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A Global Taxonomic Review and Analysis of the Development of BIM Research between 2006 and 2017

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Abstract

Purpose

This paper aims to review the status of development of Building Information Modelling (BIM), its trends and themes across the six continents of the world.

Design/methodology/approach

A total of 914 journal articles sought from the search engine of Web of Science (WOS) based on the country/region option of the WOS to group them into continents. A best-fit approach was then applied in selecting the suitable software programs for the scientometric analysis and comparisons and deductions were made.

Findings

The findings revealed that there are differences in the development of BIM across the six continents of the world. South America and Africa are lagging in the BIM research, Australia and Asia are growing, whilst Europe and North America are ahead. Also, there exist differences in the research themes and trends in these continents as against the single view presented in extant studies.

Originality

This study introduced a new approach to carry out a comparative and taxonomic review and has provided both academic researchers and industrial practitioners with a clear status of development of BIM research and the trend across the six continents of the world.

Introduction

Building Information Modelling (BIM) has been changing the way that the Architectural, Engineering, Construction, and Operation (AECO) firms function over the last decade (Azhar, 2011). Many benefits have been reaped from the adoption of BIM in the construction industry ranging from productivity increase, reduction in design errors, clash detection, saves time & cost, effective collaboration, abundant lifecycle data. An increase in the level of awareness and adoption in the industry has thus been recorded.

Consequently, there is an increase in the study of Building Information Modelling over the years with extant literature focusing on adoption(Gu and London, 2010, Arayici et al., 2011, Gray et al., 2013, Aibinu and Venkatesh, 2014, Poirier et al., 2015), challenges & benefits(Azhar, 2011, Sun et al., 2015, Hong et al., 2016, Hosseini et al., 2016, Liao and Teo, 2018, Puolitaival and Forsythe, 2016), application(Becerik-Gerber et al., 2012, Karan et al., 2016, Karan and Irizarry, 2015, Irizarry et al., 2013, Jalaei and Jrade, 2015, Kim et al., 2016, Kim and Teizer, 2014, Kim et al., 2015), and implementation framework (Succar, 2009, Singh et al., 2011, Porwal and Hewage, 2013, Wang et al., 2013, Love et al., 2014, Rahmani Asl et al., 2015). The scope of the extant literature is country specific, with few comparing countries in their approach.

Various researchers have attempted the review of these studies in the past using either manual review (Ghaffarianhoseini et al., 2017, Gu and London, 2010, Wong and Yang, 2010), bibliometric analysis (Yalcinkaya and Singh, 2015) , latent semantic analysis, or scientometric analysis (Oraee et al., 2017). Volk et al. (2014) presented a literature review using 180 articles of Building Information Modelling for existing buildings and concluded that challenges arise for implementation of BIM in existing buildings in the area of process automation. Li et al. (2017) mapped the domains of knowledge in BIM using bibliometric approach and key research areas that are germane to the development of BIM knowledge were identified. Similarly, Santos et al. (2017) and Olawumi et al. (2017) adopted a bibliometric approach. Santos et al. (2017) reviewed BIM literature from 2005 to 2015 using 381 articles and emerging fields were also identified in a similar way to Olawumi et al. (2017). A critical review of the nexus between BIM and green buildings was presented by Lu et al. (2017) and a “Green BIM triangle” taxonomy was proposed. Latent Semantic Analysis (LSA) was adopted by Yalcinkaya and Singh (2015) for BIM literature from 2004 to 2014 and 12 principal research areas were sought. A scientometric analysis visualization was adopted by He et al. (2017), Zhao (2017), and Hosseini et al. (2018a). He et al. (2017) mapped the managerial areas of BIM while Zhao (2017) and Hosseini et al. (2018a) identified key authors, keywords, and emerging research topics using literature with a single view.

Despite these reviews being important to the understanding of BIM research development, they adopted a single global view of the development. These are often not representative of the research development in each continent/country, as the results are often biased against continents/countries with few publications and favours continents/countries with a high number of publications. Thus, global review favours leading countries and there still exists a lack of clear understanding of how the building information modelling develops in each continent and if there are similarities/differences in the development. Jung and Lee (2015) asserted that BIM varies from continents to continent; from country to country, client to

client and discipline to discipline (Gu and London, 2010, Succar, 2009). Also, these previous research studies have adopted solely one software program for their analyses which can be distance-based or graphical-based and time-based approach in its visualization This study introduces a new approach for a comparative and taxonomic review of literature in the context of the six continents (South America, Africa, Australia, Europe, North America, and Asia) of the world and examines the status of development of BIM research, the similarities, and differences between the various continents. Also, a best-fit approach will be adopted for the use of software programs in visualizing the networks: VOSViewer (distance-based approach) and CiteSpace (graphical-based and time-based approach) will be adopted and the best view is presented.

