the basis for consideration.
6. ***Extract the required data***. In this step, a required data is extracted according to the research questions, presented in step 1.
7. ***Write a review report***. In this step, review report is written and discussion is conducted.

3. Results of the review

In this section, results of our literature review are presented. Table 2 shows a summarized results of our literature review, where it is clear that, in three databases, found 8 511 different publications wee found. Below, in this section, according to the searching possibilities of databases, more detailed analysis of the results will be presented.

Table 2. Summarized results of literature review in SpringerLink, Thomson Reuters Web of Science and ScienceDirect databases

	Databases (search conducted 2016-12-01)			
Year of publication	SpringerLink	Thomson Reuters Web of Science	ScienceDirect (including Elsevier)	
2010–2017	171	1754	1 986	
2000–2009	768	156	409	
1990–1999	507	3	349	
<1990	489	0	374	
Total:	3480	1913	3118	8511

3.1. SpringerLink

In Table 3, an extended version of our literature review in SpringerLink is presented. Each column represents number of publications according to a specific attribute. For the purpose of detailed analysis, the most popular attributes available in the SpringerLink database have been chosen. *Note* that the original names of attributes have been left in Table 3. Moreover, the searching query, presented in Section 2.1 Step 4, was refined according to the search engine used in SpringerLink as follows:

"building information model" OR (BIM) AND (construction OR building)

Table 3. Extended results of a literature review in SpringerLink

Year of publication	Content type					Discipline			Language	
	Chapter	Article	Reference Work Entry	Protocol	Book	Computer Science	Engineering	Environment	English	German
2010–2017	1 075	576	47	13	5	683	551	168	1 570	144
2000–2009	487	269	8	4	0	230	144	26	718	50
1990–1999	385	122	0	0	0	162	57	15	494	13
<1990	320	169	0	0	0	51	75	11	405	61

[1] VGTU has access to Thomson Reuters Web of Science.

Note that in Table 3 attributes the values of which are less than 10 are not presented (relevant for other languages).

As can be seen in Table 3, the most popular content types are chapters (or proceeding papers) and articles (or journals). The most popular research areas are Computer Science, Engineering, and Environment. The most popular language is English.

3.2. Thomson Reuters Web of Science

In Table 4, an extended version of our literature review in Thomson Reuters Web of Science is presented. Each column represents number of publications according to a specific attribute. For the purpose of detailed analysis, the most popular attributes available in the Thomson Reuters Web of Science database were chosen. *Note* that the original names of attributes have been left in Table 4. Moreover, the searching query presented in Section 2.1 Step 4 was refined according to the search engine used in Thomson Reuters Web of Science as follows:

TOPIC: ("building information model") OR TOPIC: (BIM) AND TOPIC: (construction OR building)

As can be seen in Table 4, the most popular document types are proceeding papers and journals. The most popular research areas are Engineering, Construction Building Technology and Computer Science. The most popular language is English. However, other languages are also used in publications.

A distribution of publications according to five most popular journals during 2016–2000 are presented in Table 5. Previous years (before 2000) are not analysed in details because of BIM origination.

As can be seen from Table 5, Elsevier publishes the most popular and significant journals on the topic of BIM.

3.3. ScienceDirect

Table 6 presents an extended version of our literature review in ScienceDirect. Each column represents a number of publications according to a specific attribute. For the detailed analysis, the most popular attributes available in the ScienceDirect database were chosen. *Note* that in Table 6 the original names of attributes have been left. Moreover, the searching query presented in Section 2.1 Step 4 was refined according to the search engine used in ScienceDirect as follows:

((building information model) OR BIM) AND (construction OR building)

Moreover, refined search results according to research are presented in Table 6. The following research areas were chosen: Business, Management and Accounting; Computer Science; Decision Sciences; Design; Economics, Econometrics and Finance; Energy; Engineering; Environmental Science; and Social Sciences. Areas covering Art, Agriculture, Medicine, and Philosophy were excluded from the search.

