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SCIENTOMETRIC ANALYSIS OF BUILDING INFORMATION MODELLING (BIM) IN FACILITY MANAGEMENT (FM)

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Abstract
Over the last few years, the emergence of BIM has successfully achieved a paradigm-shift in Architectural-Engineering-Construction and Facility Management (AEC/FM) sectors. This has led to many articles and papers that have been published in those sectors. In order to statistically classify and categorize those publications, Bibliometric and Scientometric Analysis research have been conducted to extract much useful information. However, the existing research sheds a light on the use of BIM in the construction industry in general, focusing on the design and construction phases. Literature review has shown no Bibliometric and Scientometric Analysis of BIM in FM in particular. This research addresses this lack and establishes the first Scientometric Analysis study of BIM in FM. This study employed a quantitative approach using science mapping techniques to examine BIM-FM articles using the Web of Science (WOS) database for the period between (Jun 2003- Oct 2017). The findings guide researchers who are interested in BIM-FM topics by providing visual maps analysis of that area in a simple, easy, and readable way. Finally, knowledge gaps in this domain can be identified more easily with those findings of Scientometric Analysis.

Key Words: Scientometric Analysis, FM, BIM, Construction Industry, Web of Science.

1. Introduction

Building Information Modelling (BIM), which is also known as Virtual Prototyping Technology, has rapidly changed the world of the construction industry. According to Azhar et al. (2012), BIM is both a

process and a technology. The technology component helps project members to visualize the construction activities of the whole project in a simulated environment to recognize any potential design, construction, and operational conflict while the process part enables a high level of cooperation and promotes the integration of the functions among stakeholders on the construction projects. Despite this growing interest in AECO by implementing BIM, however, analysis on the status of BIM is scarce, specifically in the FM sector. Researchers have yet to statistcally analyze the quality and amount of research that has been achieved in this field in a comprehensive way. This limitation has led to the need for the current research. A Scientometric Analysis has been used in this study using the WOS database to find the research fields with the highest research output, the countries in charge of most BIM-FM research, the journals that publish most research, top citations, and the most famous authors.

2. FM Concept

Until now, there has been no clear and specific definition for FM. That is why there are many definitions that define FM from different perspectives. The International Facility Management Association (IFMA) defined FM as " A Profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process, and technology (IFMA, 2014). Facility Management has Also been described as "a hybrid management discipline that combines people, property and process management expertise to provide vital services in support of the organization"(Shiem-Shin Then, 1999).
Further, Schneider et al. (2006) defined FM as “operating a group of assets over the whole technical lifecycle guaranteeing a suitable return and ensuring defined service and security standards”. Atkin and Brooks (2009) cited Barrett and Baldry (2003), who defined facilities management as “An integrated approach to maintaining, improving and adapting the buildings of an organization in order to create an environment that strongly supports the primary objectives of that organization."
According to Ikediashi (2014), most of these definitions relate to the fact that FM is about integrating process, people and place as illustrated in Figure (1):

Figure (1) Facility Management components (Ikediashi, 2014)

In fact, the operation and maintenance phase in building projects is considered the longest phase of the building lifecycle. It shares about 60-85% of the total life-cycle cost, whereas both the design and construction phases account for 5-10% (Lewis et al., 2010). In the same context, according to (Teicholz, 2004), less than 15% of the total cost of ownership is spent on design and construction while the remaining percent spent on the operation and maintenance phase. Consequently, many researchers have recommended

optimizing this sector by adopting more advanced processes and technologies. The following sector discusess BIM adoption and its potential benefits to all project phases including the FM.

3. Building Information Modelling Definitions

There are many definitions of BIM-based on different perspectives. For example, the National Building Information Modelling Standards (NBIMS) committee of USA defines BIM as; “a digital representation of physical and functional characteristics of a facility (NBIMS, 2007). Further, Succar (2010) defined BIM as "a set of interacting policies, processes, and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle".

4. Research methods for the current study

Science Mapping represents how fields, specialties, disciplines, and individual authors or documents are correlated to one another (Small, 1999). It has proven benefits in dealing with comprehensive bodies of literature visually and statistically. According to Cobo et al. (2011), Science Mapping has certain features in depicting systematic patterns in a massive amount of literature and bibliographical units.
Scientometric Analysis, Bibliometric Analysis, and Informatics Analysis can be categorized under Science mapping studies. Scientometric analysis has been adopted in this study due to its comprehensive capabilities and freely available software such as VOSviewer. Zhao (2017) in his study *“A scientometric review of global BIM research: Analysis and visualization”* employed a scientometric method for analysing global BIM research between 2005 and 2016. He conducted co-citation analysis, co-author analysis, and co-word analysis. A Total of 614 dataset records from the Web of Science database was analyzed. This study captured related BIM literature in the construction industry in general. Following are some of his scientometric analysis findings in term of a co-word network and a journal co-citation network illustrated in Figure (2).

