Nicola Moretti
Paolo Ettore Giana

19

A Literature Review on BIM Maturity in the AECO Industry

KEYWORDS: Performance measurement, BIM, BIM maturity, Maturity levels, Bibliometrix.

Physical assets are, nowadays, more and more included in the digital environment, providing huge amount of data, and involving a complex network of stakeholders. Many Information Communication Technologies (ICTs) are employed in Architecture, Engineering, Construction and Operation (AECO), in order to tackle the digital transformation. Currently, one of the most acknowledged approaches for managing the new complexity of the built environment is Building Information Modelling (BIM). This article addresses the issue of the maturity of organisations, which adopt or are willing to adopt a BIM approach. Therefore, research aims at providing a critical review on BIM maturity of organisations operating in AECO. The BIM approach can be considered a step forward for supporting the development of digital processes able to foster the achievement of their business objectives. The scope of the research concerns the overall dynamics of the AECO sector concerning the digital revolution affecting management of the built environment processes along the life cycle of physical assets. Therefore, a literature review on Scopus databases has been carried out and most relevant dynamics in the literature production have been identified and investigated trough bibliometric, trend and cluster analyses carried out on the selected sample of articles. In summary it can be stated that the BIM maturity allow to evaluate organisations' digitalisation potential enabling the reengineering of business processes. Moreover, the evaluation of organisations' BIM compliant approaches can provide a sound assessment method during a bid process, contributing to the transparent and effective selection of the most virtuous firms.

INTRODUCTION

The built environment, today, is more and more characterized by the digitalization of processes, from the early stages of the design, until the decommissioning of the assets (RIBA 2013). This trend leads to the massive employment in Architecture, Engineering, Construction and Operations (AECO) of digital tools able to manage the information complexity provided by the digitalised built environment. Within this context, one of the most acknowledged and recognised methodology for information management is Building Information Modelling (BIM) approach. According to the framework defined by the British Standard Institution (BSI, 2014), BIM can be intended as the management of information flows along the life cycle of the asset through the use of digital modelling (British Standard Institution 2018), namely a set of digital processes, enabled by digital tools, procedures, methodologies, furthering efficiency of the information exchange and collaboration among players.

Despite the clear advantages offered by this powerful approach, still its adoption seems to be not completely embedded in the attitude of the AECO players. This is probably due to the need for a paradigm shift in the behaviour on the market of these subjects that often seems to be not completely aware of the remarkable benefits that could be achieved in the middle-long term perspective (Pärn, Edwards, and Sing 2017). Therefore, the research aims at providing a critical review on BIM maturity of organisations operating in AECO.

THE BACKGROUND OF THE RESEARCH

Many approaches for the BIM performance measurement can be found in literature (Yang et al. 2010; Andone 2009; Shin and Chai 2016; Chen, Dib, and Cox 2014; Giel and Issa 2014; Kassem, M.; Succar, B.; Dawood 2012). Nevertheless, the most part of them agree with the definition of two fundamental terms: (i) adoption, and (ii) maturity. The former concerns the ability of an organisation of handling BIM tools, and delivering BIM based products, according to increasing levels of skills. The latter quantifies the capability of an organisation to provide standardised guidelines, and procedures, to be distributed among its members, and to be applied whenever a BIM output must be achieved (Bilal Succar, Sher, and Williams 2013). Therefore, while the BIM adoption can be considered a bottom-up approach, the BIM maturity should be considered as an issue which can be addressed according to a top-down approach: the management of the organisation must be aware of strategic choices and advantages coming from the adoption, standardisation, and implementation of the BIM approach.