This study will track the evolution of BIM research, key researchers, research keywords, co-citation clusters, and will deduce the salient and emerging research themes in each continent. A comparison will then be carried out to determine similarities and differences across the continents. This study will contribute a new approach to reviewing literature/visualization and it will enable interesting comparisons to be made. It will also present the emerging research themes and status in each of the continents. The paper is structured into six parts; the first part is the introduction part, the second part is the research methodology, third part explains the data collected, the fourth part is the bibliometric analysis of the data collected, the fifth part is the discussion of findings and the last part is the conclusion.

Research Methodology

Articles were retrieved from the search engine of Web of Science (WOS) 'which consists of important and influential journals in the world' (Song et al., 2016, Zhao, 2017, Olawumi and Chan, 2018) with the search query *"Building Information Modelling", "Building Information Model*", "Building Information Modeling";* the "*" represent fuzzy search. The search outputs were confined to only those articles published in English and in construction-related areas as this is the practice in related studies (Santos et al., 2017, Jin et al., 2018, Hosseini et al., 2018a). Journals encompass up to date and quality information about research in a domain as compared to conference papers (Yi and Chan, 2014, Zheng et al., 2016). The searched outputs were then categorized into different continents (Africa, Asia, Australia, Europe, North America, South America) using the country/region option of the WOS search output. Each continent was then saved on the WOS savelist and a new search was carried out using the advanced search with the query *"Building Information Model", "Building Information Model*", "BIM"* and a larger output was recorded compared to the first search. The search was refined as done previously with the basic search and the same continent were then joined together to eliminate double entries in each of the data set (continent). The search range was from 2004 to 2017 in order to cover more than 10 years of publications which are deemed enough and typical (Jin et al., 2018). The research design outline is shown in Figure 1 and the distribution of the articles for each of the continent is shown in Figure 2 and 3.

Analysis tools

The VOS viewer (van Eck and Waltman, 2010) (Version 1.6.9.0) and the CiteSpace (Chen, 2014) (version 5.3.R4) were used to analyze the documents collected from the WOS. Past research studies (Olawumi and Chan, 2018, Hosseini et al., 2018a, Song et al., 2016, Hosseini et al., 2018b) have made use of either Citespace or VOS viewer for visualization of different research areas (BIM, Offsite Construction, Sustainability, Public Private Partnership). "VOS viewer" is an easy-to-use software for visualizing bibliometric networks using distance-based approach (van Eck and Waltman, 2010). The distance-based approach gives a visualization in which the distance between the nodes approximately indicates the relatedness of the nodes. The software also performs normalization for differences between the nodes by default using association strength normalization (van Eck and Waltman, 2010). It also clusters similar items (e.g. authors, countries, documents, journals, keywords, etc) using the smart local moving algorithm (van Eck and Waltman, 2011, Waltman et al., 2010). The software offers the option of fractional counting methodology and full counting methodology for the network visualization; the fractional counting methodology was used as recommended (van Eck and Waltman, 2011). Further information on the use of the software VOSviewer are available in the literature (van Eck and Waltman, 2010, 2011; Waltman, van Eck and Noyons, 2010). CiteSpace was developed by Chaomei Chen and it makes use of both graphical- based and time-based approach in its visualization (van Eck and Waltman, 2011). A comprehensive manual on how to make use of the Citespace is available in the literature (Chen, 2014). The time slice option of the CiteSpace was set to a year as the year range of the WOS output is from 2006 to 2017. Also, the Pathfinder utility was used as recommended by (Chen, 2014). The two tools (CiteSpace and VOSViewer) were combined to cover for each other lapses generated (as VOSviewer often gives detailed network with fewer dataset while CiteSpace gives detailed additional information with networks) and to select the best outputs from each of the tools for the different networks.

Figure 1: Outline of the research design

Data Collected

The first article published was recorded in 2006 and the year 2018 is not considered, as the year is not complete yet and many research studies will still be published in the year. The articles were retrieved from WOS in August 2018. The distribution of the articles is as shown in figure 2 and figure 3.

Figure 2: Data collected

The networks for the dataset of South America, and Africa were visualized using the VOS viewer because of its small size and the generated network using Citespace was not detailed enough. The fractional counting methodology was used as recommended by (van Eck and Waltman, 2011) for the networks. The CiteSpace generated the best networks for the datasets from Australia, North America, Europe, and Asia, thus, it is used in the visualization.

