# BUILDING INFORMATION MODELLING (BIM) FOR CONSTRUCTION SUPPLY CHAIN: A SCIENTOMETRIC ANALYSIS

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***ABSTRACT:*** *The automation and innovation have impacted Architecture, Engineering and Construction Industry, particularly when transitioning from traditional or conventional methods of construction to modular or Industrialized Building System (IBS). Thus, to ameliorate the processes surrounding built environment, researchers have been interested in the BIM's integration into construction industry. To ensure BIM's adoption and integration into construction supply chain, supply chain's management and procurement, we need to have an extensive comprehensive research base regarding global outlook of BIM's relation with supply chain. The purpose of this study is to identify global scientific research patterns and trends related to BIM's role in supply chain, by performing scientometric analysis. The scientometric analysis will help us analyze the work being done in this field and whether a significant literature exists that supports or helps in adoption of this idea. Most of the already existing research on BIM is performed on various other aspects of BIM like infrastructure sustainability, green buildings, design, framework, management of facilities and other BIM related managerial aspects. Thus, it is highly imperative to systematize and analyze the existing global scientific literature research to identify the global trends and frontiers on current BIM's relation with construction supply chain. Not only this would pave the way towards identification of current relevant literature but would also lay down the foundations for digital transformation in construction.*

***KEYWORDS:*** *Building information modelling (BIM), construction, digitalisation, procurement, scientometric, supply chain management*

## 1. INTRODUCTION

The concept of integration of services is not new, over the past several decades this concept has been applied in various industries. However, integration in construction supply chain is still lagging as opposed to other sectors. There are several reasons behind it, including complexities in construction processes owing to the fragmented procurement processes, multiple project stakeholders and several other challenges. The instability and fragmentation occur when supply chains are temporarily created or setup for each individual one-off construction projects. (Papadonikolaki, et al., 2015). Meanwhile, Building Information Modelling (BIM) is a kind of technology that can collect, create, impart, and share accurate information among different stakeholders of construction supply chain. BIM is equipped and able to tackle operational, organizational, and other technical complexities in the construction supply chain. BIM not only enhances visualisation, design coordination and construction sequencing but also aids in construction processes through its various built-in features. These features include clash detection visualisation, scheduling and controlling capabilities. (Rathnasinghe & Kulatunga, 2019).

However, BIM's impact on challenges, faced by construction supply chain (CSC) at organisational level, is not thoroughly researched. The integration of BIM and CSC are still quite theoretical and conceptual, lagging in substantiated research. Only after extensive research and observing BIM's impact on the construction supply chain and its management, we can be fully assured of its contributions to the CSC. These gaps and voids in research thus need to be further explored. Thus, the following literature review will focus on the BIM's role and contributions so far to the CSC and its management. The literature review will also shed light on the underlying problems and background in the supply chain processes (Le et al., 2022). The research proposal has immense significance in terms of contributing to the theoretical knowledge related to the problem statement. The author believes that the

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need for this proposal is highly imperative as it further compliments the existing knowledge in context of BIM's multi-dimensional relations to construction supply chain at large and procurement.

The idea of construction supply chain has been around for a while now but still the constraints and challenges exist in construction supply chain owing to its uniqueness in each individual project. That means, every project being delivered is different in some ways from other projects rendering it difficult for integration to happen. This further tells that the construction supply chain is not strongly tightened interrelated process but a loose system which despite being important to global economy, is somewhat inefficient and untrustworthy. Thus, the research gap exists when it comes to addressing the issues (Papadonikolaki, et al., 2015). Moreover, if we narrow down the supply chain of Architecture, Engineering and Construction industry to mere procurement, again we'll find many unanswered problems. Integrating BIM with project delivery contract methods should ideally give rise to some new contract types specific to BIM usage but that hasn't been done yet and is a largely unexplored area.

## 2. LITERATURE REVIEW

The late twentieth century saw an evolution in logistics and supply chain management. This evolution had a direct impact and affected the construction supply chain and its management, due to its importance and magnitude. Since then, several problems and shortcomings in the construction supply chain management have been identified by the researchers involved in this field. Many problems were identified such as incoherence, lack of integration and inefficiency of the procurement or supply chain process (Khalfan et. al., 2015). A report on commercial construction industry highlighted that the mega projects take almost 20 percent more time to get completed than their scheduled completion date (McKinsey & Company, 2015). The report proclaimed that the construction industry still lagged in adopting innovative technologies when it came to information sharing about projects.

BIM can play a pivotal role in data collection, integration, and provision. The goal is to obtain or gather data which is accurate enough that it can be channeled to other projects to aid or assist in the building processes including Construction Supply Chain. This includes the gathered data that can link the mega scale projects and can be modelled using Building Information Modelling systems (BIM), and then exploring further ways to link these information and models to the construction supply chain (Wang et. al, 2017). To help everyone involved to have a better understanding and clarity of the overall project, the data that is already gathered in the BIM system can help in driving labour and material requirements hence assisting in a construction supply chain management (Wang et. al, 2017).

The approaches related to BIM and supply chain management revolve around supply chain integration with BIM to enhance and improve construction processes. Hence, it is believed that BIM can act as a catalyst for supply chain management adoption in construction (Wang et. al, 2017). The supply chain's integration is linked with both stakeholders and processes involved who are expected to coordinate and collaborate across various SC levels with long lasting trustworthy relationship. The researchers observed that supply chain stakeholders early risk management/allocation, involvement, participation, information technology investment and long-term procurement could further strengthen SC integration. (Getuli, et al., 2016). BIM can also help to enhance performances of mechanical, engineering, and plumbing aspects of the project. This can be done only with the stakeholder's cooperation, that means, early joint planning, joint decision making and operations. Construction supply chain partnership can be helped by Building Information Modelling through data-information sharing, trust building and enduring long-term commitment (Le et al., 2022).