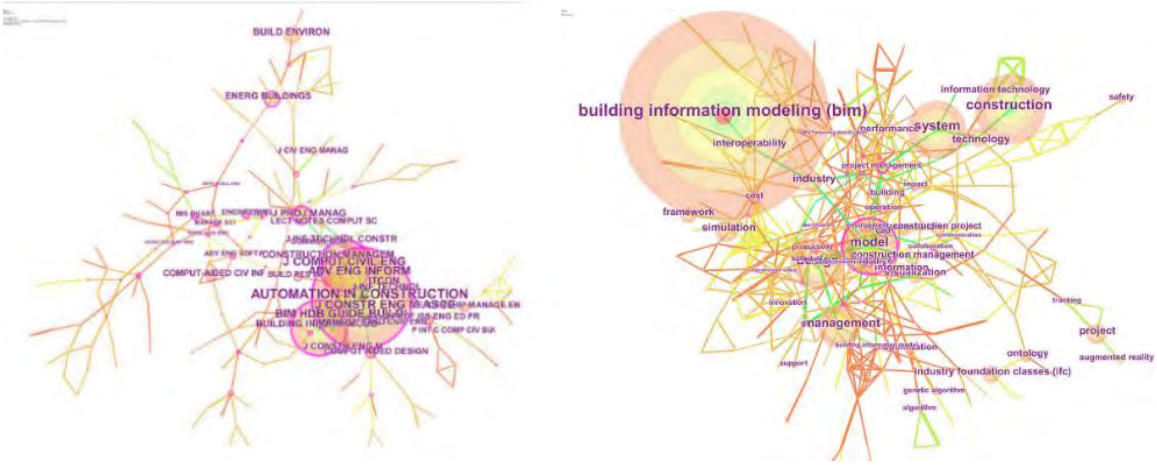

Figure (2); source (Zhao, 2017)

In the same aspect, He et al. (2017) study “Mapping the managerial areas of Building Information Modelling (BIM) using scientometric analysis” dealt with similar aspects.
They employed abstract and keyword term analysis of 126 related articles published between 2007 and 2015. Their findings showed the transformation of BIM from an individual approach to a wide-ranging organizational strategy. The study provided a new way of managing BIM projects by providing an accurate representation and analysis of previous efforts.

Previous literature has argued the importance of BIM in the whole project lifecycle. However, none of them studied BIM in FM in particular. Accordingly, this study aims to bridge this gap. It considered the first Scientometric analysis for BIM in FM. Science mapping has been adopted as the main methodology due to its descriptive and diagnostic merits.

1. Selection of tools

Scientometric analysis has different available tools such as VOSviewer, BibExcel, CiteSpace, CoPalRed, Sci2, VantagePoint and Gephi (Cobo et al., 2011). VOSviewer was used in this study, as it is simple, freely available and has a wide range of features to achieve the Scientometric networks effectively.

2. Data acquisition

VOSviewer allows users to download bibliographic records directly from the Web of Science (WOS), Scopus, Google Scholar and PubMed. From these options, WOS was selected for its reliable searching features and the availability of most sources. The search keywords in WOS was "Facility Management" OR "Facilities Management" OR "Asset Management" OR "Assets Management", to retrieve the bibliometric data associated with published studies on FM in general. The search had timeframe limitation with the date range set between 2003 and 2017. Searching attempts using these keywords were conducted on the title of published studies only. This produced more than 1300 documents. After that, the results were refined based on limiting the search by applying another keyword, specifically "BIM", to filter only articles published in the area of BIM-FM which is the objective of this study. On 1st Oct 2017, 41 articles were identified, for which all bibliometric data were extracted and downloaded from WOS, forming the database used in this study.

3. Scientometric techniques

A scientometric analysis was adopted for this study in two stages. The first stage included the creation of networks through analyzing the co-occurrence of keywords, and co-citation analysis (references, sources, authors), and co-authorship analysis (author, organization, countries). In the second stage, the generated maps in stage one were analyzed to distill useful information. Price and Gürsey (1975) stated that these measures showed "the conceptual, intellectual, or social evolution of the research field, discovering patterns, trends, seasonality, and outliers".