Figure 3: BIM publications from WOS 2006 – 2017

Data analysis (Bibliometric analysis) and result

This section presents the result of the data analysis applied in this study using the VOS Viewer and CiteSpace. Three bibliometric analysis were employed to analyse the data set for each of the continents. Co-author analysis, co-citation analysis (author co-citation and documents co-citation) and co-word analysis were used. Other bibliometric techniques such as network of countries and institutions, and network of co-occurring subject categories (Olawumi and Chan, 2018) which are often adopted in similar studies that used global view were not employed in this study as the aim of this study is to track the evolution of the BIM research and comparison in the six continents as regards the research trend. Also, the techniques employed such as co-citation would enable analysis of the underlying intellectual structures, and the quantity and authority of references cited by publications (Zhao, 2017). Deductions could be made from this analysis as it points to likely areas of current focus in the continents. Similarly, the co-word analysis indicates the level of attention paid to such words in the BIM literature and deductions could be made as regards what the keywords connote and their likely contextual collocation in the research domain (Oraee et al., 2017). Thus, these techniques (co-author analysis, author co-citation, documents co-citation and co-word analysis) were deemed fit for the aim of this study.

Co-author analysis: This involves the visualization of the top authors in BIM for each of the continents (Song et al., 2016, He et al., 2017, Zhao, 2017, Hosseini et al., 2018a, Olawumi and Chan, 2018).

South America

The network generated 181 links and total link strength of 520.00 as shown in figure 4. VOS viewer is a distance-based approach thus the closer researchers are located to each other in the visualization, the more strongly related they are. Karoline Figueiredo has the highest total link strength (TLS) of 87 because of his position and has 19 links in the network. Total Link Strength (TLS) is the strength of the links of an item to other items (van Eck and Waltman, 2011). Luis Fernado Alacron has TLS of 55 and 11 links in the network; Bernold Leonhard has 36 TLS and 8 links in the network. All the authors have one publication each as reflected by the size of the items in the network which signifies the porosity of BIM research in this area. Figueiredo Karoline, Assed Haddadd, Mohammad Najjar, and Mariana Palumbo can be regarded as the top authors as they have the highest TLS of 85 each followed by Luis Fernado Alacron with 55 TLS.

Figure 4: Co-authorship network (South America)

Africa

The network as shown in figure 5 generated 96 links and total link strength of 762.42; items were grouped into two clusters and items in the same cluster are of the same colour. The distance between the nodes (authors) is related to the relationship between them (van Eck and Waltman, 2011). It thus follows that Mohamed Marzouk (citation = 28, TLS= 138.43); has the highest number of publications and has high level of relatedness to Eslam Mohammed Abdelkader (citation = 2, TLS= 47.6), Akintola Akintoye (citation = 2, TLS= 42) compared to Saheed Ajayi (citation = 37, TLS= 121.60) that is far away from the cluster.

Figure 5: Co-authorship network (Africa)

Australia

The network generated 848 links and total link strength of 3698.81 as shown in figure 6. The items were grouped into two clusters and items in the same clusters are of the same color as shown. The top authors in this data set are Xiangyu Wang (Citation = 408, TLS = 775.12); Bilal Succar (Citation = 366, TLS = 12.12); Peter Love (Citation = 243, TLS = 324.77); Chan-Sik Park (Citation = 108, TLS = 115.86); Mathew Gray (Citation = 97, TLS = 173.56).

Figure 6: Co-authorship network (Australia)

North America

A co-authorship network of 52 nodes and 44 links was formed as shown in Figure 7. The network has modularity (Q = 0.7599) and mean silhouette, S= 0.5766. The structure of the network is quantitatively represented by modularity and silhouette; the value of Q > 0.70 represents a scattered and loosely assembled clusters and S measures the homogeneity of the clusters (Chen, 2014, Olawumi and Chan, 2018). These network clusters are loosely packed with the modularity value and the homogeneity is neither low nor high. The productive authors in this region are Chuck Eastman (frequency = 11); Raja Issa (frequency = 11); Yong-Cheol Lee (frequency = 7); Sheryl Staub-French (frequency = 6); Hyungjin Kim (frequency = 5). Chuck Eastman, Raja Issa, and Sheryl Staub-French form a closed connected loop with each of them at the centre. A citation burst which is an indication of an active author with citation surge which is based on Kleinberg's algorithm (Chen, 2014) occurred for Raja Issa (strength of 3.2636) between 2013 to 2014.

Figure 7: Co-authorship network (North America)

Europe

A total of 713 researchers coauthor the 268 articles from this continent. The network has highly loosely packed clusters signifying the advanced nature of the research in different

clusters. The productive authors in this region are Yacine Rezgui (frequency = 8); Borrmann Andre (frequency = 5); Hartmann Timo (frequency = 4); Kirti Ruikar (frequency = 3).