The resistance to the digitalization of AECO market

According to the report published by McKinsey Institute (McKinsey Global Institute, 2017) on labour productivity, it is interesting to analyse data on digitalization. Namely, construction sector is following both in term of productivity, and digitalization all the other sectors, especially manufacturing, and agriculture. Literature shows clearly the benefit that BIM can provide to AECO industry (Gurevich and Sacks 2014; Alvarenga 2017; Al Hattab and Hamzeh 2015; Sacks et al. 2010; Rischmoller, Alarcón, and Koskela 2006; Jeong et al. 2016). According to data of Eurostat, and Italian Office for National Statistics, a burden factor is the ratio between the value of investment in engineering the project, and the whole sector value, showing a value of 0.12 in Italy compared to the 0.23 in G7 area. This comparison highlights the low investments in the engineering component of the process compared to the whole industry. This factor shows the low interest of the sector in changing. Focusing on the Italian public sector, an analysis of the design tenders awarded through Most Economically Advantageous Tender (MEAT) processes published in 2017 (OICE 2018), shows an average award with 30 out of 100 points assigned to the economical factor. The public administrations bend the use of the MEAT process to a call for tenders which evaluates just the economic factor. This approach less and less enhances the project engineering, which could provide a remarkable optimization of the final product (Philipp Gerbert 2016) (i.e. in terms of sustainability, performance, cost, etc.). This approach imposes a lot of collateral costs in construction phase (Love et al. 2011), BIM approach could reduce all these variance in performances (Peansupap and Ly 2015). Design firms react to this reluctance to investment reducing the effort on the final product. Firms invest in the project less in order to maintain profitability, due to the huge discount offered during the tender(Baddeley and Chang 2015). This attitude, on behalf of the contracting authorities, outlines an inherent condition of the sector that leads it to analyse just investments in the short term(World Economic Forum 2017).

SAVINGS VERSUS QUALITY IN THE PUBLIC TENDERS

A second consideration concerns the average discount carried out by the firms that won design tenders. According to data published by the Italian association of Italian engineering, architectural and technical economic consulting organizations (OICE 2018) in June, the reduction in terms of price, between the pre and post awarding procedures, is 30.2% for tenders published in 2014 and 40.0% for those published in 2015. The tenders published in 2016 reached an average decrease of 43.0% and

those published in 2017 had an average decrease of 40.9%.
This situation is empathised especially considering the trend of the discount average of design tender. This attitude of offering a service at a high discount provides a decrease in the quality of the service (Aziz and Hafez 2013). Namely, it provokes an approach where there is a reluctance to innovation, in particular of new methodologies, such as BIM (Murphy 2014). According to NBS (Waterhouse and Philp 2016; Waterhouse et al. 2018), the BIM approach is not perceived by all designers, and contractors as an advantage to have a holistic view of the project, and provide a better result, but as a requirement of the clients. Namely, Public Authorities require BIM even if they do not have a clear knowledge of what they can achieve through the application of this methodology. For this reason, the computational approach is possible only if the clients, and the people who really want to apply this methodology are well focus on the objective. Moreover, a deeper knowledge and awareness of potentialities offered by the adoption of the BIM methodology is required to foster the virtuous processes.

THE AIM OF THE RESEARCH

The aim of this paper is to provide a critical review on the measurement of the BIM maturity level of organisations, which adopt or are willing to adopt a BIM approach.
This work sets the foundation to understand the lacks in the state of the art, and the interests of the industry. In order to obtain this result, the research provides a comprehensive critical overview of the scientific theoretical framework starting from the market conditions and behaviours. The investigation is conducted on the historical trend to outline and forecast the trend of AECO interest.
Therefore, a set of bibliometric analysis have been carried out, on a selected sample of references retrieved from Scopus database. The references have been processed through Bibliometrix (Aria & Cuccurullo 2017): an R-tool allowing many bibliometric analyses, clustering and mapping operations. The paper concludes with some insides in the knowledge gaps emerged from the bibliometric and suggest future research trajectories.