5. Findings and Discussions

The following sections present the research findings. It is worth mentioning that VOSviewer Software shows all *letters* in **lowercase** and this can be a bit confusing for readers, as they are not used to deal with this status. For instance, BIM will be shown as *bim,* and so on.

1. Timeline trends of BIM-FM research

As mentioned, the search criteria have been set to include any year between 2003- Oct. and 2017. Figure (3) shows the number of publications in each year. For instance, in the year 2015, the number of publications is the highest with 12. In general, the figures show an increase in the number of publication in BIM-FM during the time with a minor fluctuation in the last two years. No, research between was between 2003 and 2009.

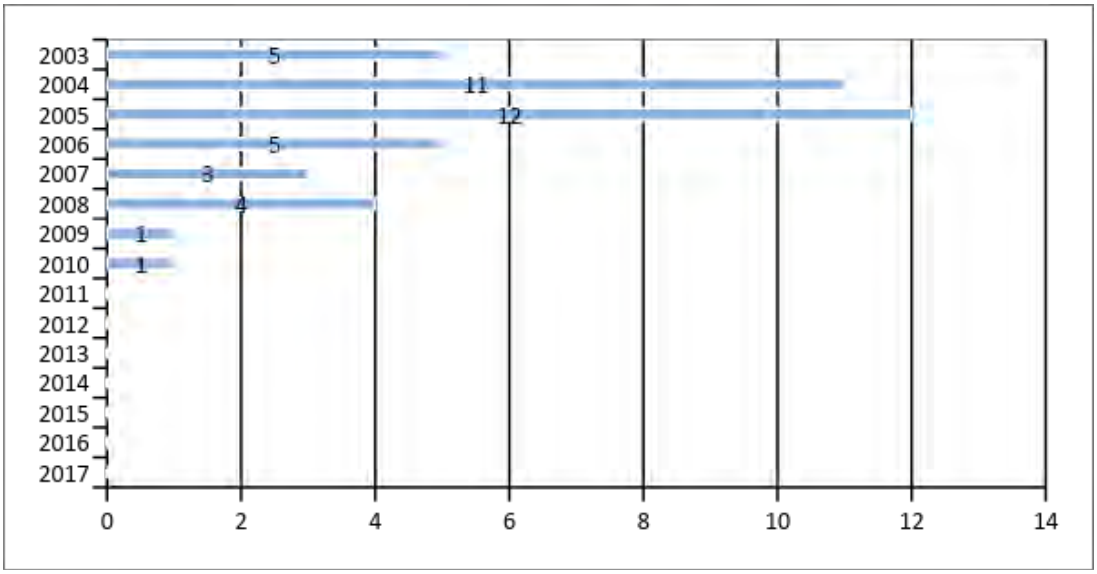

Figure (3) Publication year

It is worth noting that the first study on BIM-FM within the dataset was entitled 'Active3D: Semantic and Multimedia Merging for Facility Management' by Vanlande, Renaud; Cruz, Christophe and Nicolle, Christophe (2010), published in the 6th International Conference on Web Information Systems and Technologies in Valencia, SPAIN on 2010. The poverty of research in the BIM-FM area can be seen clearly.

2. Research areas (co-occurrence of keywords analysis)

A preliminary network was created comprised of 16 nodes and 55 links, illustrating the main areas of research identified in BIM-FM research. However, this network has included some similarities among the nodes. In order to remove similarities, another analysis has been conducted to extract the most weighted nodes, resulting in 16 nodes and 26 links as shown in the following Figure (4).

Calculating network measures can be done by extracting certain information from the network itself through VOSviewer software. Degree centrality represents measuring the centrality of a node in a network using the number of connections, which indicates the effect of a node on other nodes.

According to Cobo et al. (2011), " a modified version of degree centrality, weighted degree in the network, takes into account the average mean of the sum of the weights of the links on all the nodes in the graph". In addition, he argues, "Involving the weight of links into calculating degrees will reveal the focal points or the level of involvement of nodes in a given network".