A distribution of publications according to five most popular journals during 2016–2000 are presented in Table 7. Years before 2000 have not been analysed because of BIM origination.

Table 4. Extended results of a literature review in Thomson Reuters Web of Science

Year of publication	Document type					Research Area						Language				
	Proceedings Paper	Article	Review	Editorial Material	News Item	Engineering	Construction Building Technology	Computer Science	Architecture	Materials Science	Automation Control Systems	English	German	Spanish	Croatian	Turkish
2010–2017	920	787	31	20	4	962	581	484	173	79	27	1721	19	5	3	2
2000–2009	105	54	2	1	2	74	76	42	26	7	6	154	1	0	0	0
1990–1999	1	2	0	0	0	0	0	1	1	0	1	2	0	0	0	0

Table 5. A distribution of publications according to journals in Thomson Reuters Web of Science

Year of publication	Journal title (Publisher)						
	Automation in Construction (Elsevier)	Procedia Engineering (Elsevier)	Applied Mechanics and Materials	Advanced Engineering Informatics (Elsevier)	Journal of Computing in Civil Engineering	Energy and Buildings (Elsevier)	Building and Environment (Elsevier)
2010–2017	208	81	80	51	50	15	8
2000–2009	11	0	0	4	2	0	0

Table 6. Extended results of ++--+ literature review in ScienceDirect

Year of publication	Content type		
	Journal	Reference Work	Book
2010–2017	1 878	10	105
2000–2009	356	6	61
1990–1999	315	0	44
<1990	339	0	50

As can be seen in Table 7, Elsevier publishes the most popular and significant journals on the topic of BIM.

3.4. Related papers on BIM studies

Based on the search results, it was concluded that systematic literature reviews on BIM are now popular. Therefore, in this section several papers on BIM literature review are presented and discussed.

For the study, reviews on BIM in the period of 2008–2016 were chosen. The search in ScienceDirect of reviews on the topic of BIM in construction results in more than 1 864 journals. From those journals, the most appropriate and recent to data have been chosen. A brief review of 9 studies is presented below.

Merschbrock & Munkvold (2012) published their review paper on BIM in "*Communications of the Association for Information Systems*" in 2012. Their review process was performed in 2011–2012, and they found 1 227 articles in keeping with their defined keywords in Elsevier SciVerse Scopus. Their review can be characterized as a scoping study (Arksey & O'Malley, 2005), seeking to examine the extent, range and nature of the research activity on three-dimensional BIM topics. The authors have chosen 264 papers for the detailed study and have identified that the interest in the BIM topic had risen almost exponentially from 1996–2010. Authors of (Merschbrock & Munkvold, 2012) in their publication have identified the leading main five journals publishing BIM articles. Moreover, they explored that the bigger amount of publications proposing how to extend BIM by IT to achieve users' goals. Finally, authors of (Merschbrock & Munkvold, 2012) have found that the main topics concerned BIM and IT are working in groups and facilitating the impact of BIM on organizations. Other publications had analysed an influence of BIM on organizations culture (Anumba, Dainty, Ison, & Sergeant, 2006; Gal, Lyytinen, & Yoo, 2008), production process (Arayici et al., 2011; Sacks, Treckmann, & Rozenfeld, 2009) and measuring business value of BIM (Delone & McLean, 2003; Melville, Kraemer, & Gurbaxani, 2004).

Yan and Damian (2008) in their paper have presented BIM benefits and limitations. Therefore, they reviewed a historical evolution of design tools. Then, they have questioned about 70 AEC professionals how they use BIM, and what are BIM benefits and limitations. Finally, authors have found that USA is the leading country in BIM usage. However, a large number of companies are not currently using BIM, and are not going to use BIM in the future. So, authors have concluded that the BIM technology should be improved in the future to rich an appropriate maturity level.