During the early days of BIM development and while it was undergoing further technological advancement, one of the associated areas of interest was supply chain procurement and legal aspect of BIM. During early 21st century the BIM advocates observed that the two of the major hinderances in potential data sharing through BIM's platform; are legal constraints and varying frameworks of contracts. These two were seen to be obstacles in putting BIM in practice. Some of the key issues that surfaced include roles and responsibilities of individual stake holders being affected by use of BIM, liability and copyright issues associated with the BIM models, sharing of BIM's data and model ownership, and stakeholders focusing more on their individual components of the project rather than giving due consideration to the bigger picture of process (Holzer, 2015).

## 3. METHODOLOGY

This study aims to identify research patterns and trends about the global BIM research and how it is related to construction supply chain, construction supply chain management, and procurement in AEC industry. The research question focusses on how BIM is related to or being utilized for construction supply chain, supply chain management at large and procurement. The research method revolves around devising a framework of research design that defines and outlines the criteria for scientific databases, rules of search, defining data curtain, retrieving, processing, and analyzing of preliminary and final datasets. Therefore, this study employs the scientometric method, that is the sub-field of bibliometric analysis that is concerned with analysis and measuring of scientific literature. Bibliometric analysis can be defined as quantitative and statistical analysis of research data like journal publications, articles, and their patterns to identify the impact of those publications as well as to identify further research trends or patterns (Iftikhar et. al., 2019). The concept of bibliometric review was said to be introduced by Pritchard in 1969, who argued that this form of analysis had the potential to provide comprehensive insights into the research literature. (Pritchard, 1969). Fig. 1 outlines what would the scientometric analysis and mapping process would entail at each stage of the implementation. It illustrates what would be included at each step of this research project.

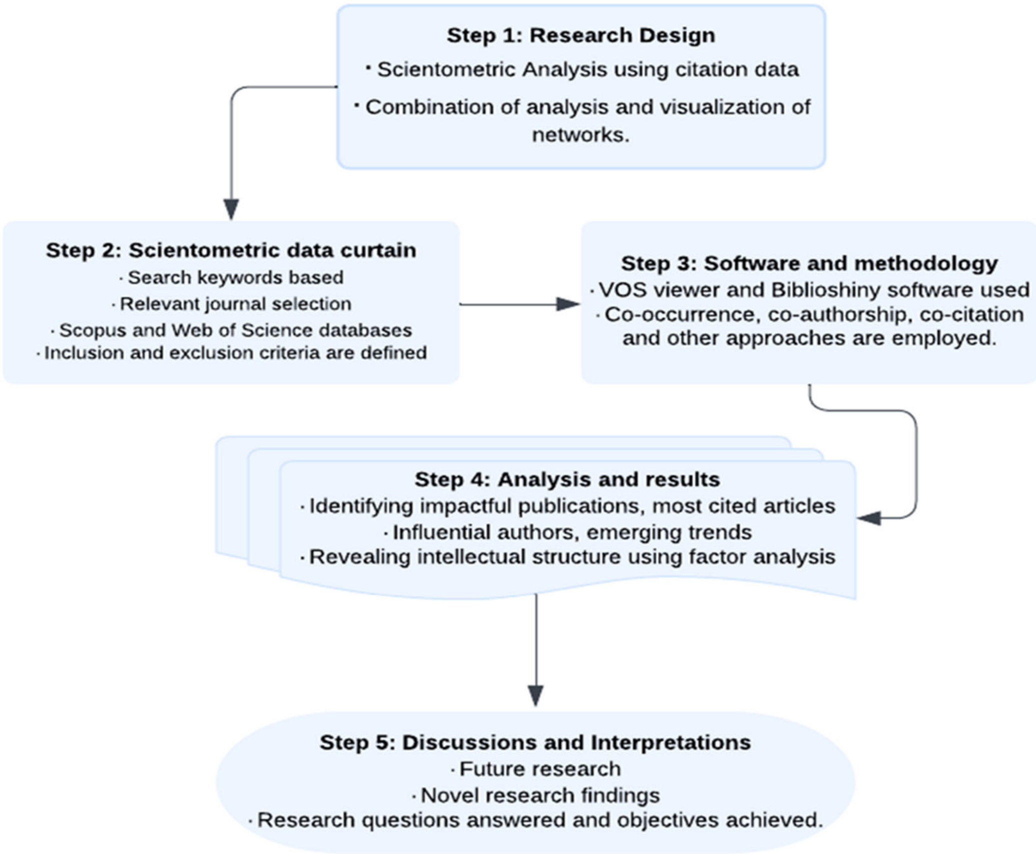


Fig. 1: Scientometric analysis and research mapping process

## 4. RESULTS AND DISCUSSION

Scientometric analysis was analyzed using several software as discussed and explained in research methods. The first analysis will revolve around outlining analytics related to Co-Authorship (type of analysis) and Authors (unit of analysis). The visualization results of 176 scientific documents retrieved from 'Web of Science' database, which were fed to VOS viewer. Hence, a visualization of co-authorship network was developed to analyze authors that had accounted for scientific research related to Building Information Modelling's role in procurement of construction projects, amelioration of construction supply chain and playing part in supply chain's management.

## 4.1 Visualisation Using VOSviewer

The VOS viewer was set to ignore publications which had large number of authors (maximum level set at 25 authors). The author's threshold with minimum number of documents was set at 2, whereas the minimum number of citations of an author were set to 1 citation. After applying the analytical functions, out of 464 authors, 46 authors met the threshold. These 46 authors had accounted for the most documents and citations in this respective research area. The table below outlines the data regarding these authors. The analysis reflects the most productive authors who had made significant research contributions to Building Information Modelling's role in AEC industry, especially, the areas related to supply chain management and procurement. As shown in Table 1, the 3 most productive researchers were found to be Chong, Heap-yih (7 documents,146 citations), Wang, Xiangyu (6 documents,142 citations) and Love, Peter (4 documents,124 citations). This was followed by authors Grilo, Antonio (3 documents, 95 citations), Jardim-goncalves, Ricardo (3 documents,95 citations) and Lee, cen-ying (3 documents, 94 documents).