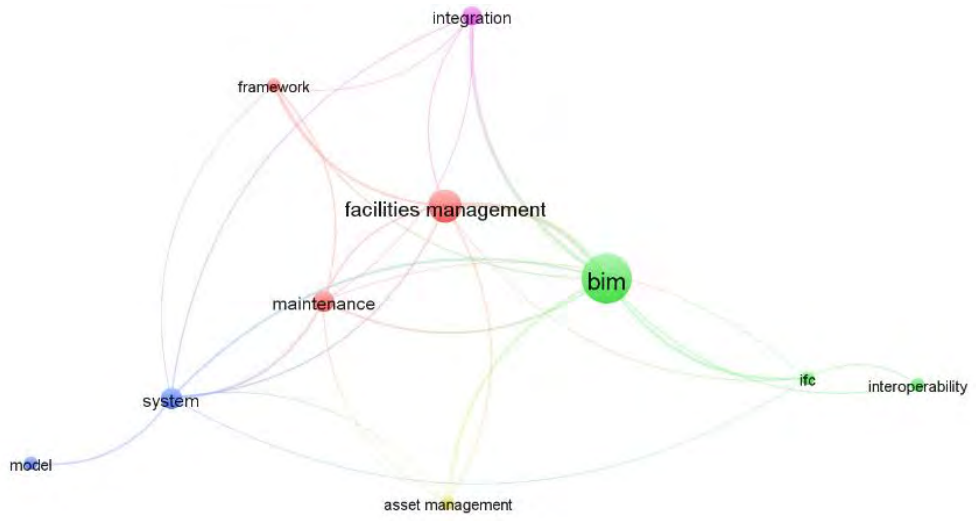

Figure (4) Main research areas after removing the similarities

Table (3) shows the results of analysis of the networks throughout VOSviewer output. The main research areas have been ranked according to the relative importance as shown in Table (3).

Table (3) Main research areas (co-occurrence of keywords analysis)

Research Area (Brief name/ Full Name)	Occurrences	Degree Centrality /Links	Weighted Degree Centrality/	Relative Importance
bim / BIM	20	8	16.00	1
facilities management / Facilities Management	11	7	10.00	2
system / System	6	8	6.00	3
maintenance / Maintenance	6	7	5.00	4
integration / Integration	5	5	5.00	5
framework / Framework	3	5	3.00	6
ifc/ IFC	3	5	3.00	6
asset management / Asset Management	3	4	3.00	7
Interoperability / Interoperability	3	2	1.00	8
model / Model	3	1	1.00	9

Several findings can be extracted from Table (3) and Figure (4) which, reflect gaps and issues within BIM-FM literature as follows:

1. There is a special focus on research areas such as ***bim***, ***facilities management***, and ***system***.
2. As an unexpected finding, there are less important research areas that focus on ***ifc*** and ***interoperability***. This reflects a lack of literature and attention by the researcher to these significant areas that are located in the bottom of the ranking. Hence, more research is required for Industry Foundation Classes and interoperability topics, which are considered the core of the connection between BIM and FM.
3. As illustrated in Figure(4), ***bim***, ***facilities management***, ***maintenance*** , ***framework***, ***integration, ifc, asset management*** *and* ***interoperability*** are linked together as one largest cluster in the network. These areas are positioned as central areas of research in BIM-FM and this might be attributed to the importance of BIM literature and the potential benefits of BIM in FM. In addition, Figure (4) shows the lack of research studies that integrate BIM and FM in general, which leads to a serious gap within the existing literature on FM. This might lead to the following conclusion: the integration of FM processes with BIM implementation requirements is still considered a barrier to more extensive implementation.

3. Top research outlets (direct citation analysis of outlets)

Direct citation analysis of outlets is very important for the interested researcher. Dealing with highly cited sources can be considered one of the best ways to reach accurate and reliable information in the certain domain. Accordingly, main cited sources in BIM-FM field and their relatedness are visualized through VOSviewer after the exportation of the related database from WOS. Figure (5) shows the main cited sources in BIM-FM field and their relatedness.