METHODOLOGICAL APPROACH

The critical literature review on BIM maturity has been implemented thanks to the use of the R-tool Bibliometrix (Aria and Cuccurullo 2017). Bibliometrix allows to exploit a set of functions able to provide a comprehensive view of a specific sample of references. The sample has been retrieved from Scopus, one of the most acknowledged and reliable databases of scientific literature. For the selection of the sample, the following keywords have been used: BIM OR "Building* Information Modeling" OR "Building* Information Modelling" OR "Building* Information Model" AND Maturity and the Scopus database has been inspected in fields “Article title, Abstract, Keywords”. The research has been carried out in early July 2018. A wider set of references would have been retrieved if all fields in the database had been inspected, though the reliability of data collected would have been reduced remarkably.
Despite the topic of the maturity level is well defined and the boundaries are recognisable, the BIM in literature is defined in different ways according to the regional provenance of the authors and to their own personal choices. Therefore, many definitions of the keywords have been employed: BIM or "Building* Information Modeling" or "Building* Information Modelling" or "Building* Information Model". The research provided as outcome 110 references.
The following step concerned the cleaning of the selected references, since some of them are not associated to an author (authors field is marked as [No author name available]).
This operation gave as output a database of 100 references. On the cleaned database the bibliometric analyses have been carried out and key insights have been identified. Analyses can be divided in five groups.
The first group concerns the general knowledge of the database. These statistics summarise information as the number of total documents retrieved, the number of sources, number of keywords etc (Table 1). The first group is followed by four thematic sets of analyses concerning the chronological distribution of the scientific production, analysis by author, by country and the thematic analyses of the keywords. The discussion of these results allows to spot the gap in literature and main characteristic of the literature production on the measurement of the BIM maturity level in Scopus database.

LITERATURE REVIEW AND ANALYSIS

Table 1 summarises the main statistics performed through the use of Bibliometrix. As can be seen, the number of papers retrieved after the cleaning process is great enough to perform some substantial statistics, despite 100 are not representative of a wide literature production on the BIM maturity from 2008 to 2018. Nevertheless, the high number of citations per documents shows a potential high interest in the topic.

Documents	*100*
Sources (Journals, Books, etc.)	*72*
Keywords Plus (ID)	*679*
Author's Keywords (DE)	*266*
Period	*2008 - 2018*
Average citations per documents	*10.07*
Authors	*257*
Author Appearances	*289*
Authors of single authored documents	*9*
Authors of multi authored documents	*248*
Documents per Author	*0.393*
Authors per Document	*2.54*
Co-Authors per Documents	*2.86*
Collaboration Index	*2.82*

HISTORICAL SERIES

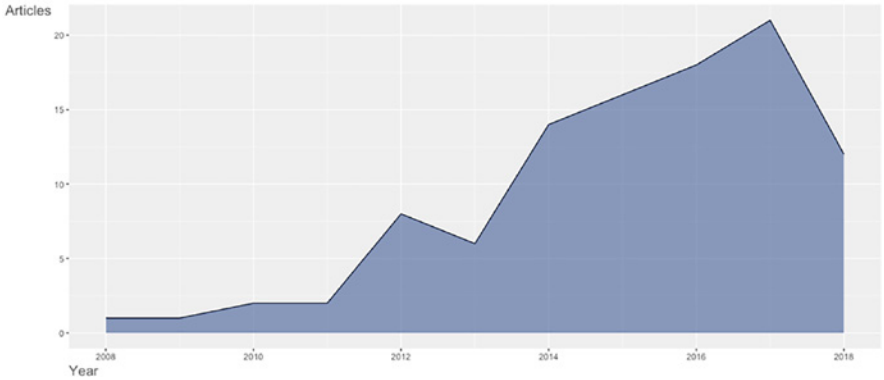
The increasing interest in the topic is also confirmed by the scientific production over the years, with a particular increasing of publications from 2011 to 2017-18 (Figure 1). The adoption of BIM became in these years a hot topic in many countries.

This trend is also confirmed by an increasing number of papers published in conference proceedings in the timespan indicated above. A slower growth is registered from 2008 to 2011, though the annual percentage growth rate is 28.21%. Despite the scientific production shows a rapid increasing from 2011 to 2018, a countertrend dynamic can be observed for what concerns the average total citations per year (Figure 2). In 2009, in this case, a peak of more than 350 total citations is registered.

The number of citations, if taken as a single index, do not express the quality of scientific production. In fact, the interest on the topic started growing since the first highly cited publication (B Succar 2009), since then only a few publications on the topic were made compared to the actual production. From that moment on, the literature production rose exponentially. This trend could explain the decreasing of average citations per year after the 2009.

Analysis by author

Further analyses concerning the authors' productivity have been done. At first a ranking of most productive authors in the timespan 2008-2018 has been developed (Figure 3).