Table 1: Publications and citations per author

| No | Author | Documents | Citations |
|---|---|---|---|
| 1 | chong, heap-yih | 7 | 146 |
| 2 | wang, xiangyu | 6 | 142 |
| 3 | love, peter e. d. | 4 | 124 |
| 4 | grilo, antonio | 3 | 95 |
| 5 | jardim-goncalves, ricardo | 3 | 95 |
| 6 | lee, cen-ying | 3 | 94 |
| 7 | sing, chun-pong | 2 | 75 |
| 8 | matthews, jane | 2 | 66 |
| 9 | hosseini, m. reza | 3 | 46 |
| 10 | eadie, robert | 2 | 33 |
| 11 | edirisinghe, ruwini | 2 | 32 |
| 12 | skibniewski, miroslaw j. | 2 | 31 |
| 13 | mahdjoubi, lamine | 2 | 27 |
| 14 | rowlinson, steve | 2 | 27 |
| 15 | holzer, dominik | 2 | 26 |
| 16 | vass, susanna | 2 | 21 |
| 17 | zhou, jingyang | 2 | 21 |
| 18 | cheng, jack c. p. | 3 | 19 |
| 19 | das, moumita | 2 | 19 |
| 20 | ciribini, angelo l. c. | 2 | 15 |
| 21 | edwards, david john | 2 | 15 |
| 22 | mahamadu, abdul-majeed | 2 | 15 |
| 23 | scaysbrook, stephen | 2 | 15 |
| 24 | meng, xianhai | 2 | 14 |
| 25 | joseph-akwara, esther | 2 | 12 |
| 26 | law, kincho h. | 2 | 12 |
| 27 | gaterell, mark | 2 | 10 |
| 28 | lee, cen ying | 2 | 8 |
| 29 | tezel, algan | 3 | 7 |
| 30 | jin, ruoyu | 2 | 7 |
| 31 | li, haijiang | 3 | 6 |
| 32 | lindblad, hannes | 3 | 6 |
| 33 | ren, guoqian | 3 | 6 |
| 34 | abrishami, sepehr | 2 | 6 |
| 35 | abu-samra, soliman | 2 | 6 |
| 36 | chaabane, amin | 2 | 6 |

| | | | |
|---|---|---|---|
| 37 | phuoc luong le | 2 | 6 |
| 38 | thien-my dao | 2 | 6 |
| 39 | mejlaender-larsen, oystein | 3 | 5 |
| 40 | fai, s. | 2 | 5 |
| 41 | sacks, rafael | 2 | 4 |
| 42 | ariffin, hamizah liyana tajul | 2 | 2 |
| 43 | mustaffa, nur emma | 2 | 2 |
| 44 | papadonikolaki, eleni | 2 | 2 |
| 45 | he, dandan | 2 | 1 |
| 46 | li, zhongfu | 2 | 1 |

## 4.2 Network Visualisation

The network visualisation is shown in Figure 2 Network Visualization Co-authorship, that illustrates the total link strength of 60 with 32 links and 25 clusters. The co-authorship link strength refers to the collaboration strength of the authors. The nodes represent the author whereas thickness or size of nodes represent the documents. The edges or links refer to co-authorship collaboration between the authors, the thicker the lines, the stronger the collaborations. As mentioned previously, there are a total of 25 clusters, but we will analyse only top 3 clusters as they are indicative of strong collaborative research authorship between them. Fig. 2 shows the biggest cluster, cluster 1, is denoted by red colour and comprises of 5 top productive others; Chong, heap-yih being the most productive of the lot with total link strength of 12, 7 documents and 4 links (1 link with each other author in the cluster 1). Following Chong is Wang, Xiangyu with 3 links with Chong, Lee and Cin-Yeng. Wang had co-authored total of 6 documents with a total link strength of 10.