Authors of (Volk, Stengel, & Schultmann, 2014) reviewed more than 180 publications on BIM implementation. Results showed that nerveless BIM topic becomes more and more popular per years (2002–2012). Nerveless, BIM is not used in the existing buildings because of high efforts necessary 1) to convert existing buildings data into semantic BIM objects, 2) to update existing information in BIM, and 3) to handle inaccurate data, objects and relations occurring in existing buildings. Therefore, ways of process automation and BIM adaptation to existing buildings should be developed in the future.

In (Soust-Verdaguer, Llatas, & García-Martínez, 2016a) authors analysed 20 case studies according to ISO 14040, ISO 14044, EN 15978, and EN 15804 standards. The main result obtained in the paper is that authors develop recommendations to develop simplification strategies that allowing us to compare single-family houses in Life Cycle Assessment (LCA).

Shou, Wang, J., Wang, X., and Chong (2015) have reviewed 40 case studies in academic journals and conference proceedings and 24 case studies in industrial reports on BIM implementation and use in AEC industry. The obtained results showed that BIM case studies in academic publications show a high level of BIM implementation in practice. As well, the analysis of BIM in infrastructure and building cases shows the BIM usage together with traditional project management.

Cerovsek (2011) provides a review of issues for BIM tools and standards, and showed the necessity for the BIM research methodology.

In (Soust-Verdaguer, Llatas, & García-Martínez, 2016b) the authors reviewed recent studies centred on BIM-based LCA, and found the necessity to simplify BIM

Table 7. A distribution of publications according to journals in ScienceDirect

Year of publication	Journal title (Publisher)				
	Automation in Construction (Elsevier)	Procedia Engineering (Elsevier)	Advanced Engineering Informatics (Elsevier)	Energy and Buildings (Elsevier)	Building and Environment (Elsevier)
2010–2017	423	157	110	78	44
2000–2009	40	0	16	3	3

application, especially data acquisition. Finally, the authors propose recommendations for BIM and LCA tools.

Chen, Lu, Peng, Rowlinson, and Huang (2015), basing on the review of 75 papers, have proposed a conceptual framework for synchronizing information flows between BIM and real-life building processes. The authors have applied their framework to the prefabricated housing construction in Hong Kong. Moreover, as the authors have stated, their proposed framework needs information and management theories, and further exploration of practical uses of the proposed framework.

Eleftheriadis, Mumovic, and Greening (2017) reviewed BIM usage capabilities for energy efficiency in building structures. Migilinskas, Popov, Juocevicius, and Ustinovichius (2013) have analysed benefits and limitations of BIM practical implementation and found that those are fast growing technologies requiring implementation of standards and learning.

4. Discussing the review results

As presented in the first part of review, the scale of research on BIM has been increasing significantly. As presented in Figure 2, number of journal publications grows significantly. Authors analyse BIM in different topics. The main disciplines or areas are Computer Sciences, Engineering and Construction Building Technologies (Figure 3). Therefore, it can be concluded that the topic of BIM is familiar to researchers in other fields, especially Computer Sciences. In addition, Merschbrock & Munkvold (2012) have found that contributions in Computer Sciences would bring the knowledge further to BIM in construction.

As can be seen in Figure 4, the main journals publishing articles on BIM focus on construction and computer science. However, those journals are slightly different because publishers are included into databases. Moreover, as illustrated in Figure 4, the leading journal publishing BIM articles has not changed (Automation in Construction (Elsevier)). Other popular areas where BIM articles have been published are: architecture, environment, chemistry, etc. (see Table 3 and Table 4).

Another important finding of the research is the distribution of BIM publications according to application areas. The following detailed classification of BIM application areas in journals is presented in Table 8.