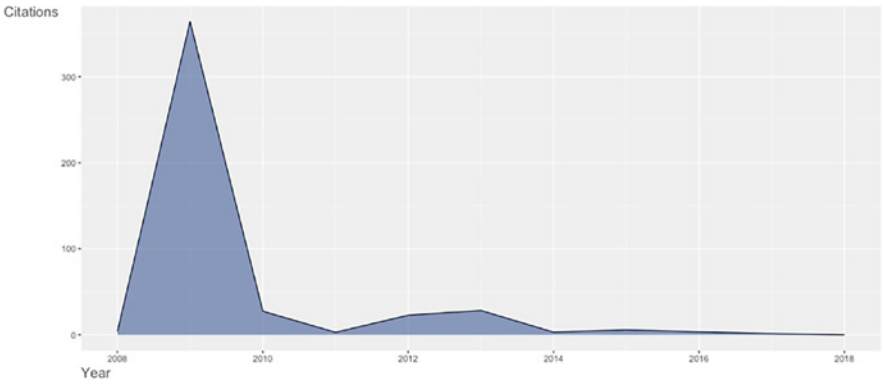


Table 1: Main Information about data.
Figure 1: Annual scientific production over the total sample of references
Figure 2: Average total citations per year

Afterwards, authors have been related among each other, as represented in Figure 4, through the authors' coupling function. Two articles are coupled if at least one cited source appears in the list of references of both articles. A coupling network can be created using the formula:

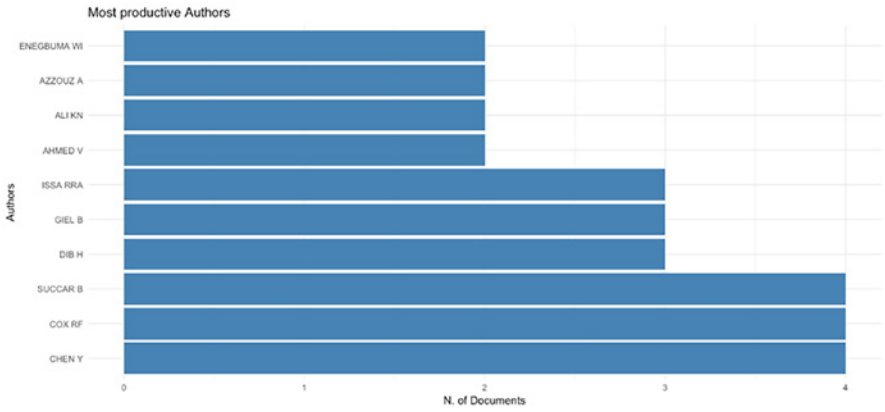
$$B_{cocit} = A \times A'$$

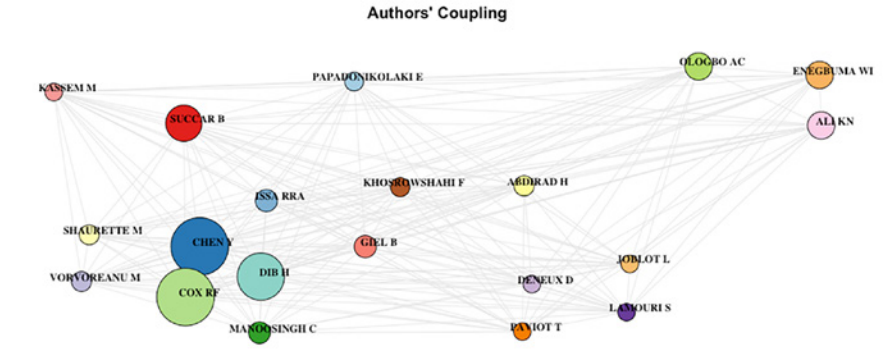
Where A is a Document X Cited reference matrix (Aria and Cuccurullo 2017).
For the analysis carried out in Figure 4, the unit of measure considered is "authors", alternatively can be used other unit of measures as "references", "sources", "countries", "keywords" etc. Figure 4 shows that most productive authors are related among each other.