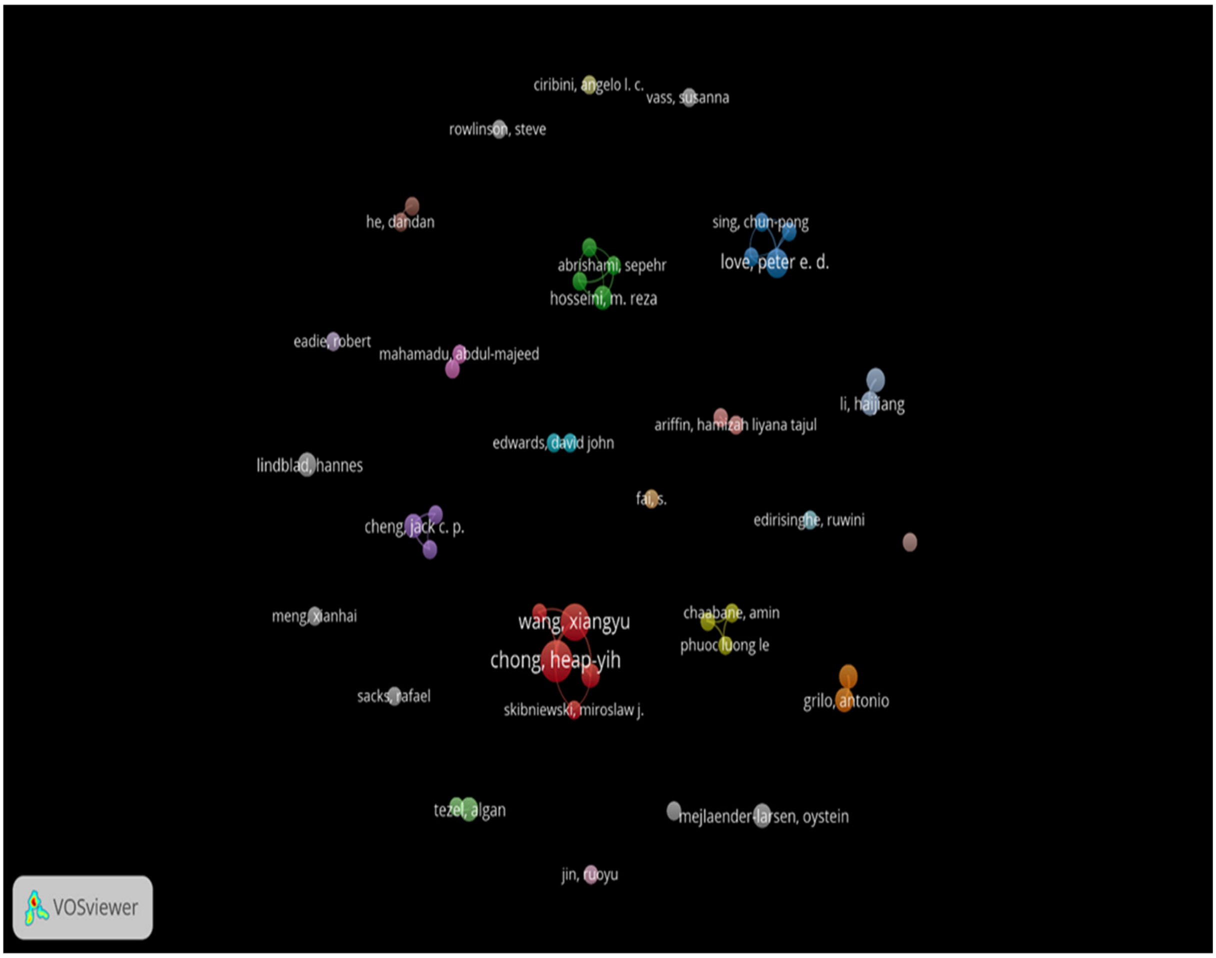


Fig. 2: Network visualization co-authorship

The cluster 2 consisted of 4 authors, 2 of these authors, Abrishami. and Abu-samra had strong collaboration links between them in terms of co-authorship of publications as both had published 2 documents but their total link strength was 5 each and had links with each other as well as 2 other authors in the cluster. The other author Husseini had the same total link strength of 5, however, he had authored 3 publications only with each of the fellow authors in its cluster. However, in blue colored cluster 3, author Love, Peter's node and edges were indicative of very strong collaborative effort with rest of the authors in the cluster. Love had total of 4 documents with total link strength of 6 and 4 documents thus depicting significant co-authorship whereas rest of the 3 authors namely Sing, Chun-pong, Matthews, Jane and Zhou, Jingyang had each collaborated 2 documents and had link strength of 4.

## 4.3 Co-occurrence keyword analysis

Over the past couple of years there has been increased involvement and information about Building Information Modelling in every aspect of Built environment and AEC Industry at large. This has led to evolvement of numerous themes and topics in research related to BIM's involvement in the construction industry. In this section we'll be discussing analytics surrounding co-occurring keywords in our results' dataset. Keywords play an important role by serving as reference point, aiding the contents' description and conceptual understanding in research literature. (Akinlolu, et al., 2020). Hence to perform co-occurring analysis of keywords, data from Web of Science was imported into VOS viewer. After feeding the said data into VOS viewer, the threshold for minimum occurrence of a keyword was set to 5 keywords. Hence, out of 781 keywords, 34 met the threshold. Table 2 tabulated the most recurring or co-occurring keywords in decreasing order of occurrence.

Table 2: Keyword occurrences

| No | Keyword | Occurences | Total link strength |
|---|---|---|---|
| 1 | bim | 57 | 150 |
| 2 | building information modelling | 33 | 100 |
| 3 | management | 29 | 108 |
| 4 | procurement | 28 | 80 |
| 5 | construction | 24 | 66 |
| 6 | performance | 23 | 89 |
| 7 | design | 22 | 86 |
| 8 | framework | 22 | 90 |
| 9 | implementation | 21 | 94 |
| 10 | model | 21 | 84 |
| 11 | collaboration | 17 | 53 |
| 12 | building information modelling | 15 | 29 |
| 13 | building information modelling (bim) | 15 | 36 |
| 14 | building information modelling (bim) | 15 | 37 |
| 15 | information | 15 | 51 |
| 16 | innovation | 13 | 65 |
| 17 | project management | 13 | 52 |
| 18 | system | 13 | 53 |
| 19 | projects | 12 | 57 |
| 20 | industry | 10 | 57 |
| 21 | technology | 9 | 42 |
| 22 | sustainability | 8 | 27 |
| 23 | adoption | 7 | 34 |
| 24 | construction industry | 7 | 27 |
| 25 | construction supply chain | 7 | 14 |
| 26 | information modelling bim | 7 | 39 |
| 27 | construction projects | 6 | 27 |
| 28 | interoperability | 6 | 20 |
| 29 | systems | 6 | 25 |
| 30 | infrastructure | 5 | 14 |

| | | | |
|---|---|---|---|
| 31 | ipd | 5 | 14 |
| 32 | lean construction | 5 | 19 |
| 33 | prefabrication | 5 | 18 |
| 34 | simulation | 5 | 27 |

The degree of co-occurrence is determined by similarity of keywords as well as their proximity to one another. The 34 top productive and repetitive keywords from 176 research publications produced total of 4 clusters as shown in the figure below. The biggest cluster of all was cluster 1 with 13 keywords and is denoted by red color. The intertwining of links and proximity of nodes reinforces the point that the various aspects of construction industry and built environment are directly proportional and related to Building Information Modelling.

### 4.3.1 Cluster 1

The first and strongest cluster had various keywords with strong and highly imperative correlation and literature's scientific structure thus helping in anticipating trends and establishing firm research base for future. As shown in Fig. 3, the first cluster had several keywords like building information model/modelling, project management, construction industry, lean construction, prefabrication, sustainability, and interoperability.