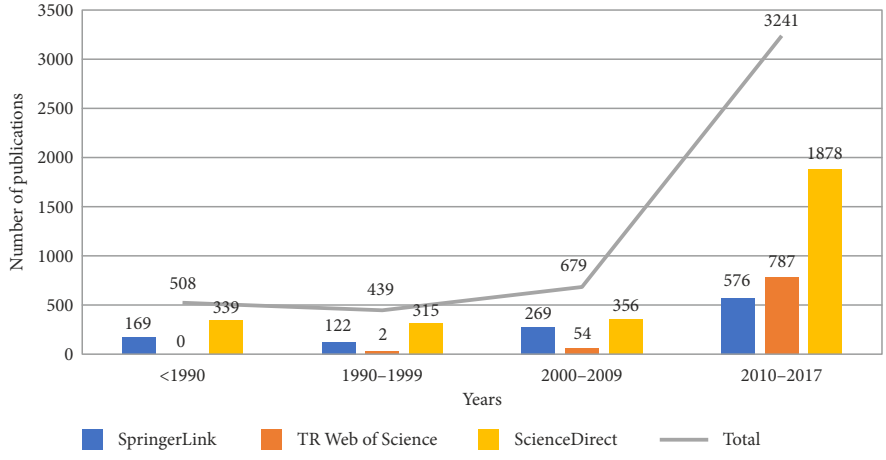

Figure 2. Number of journal publications in SpringerLink, Thomson Reuters (TR) Web of Science and ScienceDirect

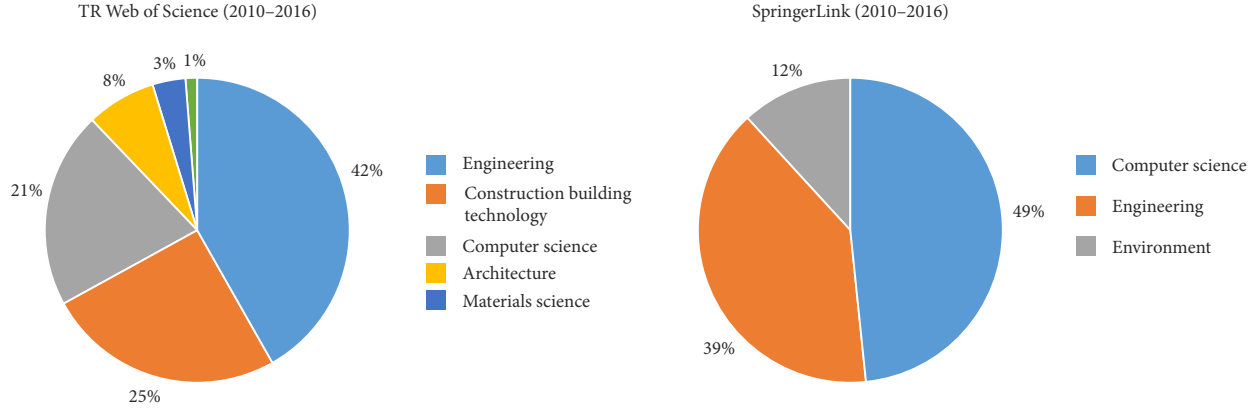

Figure 3. Distribution of publications according to the research area in SpringerLink and Thomson Reuters (TR) Web of Science at 2010–2016