Analysis by country

For the analysis of the publications, carried out following a similar approach, most productive countries have been identified and represented (Figure 5) as well as the relationship among them (Figure 6). For synthesis reasons, as in previous representations, only the first 10 most productive countries have been plotted (Figure 5), while in Figure 6 all the provenance of authors have been represented. Figure 5 demonstrate that the most part of the documents can be categorised as Single Country Publications (SCP). Arguably, this is due to the scholars' inclination to collaborate in writing articles among their own local research group.
Only Australian publications show a majority of Multiple Country Publications (MCP) against SCP. Figure 6 has been obtained in a similar way compared to Figure 4. In this case the country collaboration is calculated as a relationship where the nodes are the provenance of authors (countries) and the links are co-authorships. This relationship can be obtained thanks to the formula:

$$B_{coll} = A' \times A^{\square}$$





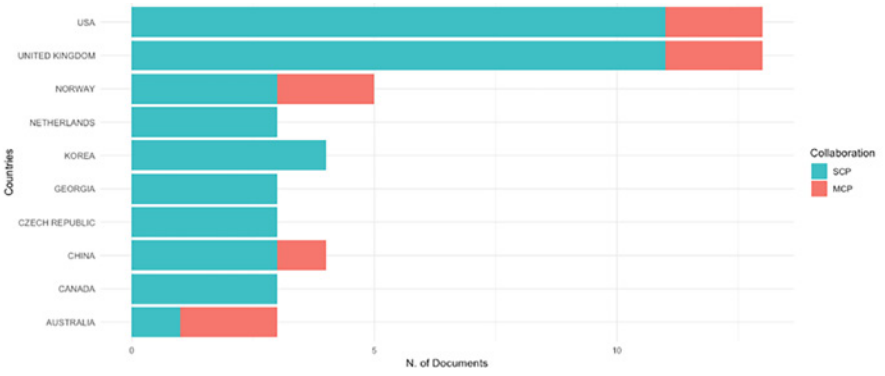


Figure 3: Most productive authors from 2008 to 2018
Figure 4: Authors' couplings among the most frequent 20 authors
Figure 5: Most productive countries: Single country publications (SCP), Multiple Country Publications (MCP)

where A is a Document × Author matrix (Aria and Cuccurullo 2017).

Keywords analysis

A further step concerns a set of analyses on the keywords retrieved from selected articles. These operations have been carried out thanks to a refinement of data. The main issue in this phase concerns the definition of Building Information Modelling.

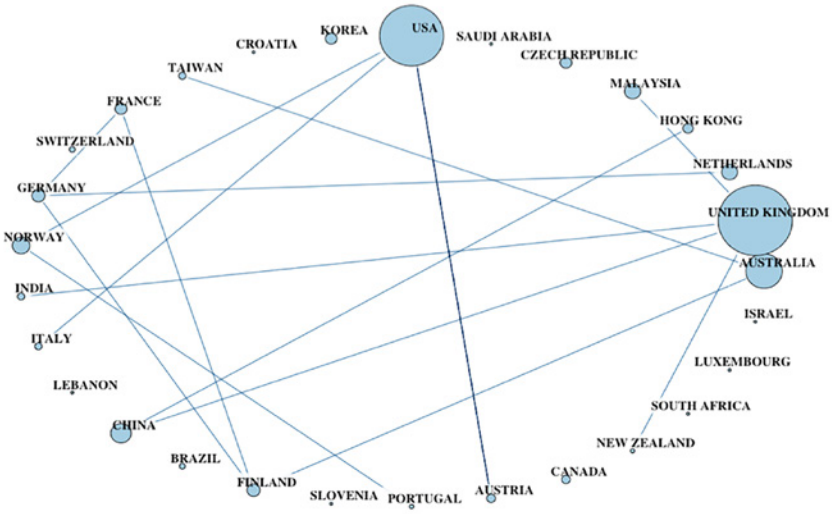
According to the provenance of the authors and to narrative choices, BIM can be named differently: "Building Information Modeling", "Building Information Modelling", "BIM" and combinations of the first two alternatives with the third. In order to gather all terminology with the same meaning, we decided to redefine all the different alternatives as "BIM". Nevertheless, this operation give rise to the loss of the heterogeneity of the definition of the term; though it allows to group all terms with the same semantics in a single entity.