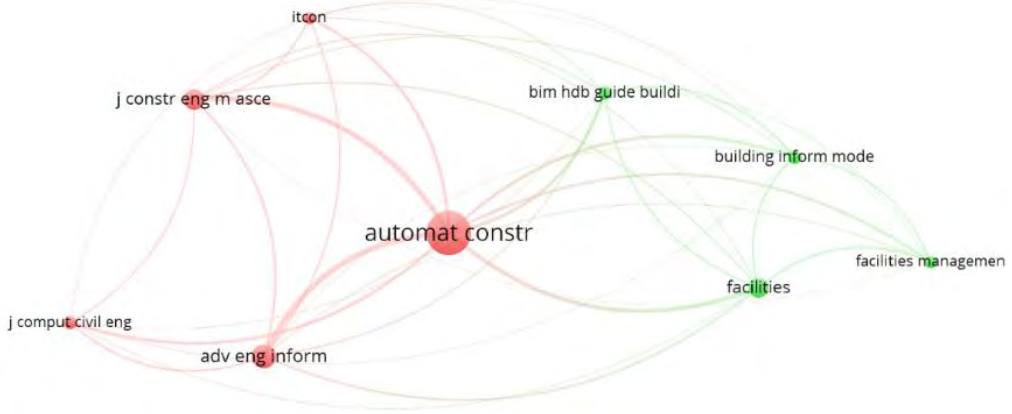

Figure (5), Network of prominent sources for publications in BIM-FM

Calculating network measures can be done by extracting certain information from the network itself illustrated in Figure (5), using the VOSviewer software as shown in Table(4):

Table (4), Top BIM-FM sources outlets

Source (Brief name/ Full Name)	Citation	Degree Centrality /Links	Weighted Degree Centrality/	Relative Importance
automat constr / Automation in Construction	139	8	70.67	1
adv eng inform / Advanced Engineering Informatics	40	8	28.72	2
j constr eng m asce /Journal of Construction Engineering and Management ASCE	30	8	26.06	3
facilities / Facilities	28	8	21.68	4
bim hdb guide buildi / BIM Guide	14	8	12.82	5
building inform mode / BIM Journal	13	8	12.12	6
j comput civil eng / Journal of Computing in Civil Engineering	12	7	10.48	7
itcon / Journal of Information Technology in Construction	11	8	10.23	8
facilities management / Journal of Facilities Management	11	7	8.75	9

Clearly, the Journal of Automation in Construction ranked in the first order with the highest number of citations and can be considered the most dominant source in BIM-FM research.

As shown in the table above, the flow of information starts from Automation in Construction with a Total Link Strength of 70.67, which is well above any other sources in the aforementioned table. In addition, the analysis shows that Journal of Construction Engineering and Management ASCE ranked 2nd with Total Link Strength of 28.72, while the Journal of Facilities ranked 3rd with a Total Link Strength of 26.06. Further, the strongest collaboration is between Automation in Construction and Advanced Engineering Informatics with link strength of 18.17. The second strongest collaboration is between Automation in Construction and the Journal of Construction Engineering and Management ASCE with A Link strength of 16.71.

4. Co-authorship analysis

- Authors

A Collaboration network analysis of authors in BIM-FM research has been conducted as shown in Figure (6). The results of the analysis showed that only Dawood, N., Kassem.M and Kang, T have two Authoring documents in the BIM-FM area. The other authors have one each. The top three cited authors were Becerik-Gerber, B., Calis, G. and Jazizadeh, F., with 80 citations each. The correlation among the authors is represented by the clusters shown below in Figure (6). Dawood, N., and Kassem.M has the strongest collaboration in BIM-FM research authorship.