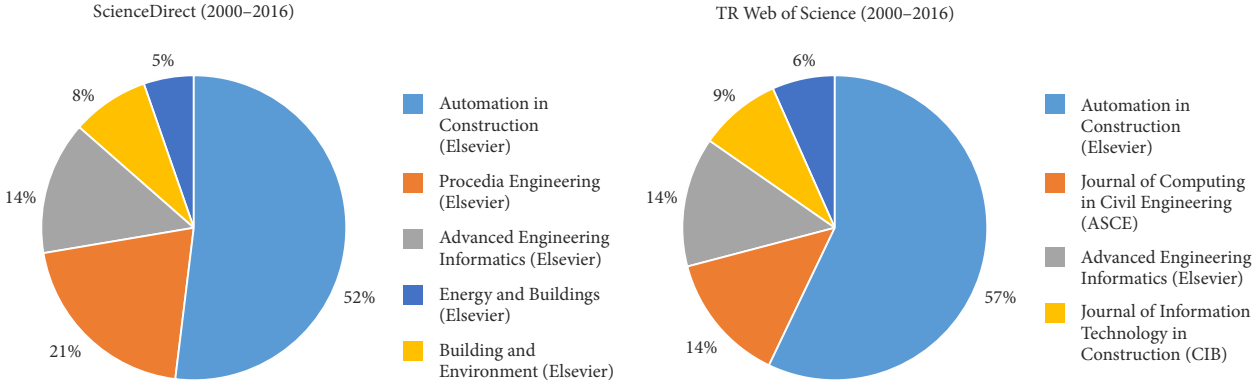

Figure 4. The leading journals publishing BIM articles

Table 8. Distribution of publications according to BIM application areas in journals

BIM application areas	Sub area	Resource
1. Buildings analysed	1.1. For new buildings	
	1.2. For improvement of old buildings, like historical buildings	(Biagini, Capone, Donato, & Facchini, 2016)
	1.3. For improvement and/or operation of old buildings, like existing buildings	(Volk et al., 2014; McArthur, 2015; Khaddaj & Srour, 2016)
	1.4. Case studies and Application of BIM	In Norway (Merschbrock & Munkvold, 2015), China (Cao et al., 2015), Austria (Gourlis & Kovacic, 2016), Australia (Atazadeh, Kalantari, Rajabifard, & Ho, 2017), England (Alwan, Jones, & Holgate, 2017), South Korea (Won, Cheng, & Lee, 2016), Iran (Shad, Khorrami, & Ghaemi, 2017)
	1.5. Cost estimation	(Ma & Liu, 2014; Lee, Kim, & Yu, 2014; Wang et al., 2016; Kim, Anderson, Lee, & Hildreth, 2013)
2. Part of the building	2.1. Energy consumption, energy saving or energy performance	(Borgstein, Lamberts, & Hensen, 2016; Guo & Wei, 2016; Shadram, Johansson, Lu, Schade, & Olofsson, 2016; Ahn, Kim, Y. J., Park, Kim, I., & Lee, 2014; Azzouz, Borchers, Moreira, & Mavrogianni, 2017; Ham & Golparvar-Fard, 2015; Di, 2015; Abanda & Byers, 2016; Gourlis & Kovacic, 2016; Kuo, Hsieh, Guo, & Cha, 2016; Jia, Srinivasan, & Raheem, 2017)
	2.2. Daylighting analysis	(Kota, Haberl, Clayton, & Yan, 2014)
	2.3. Sustainability performance	(Kreiner, Passer, & Wallbaum, 2015)
	2.4. Waste management	(Lu, Webster, Chen, K., Zhang, & Chen, X., 2017)
3. Computer sciences	3.1. Process optimisation	(Ciribini, Ventura, & Paneroni, 2016; Matthews et al., 2015; Choi, Kim, H., & Kim, I., 2015; Liu, Meng, & Tam, 2015; Nath, Attarzadeh, Tiong, Chidambaram, & Yu, 2015)
	3.2. Automation, simulation	(Kumar & Cheng, 2015; Gao et al., 2015; Hongling, Yantao, Weisheng, & Yan, 2016; Kim, Jeong, Clayton, Haberl, & Yan, 2015; Zhang, Teizer, Pradhananga, & Eastman, 2015; Wang, Cho, & Kim, 2015; Ben-Alon & Sacks, 2017; Laefer & Truong-Hong, 2017; Kim, C., Son, & Kim, C., 2013a)
	3.3. Application of newest technologies	clouds in (Jiao, Zhang, Li, Wang, & Yang, 2013; Anil, Tang, Akinci, & Huber, 2013), gbXML (Ham & Golparvar-Fard, 2015)
	3.4. Web technologies (including Semantic Web)	(Ding, Zhong, Wu, & Luo, 2016; Bilal et al., 2017; Chen & Nguyen, 2016)
	3.5. Goal-driven approach	(Won & Lee, 2016)
	3.6. Information mapping	(Kim et al., 2016b)
	3.7. Information modelling and management	(Volkov, Chelyshkov, & Lysenko, 2016; Lee, Y. C., Eastman, & Lee, J. K., 2015a; Han & Golparvar-Fard, 2017; Mazairac & Beetz, 2013)
	3.8. Visualisation	(Irizarry, Karan, & Jalaei, 2013; Rolfsen & Merschbrock, 2016; Niu, Pan, & Zhao, 2015) Real time visualization of BIM (Johansson, Roupé, & Bosch-Sijtsema, 2015)