Moreover, a network and clustering analysis have been carried out (as for analyses by author and by country) using the following formula:

$$B_{coc} = A' \times A$$

The R-package employed for the analyses allow to obtain a further semantic representation of the keywords analysed.

Therefore, Figure 9 represents the conceptual structure map obtained through a Multiple Correspondence Analysis (MCA) which allows the data interpretation according to the relative positions of the points representing a specific author keyword and their distributions in the graph. As words are more similar in distribution, the closer they are represented in the map (Aria and Cuccurullo 2017).



Author Keywords (DE)	*Articles*	*Keywords-Plus (ID)*	*Articles*
Bim	61	Bim	43
Maturity	8	Construction Industry	26
Bim Maturity	5	Information Theory	23
Information Technologies	5	Buildings	13
Construction	4	Information Management	13
Construction Industry	4	Construction	9
Implementation	3	Construction Projects	8
Information Systems	3	Project Management	8
Information Technology	3	Information Technology	7
Lean Construction	3	Maturity	7

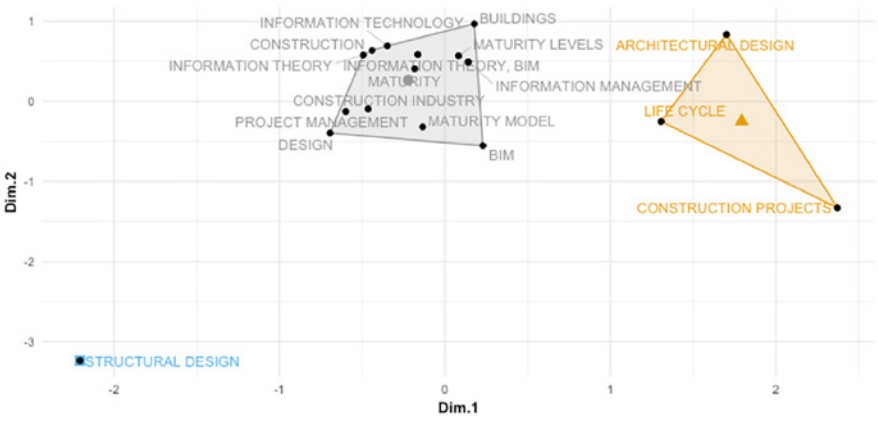


Figure 6: Country collaboration
Table 2: Most frequent keywords. DE are the Author Keywords and ID are the Keywords associated by Scopus (first 10).
Figure 7: Conceptual structure map

DISCUSSION

The analysis of the scientific production on this topic meets the evolution of the Hype cycle (Fenn and Raskino 2008). The increase of the technology applications, supporting the methodology, is reaching its pick of inflated expectations (Waterhouse et al. 2017, 2018). In fact, considering the historical series, the literature production raised a lot from 2009 until the first half of the 2018, especially forecasting the annual scientific production the trend is increasing. This evolution is caused by a demand to the BIM methodology that, most of the time, results in a simple translation of a traditional process into a digitalized one, particularly when alphanumeric information are not relevant compared to graphical ones. Analysing the literature review published at international level, there are a few authors with high number of citations. These authors are tightly linked as well. The most productive countries are connected, but this connection is not structured between the USA and UK, which are, beside all, the most productive ones. The research individuated, in the analysis of the keywords used by authors, that there is a slight alteration of the key topics due to the multiple ways of defining the BIM acronym. Indeed, the authors realigned these words to a common topic and obtain a result characterised by an improved semantic meaning. Therefore, according to Figure 9, two main semantic groups of keywords can be identified, the first regards the process management and the theories and best practices of BIM maturity models' assessment and application, the second is related to life cycle management. These two sets can be intended as the edges of the disciplinary fields which encompass the topic of the BIM maturity. On one hand these two sets represent the most suitable environment for publications, on the other hand, they can be taken as starting point for the development of new theories and practices in other contexts.