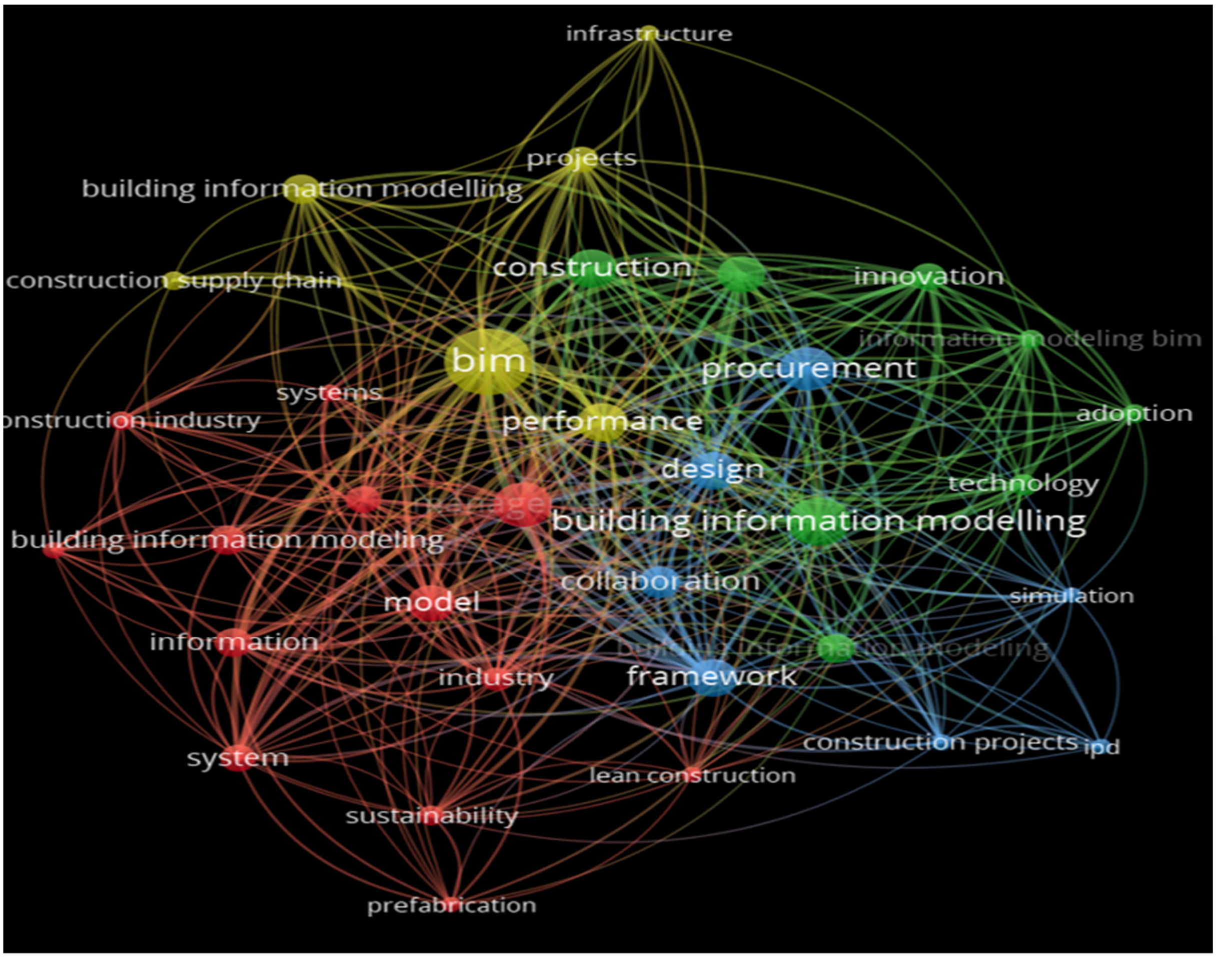


Fig. 3: Keyword co-occurrence network visualization

This cluster's keywords had most relatedness thus depicting that these areas of research in relation to BIM were most comprehensive. We'll also look at the overlay visualization of these clusters as well in the figure below. The cluster 1 had research conducted on its keywords from 2015 to 2017.38 average year. The keywords like 'lean construction' and 'prefabrication' were the latest with average year 2017 moreover both keywords had 5 occurrences each. This is indicative of the fact that although BIM's involvement with sustainability and industry is couple of years old, but still witch each passing year we are seeing innovative concepts being researched about in BIM's context.

#### 4.3.2 Cluster 2

This cluster had some interesting terminologies like technology, innovation, implementation, and adoption along with the other repetitive keywords like "BIM", "construction" etc. As opposed to the cluster 1, this cluster had more recent research trends averaging between year 2017 to 2018. The keywords like "innovation" had strong links with "BIM adoption" and "construction collaboration". Thus, it is pertinent to note that there has been increased inclusion of innovation and adoption in hot areas of global subject literature around BIM and the strong edges in "overlay visualization" are indicative of increased research trends.

#### 4.3.3 Cluster 3

The third cluster as shown in Fig. 4 revolved around keywords like "collaboration" (17 occurrences, 22 links and avg. pub. Year 2016.4), "construction projects" (6 occurrences, 16 links, avg. pub. year 2017.5), "design" (22 occurrences, 27 links, average year of publication 2016.80), "framework" (22 occurrences, 28 links and average year 2017), "procurement" (28 occurrences, 26 links, average pub. year 2016.19) whereas '"IPD or integrated project delivery" and "simulation" had 5 occurrences each with 14 and 19 links, and avg. pub. years. 2015.25 and 2016.5 respectively. Keywords like "framework", "procurement" and "simulation" were seen to be the most recent ones in this cluster, however, one common thing among all clusters is the strong link strength and proximity with the words 'BIM'. Based on centrality of nodes and strength of links, an inference could be made that these keywords play an important role in diversifying the BIM's research literature.