End of Table 8

BIM application areas	Sub area	Resource
	3.9. Analysis using patterns, semantic analysis	(Yalcinkaya & Singh, 2015; Lee, Oh, Kim, & Choi, 2015; Costa & Madrazo, 2015)
	3.10. Knowledge application, Reasoning	(Kim & Cho, 2015; Motawa & Almarshad, 2013; Han, Cline, & Golparvar-Fard, 2015; Venugopal, Eastman, & Teizer, 2015; Singh, Sawhney, & Borrmann, 2015; Lee, Chi, Wang, Wang, & Park, 2016; Lee, Eastman, & Solihin, 2016a; Shad, Khorrami, & Ghaemi, 2017)
4. Standards and quality assurance	4.1. Quality management or assurance	(Chen & Luo, 2014; Kim et al., 2016a)
	4.2. Safety planning and checking	(Kim, Cho, & Zhang, 2016; Ganah & John, 2015; Zhang et al., 2015a; Zhang, Teizer, Lee, Eastman, & Venugopal, 2013; Choi, J., Choi, J., & Kim, 2014; Zhang, Wu, Zhu, & AbouRizk, 2017)
5. Environment	5.1. Gas emission	(Giesekam, Barrett, Taylor, & Owen, 2014; Motawa & Carter, 2013)
	5.2. Green building	(Ilhan & Yaman, 2016; Wong & Zhou, 2015; Chen & Nguyen, 2016; Shad et al., 2017)
	5.3. Life quality and health	(Li, Su, Zhang, & Kong, 2017; Takim, Harris, & Nawawi, 2013)
6. Materials		(Han & Golparvar-Fard, 2015; Hoxha, Habert, Lasvaux, Chevalier, & Le Roy, 2017)

As shown in Table 8, mainly papers published in 2015–2017 of are reviewed and presented.

As the literature review shows, the BIM surveys and systematic literature reviews on BIM are more and more popular. Authors analyse BIM and related technologies according to different topics. Table 9 below illustrates a review of results on BIM literature reviews presented in Section 3.1.4. In the future, it may be supplemented by more details.

As illustrated in Table 9, the majority are literature reviews. Only some (2, 4 and 9) are supplemented by questioning. BIM research covers quite a wide range of topics (see Table 9 last column). However, the reviewed authors identify both advantages and disadvantages of BIM.

Table 9. Results of BIM literature reviews

No.	Source	Review period in years	Type of review	Number of analysed sources	Topic
1	(Eleftheriadis et al., 2017)	2009–2014	Literature review	170 articles	BIM capabilities based on life cycle energy efficiency in building structures
2	(Soust-Verdaguer et al., 2016a)	2012–2016	Literature review + case analyses	>37 publications + 20 cases	To identify the simplification strategies assumed in each paper, to clarify and to help to promote further developments on LCA of single-family houses
3	(Soust-Verdaguer et al., 2016b)	2013–2015	Literature review	180 publications	recent studies centred on BIM-based LCA
4	(Shou et al., 2015)	2006–2014	Literature review + case analyses	40 case studies in academic journals and conference proceedings and 24 BIM cases in industrial reports	BIM implementation in building and infrastructure industries
5	(Chen et al., 2015)	2005–2014	Literature review	75 papers	synchronizing information between BIM and real-life building processes
6	(Volk et al., 2014)	2002–2012	Literature review	180 publications	BIM implementation and research in existing buildings
7	(Merschbrock & Munkvold, 2012)	2011–2012	Literature review (scoping study)	264 articles	the extent, range and nature of the research activity on three-dimensional BIM topics
8	(Cerovsek, 2011)	2000–2009	Literature review	over 150 AEC/O tools and digital models	comprehensive recommendations for their advancement and development
9	(Yan & Damian, 2008)	From early past till now 2007–2008	Literature review + questioning	67 individuals from the AEC industry	the historical evolution of design tools BIM adoption, perceived benefits, and perceived barriers
10	Our review	1990–2016	Literature review	3 databases, main 9 sources	The breadth of available literature on BIM