CONCLUSIONS

Through the use of Bibliometrix, the authors developed a set of comprehensive bibliometric analyses in a streamlined way analysing and clustering the results. This approach allows to understand a massive amount of data looking into its complexity. Moreover, the research provides a solid method to understand the boundary of the evolution of the literature, despite an extension of the set of articles (e.g. considering other databases as Web of Science, Scholar, etc.) could improve the analyses and provide further meanings. Also, grey literature (reports, whitepapers etc.) has not been considered, despite it could be representative of other dynamics in literature as the adoption of the BIM by institutions and firms and may refine the conceptual structure map. The critical review helps in a better and more accurate definition of the boundaries of the BIM maturity which allows to evaluate organisations' digitalisation potential, enabling the reengineering of business processes. Moreover, through the evaluation of the companies' processes compliance with the BIM approach, a more reliable assessment during the bidding process could be achieved. This trend contributes to the transparent and effective selection of the most virtuous organisations.

Bibliografia
Bibliography

Alvarenga, Thomas Wünsch. 2017. *"BIM and Lean Construction : The Evolution Obstacle in the Brazilian Civil Construction Industry"* 7 (5): 1904–8.

Andone, Ioan I. 2009. *"Measuring the Performance of Corporate Knowledge Management Systems."* Informatica Economică 13 (4): 24–31. https://doi.org/10.1023/A:1006129603978.

Aria, Massimo, and Corrado Cuccurullo. 2017. *"Bibliometrix: An R-Tool for Comprehensive Science Mapping Analysis."* Journal of Informetrics 11 (4). Elsevier: 959–75. https://doi.org/10.1016/J.JOI.2017.08.007.

Aziz, Remon Fayek, and Sherif Mohamed Hafez. 2013. *"Applying Lean Thinking in Construction and Performance Improvement."* Alexandria Engineering Journal. https://doi.org/10.1016/j.aej.2013.04.008.

Baddeley, Michelle, and Chen-Yu Chang. 2015. *"Collaborative Building Information Modelling (BIM): Insights from Behavioural Economics and Incentive Theory."* RICS Researach 2015, no. February: 42. https://doi.org/10.13140/RG.2.1.1194.1605.

British Standard Institution. 2014. PAS 1192-3:2014 *Specification for Information Management for the Operational Phase of Assets Using Building Information Modelling.* British Standards Institution (BSI). Vol. 1. British Standard Institution (BSI). https://doi.org/Published by the British Standard Institute. British Standard Limited. ISSN9780580781360. /BIM TASK GROUP.

BSI. 2018. *"BIM - Building Information Modeling Certification | BSI Group."* British Standards Institution (BSI). 2018.

Chen, Yunfeng, Hazar Dib, and Robert F. Cox. 2014. *"A Measurement Model of Building Information Modelling Maturity."* Construction Innovation: Information, Process, Management 14 (2): 186–209. https://doi.org/10.1108/CI-11-2012-0060.

Fenn, Jackie., and Mark. Raskino. 2008. *"The Hype Cycle."* In Mastering the Hype Cycle : How to Choose the Right Innovation at the Right Time.

Giel, B., and R. R. A. Issa. 2014. *"Framework for Evaluating the BIM Competencies of Building Owners."* Computing in Civil and Building Engineering (2014) 32 (1979): 552–59. https://doi.org/10.1061/9780784413616.069.

Gurevich, Ury, and Rafael Sacks. 2014. *"Examination of the Effects of a KanBIM Production Control System on Subcontractors' Task Selections in Interior Works."* Automation in Construction 37. Elsevier B.V.: 81–87. https://doi.org/10.1016/j.autcon.2013.10.003.

Hattab, Malak Al, and Farook Hamzeh. 2015. *"Using Social Network Theory and Simulation to Compare Traditional versus BIM-Lean Practice for Design Error Management."* Automation in Construction. https://doi.org/10.1016/j.autcon.2015.02.014.

Jeong, Woon Seong, Soowon Chang, Jeong Wook Son, and June Seong Yi. 2016. *"BIM-Integrated Construction Operation Simulation for Just-in-Time Production Management."* Sustainability (Switzerland) 8 (11): 1–25. https://doi.org/10.3390/su8111106.