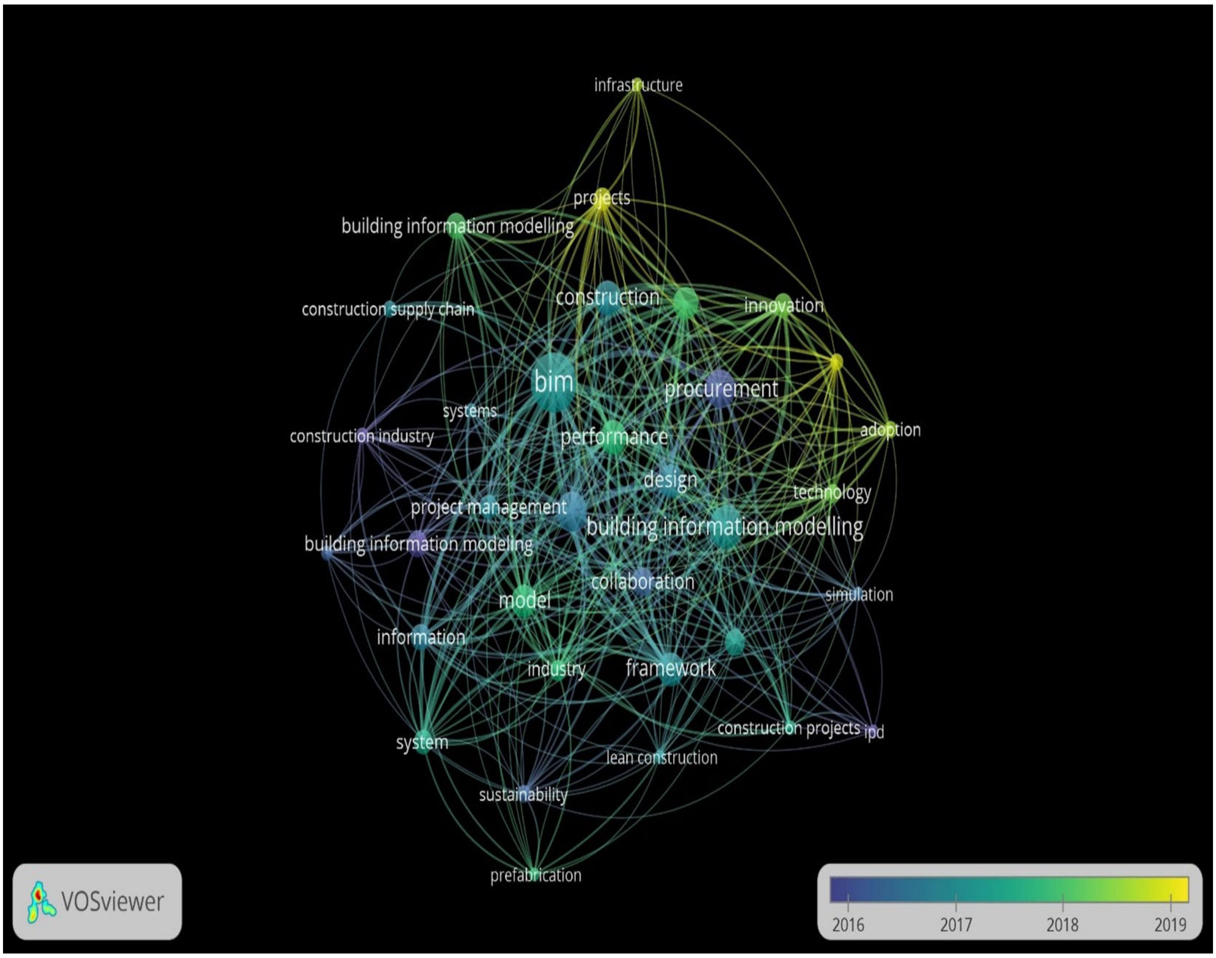


Fig. 4: Keyword cluster overlay visualization

### 4.3.4 Cluster 4

The last cluster had total of 6 keywords that included BIM, building information modelling, construction supply chain, infrastructure, performance, and projects. The green and yellow nodes (representing year 2017 and 2018) of these keywords reflect the latest research developments and collaboration in these respective fields. If we look at the item density visualization in Figure 5, item density visualization it tells us about the keywords density at a particular point and is represented by a color. The colors vary from blue to green to yellow. The closer the proximity of the keyword to the large number of other keywords and the larger the weight of those items, the more the color of that point is yellow. Hence, if we analyze the density visualization, it is self-evident that keyword "BIM" has bright yellow color and has proximity and relatedness with keywords like "performance", "procurement", "management", "design", "collaboration" and "construction". Since the word "BIM or Building information modelling" has been repetitive in each cluster thus not all same keywords have same density. For example, item density visualization in Figure. 5 illustrates "construction supply chain" in proximity with 'building information modelling' in top left corner thus reiterating the connection between the two.