In some research, like in (Cerovsek, 2011; Shou et al., 2015; Soust-Verdaguer et al., 2016a), guidelines and/or recommendations for improvement and usage of BIM technologies are provided. Sun, Jiang, Skibniewski, Man, and Shen (2017) identify many factors still limiting the application of BIM in the construction industry. Authors identify twenty-two sub-factors and classify them into five categories: Technology, Cost, Management, Personnel, and Legal. They also present some suggestions for eliminating these limiting factors. Moreover, authors, like (Chen et al., 2015), work on development of frameworks for information synchronization and management, decision making and technologies development for BIM and real-life building processes.

4.1. Future BIM trends

According to the analysed literature on BIM, different trends of BIM evolvement and publications have been found. In this section, the main directions of BIM development are presented.

Six main directions discovered in contemporary papers are presented in Figure 5. They are as follows. The *Construction Process* category covers the construction process of a building as it is, including analysis of parts of the buildings, such as energy production, daylighting, etc. *Computer Sciences* covers different information technologies and approaches used to manage, optimise, visualize and automate the construction process, information and resources required in the construction of a building. *Environment* covers the concept of a green building. *Education and training* covers human role in BIM. *Case Studies* describes different BIM case studies within an industry setting. *Standards* covers topics on applied and implemented standards, regulations and norms in BIM, including quality management, assurance, and safety planning. There are some other fields to be found in BIM publications, but those six fields are the major ones.

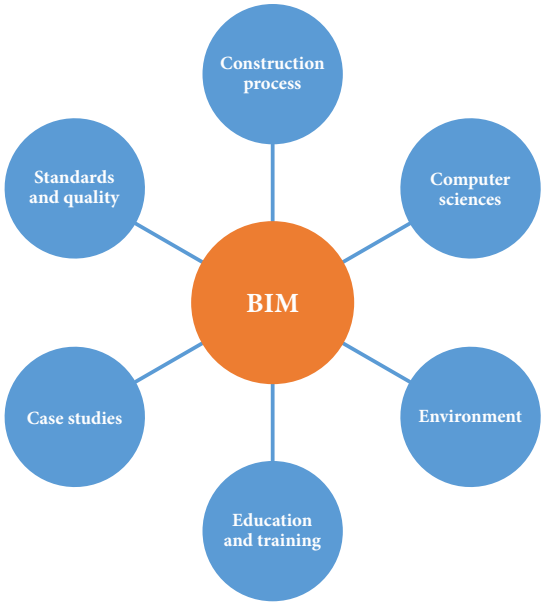

Figure 5. Current situation of the BIM evolvement

The authors of this publication believe that such distribution and interest in BIM areas is determined by the following factors: global concern about energy saving, rapid growth of information technologies and social-economic progress.