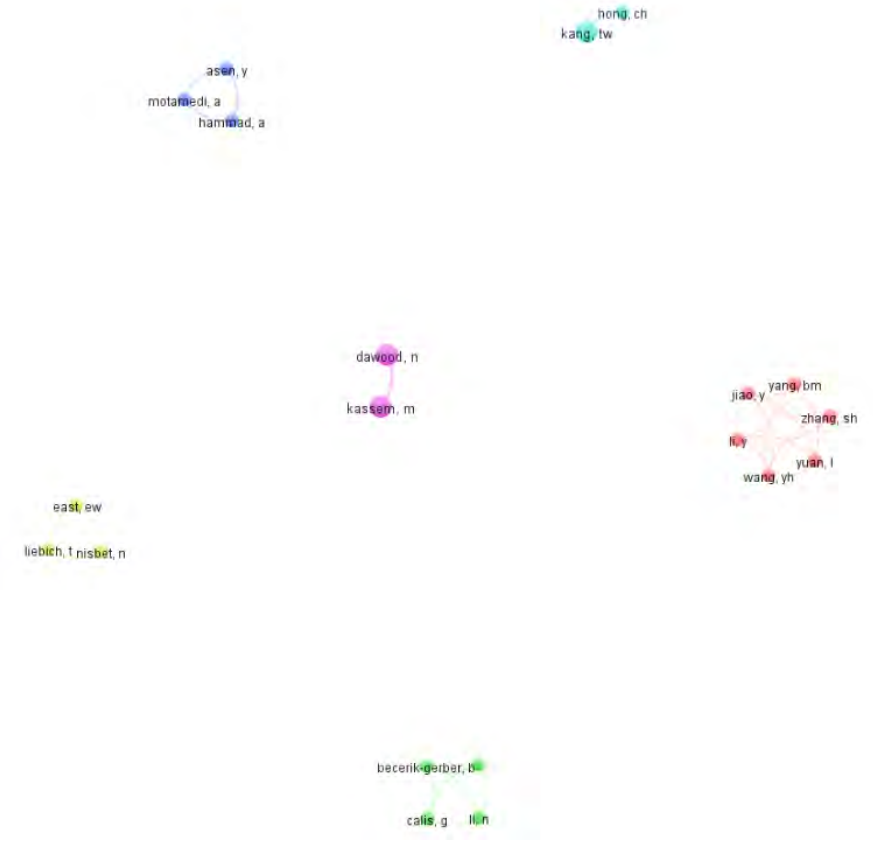

Figure (6) Collaboration network of authors in BIM-FM research

- Organizations

A Collaboration network analysis of organizations was created. According to Cobo et al. (2011), cited (Ding, 2011), this kind of organizations analysis "*benefits the field, particularly in terms of providing input into research partnership policy making* ".

As noted, some organizations in the network had no collaboration links among other organizations of the network such as Concordia University and the University of California. This needs to be noticed by these organizations in order to adjust their research policies, as they are located far from the dominant network of collaboration in BIM-FM.

Figure (7) Collaboration network of organizations in BIM-FM research

As shown in Figure (7), the red cluster consists of a number of organizations. This cluster can be zoomed up to get more information, as illustrated in the following Figure (8):

Figure (8) Cluster Zoomed

- Countries

To shed light on the most influential countries and to visualize the collaboration among them, a network analysis was conducted using VOSviewer. The number of documents and number of citations for each country were utilized as criteria to identify the degree of influence within this network, as shown in Figure (9). Accordingly, nodes sizes' are based on the degree of influence of each country within the aforementioned criteria.

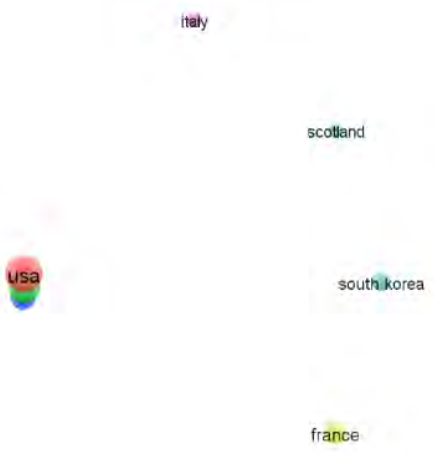

Figure (9) Collaboration network of countries in BIM-FM research

As noted, some countries in the network had no collaboration links among other countries of the network such as Scotland, South Korea, Italy, and France. This needs to be noticed by these countries in order to adjust their research policies, as they are located far from the dominant network of collaboration in BIM-FM. As shown in the previous figure, the red dominated USA cluster consists of a number of countries. This cluster can be zoomed up to get more information about those other countries as illustrated in the following Figure (10):

Figure (10) Cluster Zoomed

Obviously, the USA ranked at the top with nine documents published in BIM-FM, while England ranked as second with seven documents. China gets third position with five documents. All the others get the bottom of the list with less than five documents each according to the circle size as shown in the figure. Smaller circles mean fewer documents and citations.

Conclusion

The current study focusses on research in the field of BIM-FM between 2003 to 2017. This area of study has attracted interest in the last few years, producing a number of studies and literature reviews. However, this research represents the first Scientometric Analysis of BIM-FM in the domain, in which 41 top-ranked documents were systematically examined using a Science Mapping method through VOSviewer software. The findings of this study show what has been achieved in BIM-FM topics, the potential gaps that need to be explored in the future, and the correlation among those findings. In addition, they help researchers understand which authors and journals to consider when dealing with BIM-FM topics.

Although this research has achieved a contribution in this area, there are some limitations. Firstly, the results of the analysis depended on the database that has been extracted from WOS, and therefore it carries any of WOS's limitations in terms of how much it covers of the published studies. Another limitation is that the study is based on an exploration of "what" questions, rather than "how" and "why". Those limitations represent hot topics to be addressed in future research. Finally, it is clear that more research in the area of BIM-FM is needed. The lack of BIM studies in the FM phase put it behind the other phases such as design and construction. Hence, there is a real need to increase research effort in the BIM-FM area.

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