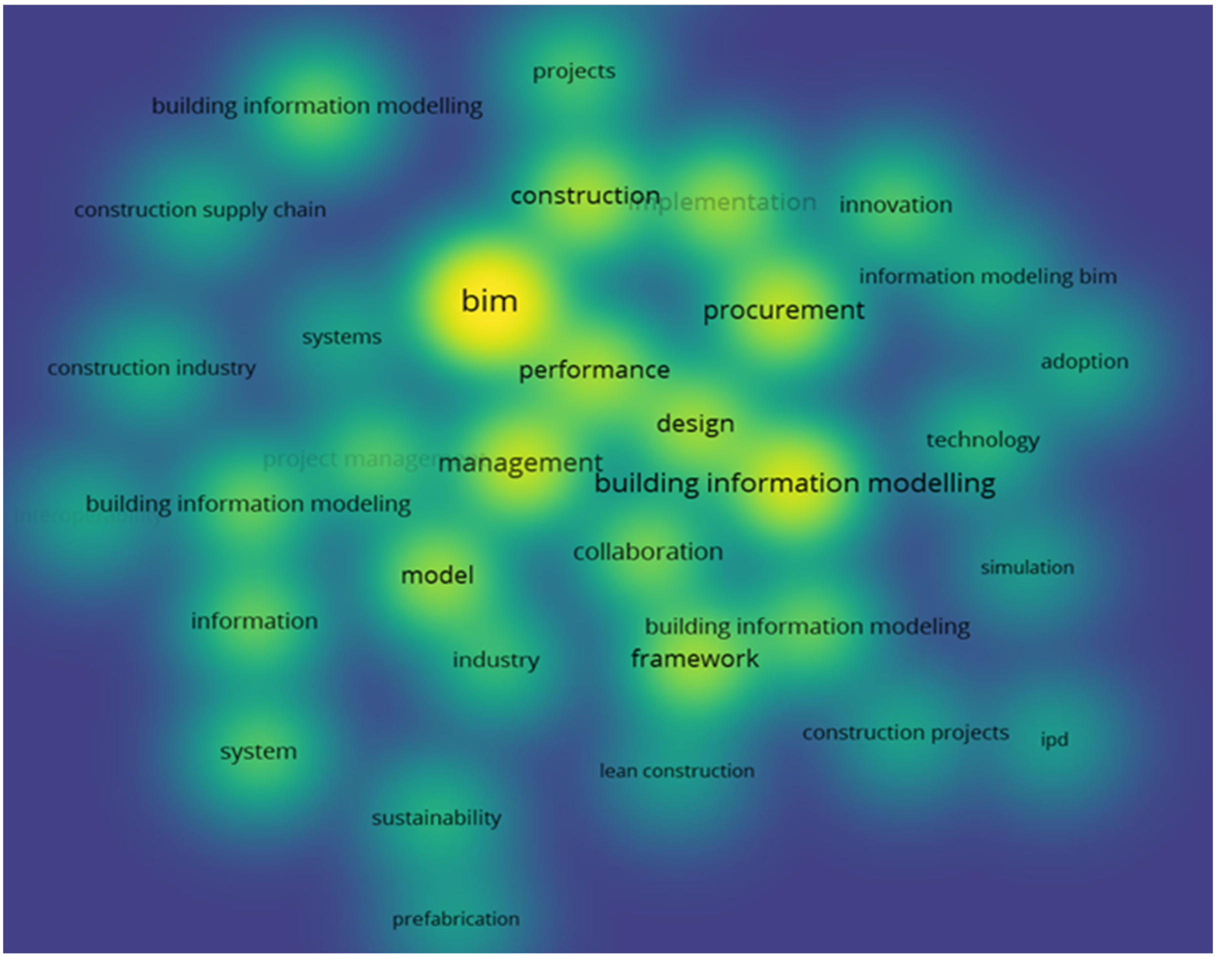


Fig. 5: Item density visualization

## 4.4 Collaboration network of countries

Consequently, the dataset produced comprehensive scientific mapping for us to analyze. The collaboration network of countries was pulled out and examined, as shown in Figure 7: Collaboration Network of Countries. The figure illustrates the biggest collaboration node being represented by UK having the strongest cross collaboration link with Australia. UK was seen to have a collaboration network with Australia, Luxembourg, Canada, South Africa, Ireland, China, Hong Kong, and Ireland. Whereas, after removing the isolated nodes several collaboration trios were identified. These trios included USA, China, and Israel. Moreover, to have a clear picture of social structure, a country collaboration map was prepared as shown in Fig. 6, that showed intercontinental collaboration on BIM usage in supply chain and construction industry.