Table 10. MCDM in BIM

MCDM applied	Application area
Fuzzy MCDM	• low-carbon building measures selection using fuzzy PROMETHEE (Chen & Pan, 2016) • bridge information modelling and cost estimation at conceptual design stage of concrete box-girder bridges (Markiz & Jrade, 2014; Zavadskas & Vilutiene, 2006) • evaluating renewable energy alternatives in Turkey (Balin & Baraçli, 2017)
Compex MCDM or hybrid models	The environmental impacts of three alternative types of envelopes (masonry, log and timber frame) of an energy efficient single-family house, simultaneously identifying the most rational alternative according to the considered criteria (reduction of expenses, non-renewable primary energy, Green House Gases and ozone layer depletion) (Motuzienė, Rogoža, Lapinskienė, & Vilutienė, 2016). Authors use the method of multiple criteria COmplex PRoportional ASsesment (COPRAS) (Kaklauskas et al., 2006) and AHP (Analytic Hierarchy Process). In (Yeh, 2017) authors employ a MCDM approach by using the interpretive structural modelling (ISM) method to deal with the interrelationship among criteria, and the analytic network process (ANP) method is employed to determine the relative weights of each criterion. Finally, in order to choose the alternative for the ideal solution of this problem TOPSIS is used. In (Turskis, Morkunaite, & Kutut, 2017) authors propose using of a hybrid model developed for ranking the heritage buildings intended for renovation according to their value. In (Valipour, Yahaya, Md Noor, Mardani, & Antuchevičienė, 2016) authors present an approach in the form of a hybrid Fuzzy method and Cybernetic Analytic Network Process (CANP) model for identifying shared risks. In (Hosseini, Lale Arefi, Bitarafan, Abazarlou, & Zavadskas, 2016) authors use the comparison of FUZZY and AHP to study different types of exterior walls for renewal and reconstruction of buildings in the earthquake area
AHP (Analytic Hierarchy Process)	• Building simulations supporting decision making in early design (Østergård, Jensen, & Maagaard, 2016) • A MCDM with BIM for fall protection planning (Melzner, Hollermann, & Bargstadt, 2012)
WASPAS (Weighted Aggregated Sum Product Assessment)	Weighted Aggregated Sum Product Assessment method with Grey attributes scores (WASPAS-G) with BIM for old equipment factory redevelopment (Pavlovskis, Antucheviciene, & Migilinskas, 2016)
TOPSIS	Integrating decision support system and BIM to optimise the selection of sustainable building components (Jalaei, Jrade, & Nassiri, 2015)

4.2. Possible extension of BIM by MCDM

A narrow and new developing area in BIM is the application of Multi-Criteria Decision Making (MCDM) methods for selection of appropriate alternatives in different construction areas. Research results in chosen databases shows that there are few related articles, and some of them are presented in Table 10.

Conclusions

As the systematic literature review shows, BIM becoming widely used in construction. It offers a number of advantages and new opportunities of improvement of efficiency and effectiveness of the construction process and enhancing the use of emerging technology throughout a project's lifecycle, not only in new buildings, but also in existing buildings, including overall infrastructures. However, as a new approach, it has disadvantages which should be overcome in the future.

As the current research shows, the main areas of developing BIM are as follows: the construction process, application of new approaches and technologies drawn from computer science, environment improvement through BIM usage, published case studies on BIM usage, standards and quality implementation in BIM, and BIM staff training and education.

However, as was found in related works, the main drawback of BIM application is lack of skilled staff (Ghaffarianhoseini et al., 2017). Therefore, the project management process is still unclear, and companies without experience with BIM might also be excluded from tendering future BIM-enabled projects (Ghaffarianhoseini et al., 2017).

Moreover, the current research shows that BIM can be extended by MCDM methods for selection of appropriate alternatives in different construction areas. Research in this field is only now beginning to grow.

Unfortunately, too little attention is devoted to the extended concept of BIM, i.e. BLM (Building Lifecycle Modelling). We then have to do with 7D modelling. BLM, by definition, covers the management of the building's life cycle, and is also closely related to the design of nearly zero-energy buildings (nZEB). The use of these concepts in engineering practice is the foundation for a holistic approach to the investment process, i.e. the Integrated Project Delirevery (IPD).

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