Figure 8: Co-authorship network (Europe)

Asia

A co-authorship network of 82 nodes and 91 links was formed as shown in figure 9. The network has a loosely coupled cluster with modularity (Q = 0.8516) and a high homogeneity with the mean silhouette, S= 0.7278. The productive authors in this region are Rafael Sacks (frequency = 18); Wang Xiangyu (frequency = 16, centrality score= 0.08); Ghang Lee (frequency = 11); Jack Cheng (frequency = 10, centrality score = 0.03); Jinkook Lee (frequency = 7, centrality score = 0.03). A Citation burst occurred for Rafael Sacks (Strength = 4.852) from 2009 to 2010 The centrality score connotes the connection of a particular node to two or more large nodes with itself in between (Chen, 2014).

Figure 9: Co-authorship network (Asia)

Co-citation analysis: This involves visualization of authors (author co-citation network) and documents (documents co-citation) that were referenced in each of the dataset (Song et al., 2016, Zhao, 2017, Olawumi and Chan, 2018).

South America

Author and Document co-citation

The top co-cited authors from the data set are Chuck Eastman (TLS= 4.00); Rafael Sacks (TLS= 4.00); Olli Seppänen O (TLS= 3.68); Xavier Brioso (TLS= 3.37); Johnny Wong (TLS= 3.37); Salman Azhar (TLS= 3.00). A total of 389 cited references were also extracted from the data set. The top cited documents are: the review work by Wong and Zhou (2015) in green BIM literature with TLS of 3; the work of Sacks et al. (2010a) on BIM data exchange for precast facades with TLS of 2; the work of Succar (2009) on BIM framework with TLS of 2; the work of Schlueter and Thesseling (2009) on energy performance assessment during early design stage with TLS of 2; the work of Seppänen et al. (2010) on last planner with TLS of 2 and the BIM handbook by Eastman et al. (2011) with TLS of 2.

Africa

Authors and documents co-citation

A total of 486 co-cited authors were retrieved from the data set. The top co-cited authors from the data set are Chuck Eastman (TLS= 9.00); Mohamed Marzouk (TLS= 7.58), Salman Azhar (TLS= 7.00), Yusuf Arayici (TLS = 6.11), Bilal Succar (TLS = 5.00), and Saheed Ajayi (TLS = 3.93). A total of 565 cited references were also extracted from the data set. The top cited documents are: the BIM handbook by Eastman et al. (2011) with TLS of 7; the

review of Pérez-Lombard et al. (2008) on buildings energy consumption information with TLS of 3; the work of Schlueter and Thesseling (2009) on energy performance assessment during early design stage with TLS of 3; the work of Gray et al. (2013) an international survey on BIM with TLS of 2; and the work of Ajayi et al. (2015) on life cycle environmental performance. Eastman et al. (2011) BIM handbook is well placed in the network, and well cited by other documents around it in the network.

Australia

Author and documents co-citation network

The author co-citation was evaluated with 248 nodes and with 606 links. The network has loosely packed clusters with a modularity Q = 0.7797 and low homogeneity with mean silhouette S = 0.315. The top cited authors are Chuck Eastman (frequency = 23, centrality score= 0.0); Salman Azhar (frequency = 17, centrality score= 0.04); Bilal Succar (frequency = 16, centrality score= 0.26); Yusuf Arayici (frequency = 15, centrality score= 0.13); Burcin Becerik-Gerber (frequency = 15, centrality score= 0.01). Bilal Succar has high betweenness score because he serves as the connecting node for nodes around, with him at the centre. Rob Howard receives attention between 2011 to 2014 with 3.3701 burst strength, Peter Love also received citation surge from 2013 to 2015 with a burst strength of 3.9573, Xiangyu Wang citation burst spans for a year (2013 – 2014) with the strength of 2.5874.

The document co-citation was evaluated with 85 nodes and 85 links. The clusters are loosely packed with modularity Q = 0.7613 and a high level of homogeneity with mean silhouette S= 0.8609. The top cited articles are that of (Succar, 2009) on BIM framework with frequency = 249, that of Singh et al. (2011) on theoretical framework multi-disciplinary collaboration platform with frequency = 143, Park and Kim (2013) on framework of Automated Construction-Safety Monitoring with frequency = 63, that of Plume and Mitchell (2007) on Collaborative design with frequency = 58 and Love et al. (2014) on benefits realization management with frequency = 54.