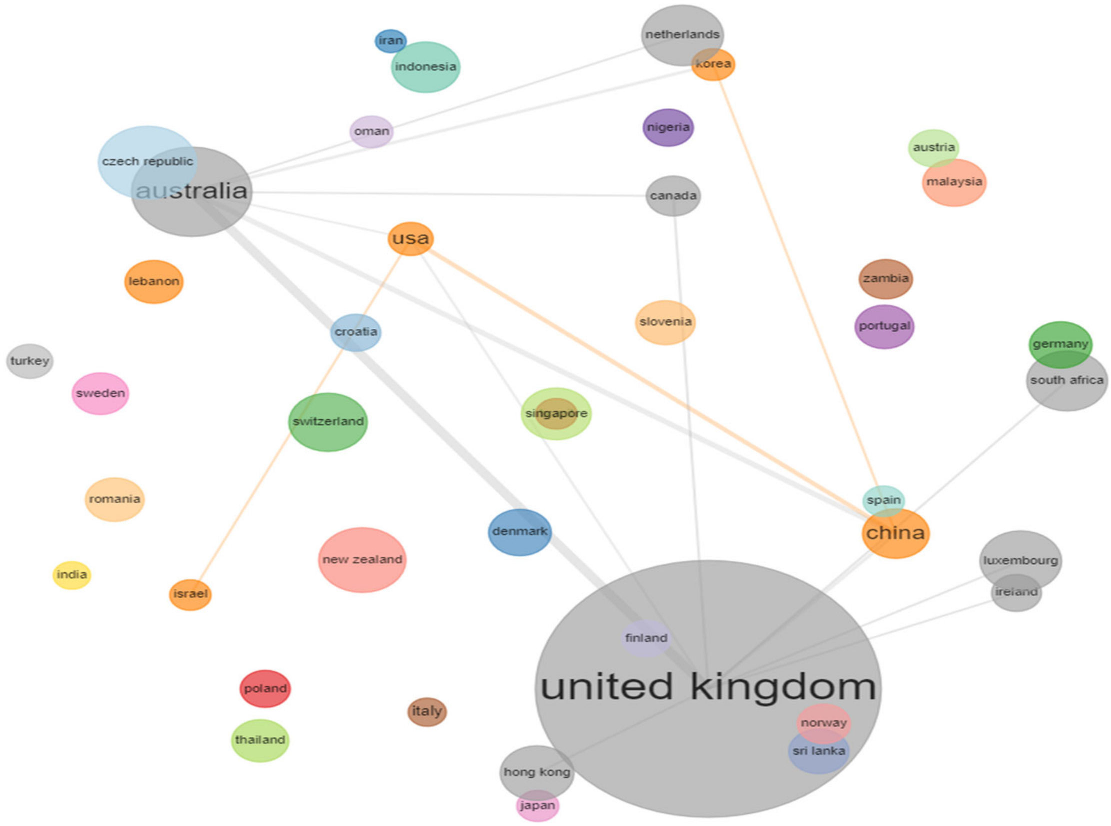


Fig. 6: Collaboration network of countries

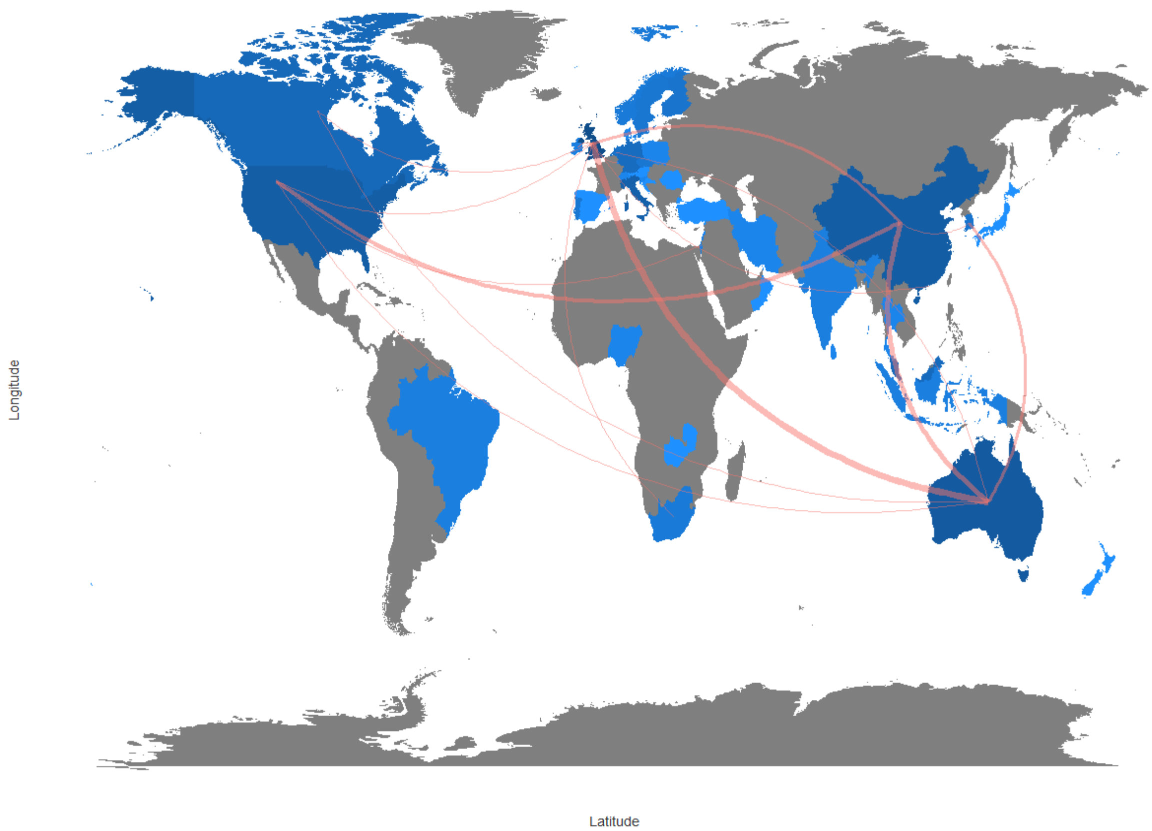


Fig. 7: Countries of collaboration

Fig. 7 shows there are three shades of blue clearly seen in the map. The darkest shade of blue seen between China, Australia, UK, and USA represent most productive contribution, whereas the thicker pink linkages depict the strength of collaboration. The lighter shade of blue comes second in production of scientific literature on BIM, construction supply chain and procurement.

## 4.5 Conclusions

The Web of Science database helped discover 176 relevant publications which were imported into VOS viewer and as per research objectives the co-authorship analysis were performed initially. The co-occurrence authorship analysis depicted various patterns. The strongest partnership cluster between authors comprised of 5 authors denoted by red color and had thickest edges thus had biggest impact. We can see the biggest cluster of 5 authors although had the strongest links and collaboration but still the average publication years were between 2014-2015. This explains that the only strong collaborations on BIM's relation with construction supply chain were done couple of years ago and are not recent. Whereas the yellow-colored clusters which are not only small in link strength and only consist of 2 or 3 authors, but also have less collaboration and occur isolated in the cluster, are the most recent ones. There is no robust or exponential growth in scientific research literature when it comes to BIM adoption into supply chain management, logistic and/or procurement. Thus, the future BIM research must be driven and molded towards these areas.

The second scientometric analysis was Co-occurrence of keyword analysis, which consisted of 4 keyword clusters, with Cluster 1 being biggest containing 13 keywords, followed by 8,7 and 6 keywords respectively. It was pertinent to observe that the word "Construction Supply Chain" only appeared once in a cluster, with 7 occurrences in cluster 4, with average publication year of 2017. The most recent or latest keyword cluster was seen to be 'adoption' (denoted by yellow) with strong links to other keywords like "technology", "information", "infrastructure", "management", "design", "framework" etc. Thus, a clear pattern can be observed here that the already existing research regarding BIM's adoption into infrastructure management and other fields is being explored but at the same time key area like supply chain is somewhat lagging. On the other hand, 280 publications from Scopus were exported to Biblioshiny for scientometric mapping purposes and collaboration network between the countries was analyzed. This was done to examine the global research patterns which would further help in identifying the parts of the world where lack of collaboration is significant. Hence paving the way for future researchers, belonging from those countries, to comprehensively explore into otherwise ignored BIM's associated aspects, particularly in construction supply chain.

The innovative contribution of this study is pertinent with the integration of BIM and CSC are still quite theoretical and conceptual, lagging in substantiated research. Only after extensive research and observing BIM's impact on the construction supply chain and its management, its contributions are clear to the CSC. Study gaps in previous research highlighted BIM's role on multi-dimensional aspects to supply chain. This study is highly imperative as it compliments the existing knowledge in context of BIM's at large and particularly in relation to construction procurement. Current challenge includes the creation of a consistent information flow that hasn't addressed BIM cooperation process among all construction stakeholders. Therefore, this study contributes towards addressing these practical issues by outlining a framework for the integration of BIM and CSC. An example of successful application of the relationship is when BIM acts as an information integrator while CSC is a secure environment for collaboration in real-world construction project. The BIM-based CSC multi-model integration framework is therefore crucial in identifying, analyzing, and making full use of the organisational, operational, and technical complexity. Additional real-world cases can be used to calibrate the model in the future to establish successful application of the relationship between BIM and the construction supply chain.

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