Kassem, M.; Succar, B.; Dawood, N. 2012. *"A Proposed Approach To Comparing the BIM Maturity of Countries."* Proceedings of the CIB W78 2013: 30th International Conference, Beijing, China, 9-12 October, 9–12.

Love, Peter E. D., David J. Edwards, Sangwon Han, and Yang M. Goh. 2011. *"Design Error Reduction: Toward the Effective Utilization of Building Information Modeling."* Research in Engineering Design 22 (3): 173–87. https://doi.org/10.1007/s00163-011-0105-x.

Murphy, M. E. 2014. *"Implementing Innovation: A Stakeholder Competency-Based Approach for BIM."* Construction Innovation 14 (4): 433–52.

OICE. 2018. *"Osservatorio Mensile Sui Bandi Di Gara Pubblici per Servizi Di Ingegneria e Architettura, Iniziative Di Project Financing e Appalti Di Progettazione e Lavori."*

Pärn, E.A., D.J. Edwards, and M.C.P. Sing. 2017. *"The Building Information Modelling Trajectory in Facilities Management: A Review."* Automation in Construction 75. Elsevier B.V.: 45–55. https://doi.org/10.1016/j.autcon.2016.12.003.

Peansupap, Vachara, and Rothmony Ly. 2015. *"Evaluating the Impact Level of Design Errors in Structural and Other Building Components in Building Construction Projects in Cambodia."* Procedia Engineering 123: 370–78. https://doi.org/10.1016/j.proeng.2015.10.049.

Philipp Gerbert, Santiago Castagnino Christoph Rothballer and Andreas Renz. 2016. *"Shaping the Future of Construction A Breakthrough in Mindset and Technology."* World Economic Forum.

RIBA. 2013. *"RIBA Plan of Work 2013."*

Rischmoller, Leonardo, Luis F. Alarcón, and Lauri Koskela. 2006. *"Improving Value Generation in the Design Process of Industrial Projects Using CAVT."* Journal of Management in Engineering 22 (2): 52–60. https://doi.org/10.1061/(ASCE)0742-597X(2006)22:2(52).

Sacks, Rafael, Lauri Koskela, Bhargav A. Dave, and Robert Owen. 2010. *"Interaction of Lean and Building Information Modeling in Construction."* Journal of Construction Engineering and Management. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000203.

Shin, Jihye, and Jungsik Chai. 2016. *"Development of Key Performance Indicators of BIM Performance Measurement in Design Phase."* Information 19 (10(A)): 4469–74.

Succar, B. 2009. *"BIM Framework: A Research and Delivery Foundation for Industry Stakeholders."* Automation in Construction 18 (3): 357–75. https://doi.org/10.1016/j.autcon.2008.10.003.

Succar, Bilal, Willy Sher, and Anthony Williams. 2013. *"An Integrated Approach to BIM Competency Assessment, Acquisition and Application."* Automation in Construction 35: 174–89. https://doi.org/10.1016/j.autcon.2013.05.016.

Waterhouse, Richard, Mark Bew, Kieran Parkinson, Adrian Malleson, Ilka May, Adam Matthews, Richard Lane, Paul Dodd, and Stephen Hamil. 2017. *"National BIM Report 2017."* NBS. https://doi.org/10.1017/CBO9781107415324.004.

Waterhouse, Richard, Jaimie Johnston, Peter Barker, Adrian Malleson, Dale Sinclair, David Philp, Simon Powell, May Winfield, and Sarah Rock. 2018. *"National BIM Report 2018."* National BIM Library.

Waterhouse, Richard, and David Philp. 2016. *"National BIM Report 2016."* National BIM Library.

https://doi.org/10.1017/CBO9781107415324.004.
World Economic Forum. 2017. *"Shaping the Future of Construction : Insights to Redesign the Industry."*

Yang, Huan, John F.Y. Yeung, Albert P.C. Chan, Y.H. Chiang, and Daniel W.M. Chan. 2010. *"A Critical Review of Performance Measurement in Construction."* Journal of Facilities Management 8 (4): 269–84. https://doi.org/10.1108/14725961011078981.