North America

Author and documents co-citation

The author co-citation was evaluated with 280 nodes and with 670. The network clusters are not too loosely packed with a modularity Q = 0.5861 and a low homogeneity with mean silhouette S = 0.3498. The top cited authors are Chuck Eastman (frequency = 123, centrality score= 0.09); Salman Azhar (frequency = 51, centrality score= 0.06); Burcin Becerik-Geber (frequency = 47, centrality score= 0.03); Rafael Sacks (frequency = 42, centrality score= 0.10); Michael Gallaher (frequency = 23, centrality score= 0.08). The thickest purple ring is for Eastman has he has high betweenness score in the network. Attention was given to Michael Gallaher and the citation burst spans between 2009 to 2012 with the strength of 4.051, also Lachmi Khemlani receive citation burst between 2012 to 2013 with the strength of 2.7022.

The documents co-citation was visualized with 245 nodes and 241 links as shown in Figure 20. The network has a loosely packed cluster and a high homogeneity with modularity Q = 0.7837 and S= 0.7829. The top cited articles are that of Zhang et al. (2013) on augmented

reality with frequency = 171; Xiong et al. (2013) on 3D model with frequency = 150; Barlish and Sullivan (2012) on BIM benefits with frequency = 129; Basbagill et al. (2013) on environmental impact with frequency = 128; Lee et al. (2006) on parametric building object behaviour with frequency = 111.

Europe

Author and documents co-citation network

The author co-citation was formed with 223 nodes and with 521 links and modularity Q = 0.6564 and S = 0.3417, signifying a low homogeneity and loosely packed clusters. The top cited authors are Chuck Eastman (frequency = 120, centrality score= 0.19); Salman Azhar (frequency = 55, centrality score= 0.08); Bilal Succar (frequency = 44, centrality score= 0.11); Rebekka Volk (frequency = 32, centrality score= 0.06); Yusuf Arayici (frequency = 30, centrality score= 0.12). Citation burst occurred for five cited authors Rob Howard (strength = 2.8209, year= 2008 to 2014); Dana Smith (strength = 3.0613, year= 2010 to 2014); Burcu Akinci (strength = 3.1535, year= 2012 to 2014); Jianping Zhang (strength = 2.7821, year= 2014 to 2015); Everett Rogers (strength = 3.0993, year= 2015 to 2017).

The network was visualized with 148 nodes and 241 links with modularity Q = 0.8136 and S= 0.625 representing a loosely packed clusters network with high. The top cited articles are that of Volk et al. (2014) on review of BIM articles for existing buildings with frequency = 272; Bryde et al. (2013) on project benefits of BIM with frequency = 169; Sacks et al. (2010b) on interaction of lean and BIM with frequency = 85; Hartmann et al. (2012) on BIM tools and construction management methods with frequency = 77; (Sacks et al., 2010a) on Building information modelling and interoperability for architectural precast facades with frequency = 75.

Asia

Author and documents co-citation network

The author network was evaluated with 205 nodes and with 474 links and modularity Q = 0.58 and mean silhouette S = 0.3901. The top cited authors are Chuck Eastman (frequency = 156, centrality score= 0.29); Salman Azhar (frequency = 75, centrality score= 0.04); Rafael Sacks (frequency = 63, centrality score= 0.30); Ghang Lee (frequency = 54, centrality score= 0.26); Bilal Succar (frequency = 51, centrality score= 0.07). Citation burst occurred for top five cited authors Rafael Sacks (strength = 4.0193, year= 2009 to 2012); Stephen Fox (strength = 3.175, year= 2010 to 2013); Sheryl Staub-French (strength = 3.1548, year= 2011 to 2014); Zhiliang, Ma (strength = 3.0806, year= 2013 to 2015); Kwong Chau (strength = 2.822, year= 2013 to 2015).

The documents co-citation was evaluated with 288 nodes and 290 links with modularity Q = 0.8508 and S= 0.6801 as shown in Figure 26. The top cited articles are that of Zhang et al. (2013) on BIM and safety with frequency = 171; Singh et al. (2011) on theoretical framework of a BIM-based multi-disciplinary collaboration platform with frequency = 143; Jung and Joo (2011) on BIM framework for practical implementation with frequency = 95; Sacks et al. (2010b) on lean and BIM with frequency = 85; Sacks et al. (2010c) on Building information modelling and interoperability for architectural precast facades with frequency = 75.

Co-word analysis: This is the visualization of the trend using the keywords supplied by the authors and the keywords generated by the database for categorizing the journals (Song *et al.*, 2010; He *et al.*, 2017; Zhao, 2017; Hosseini, Martek, *et al.*, 2018; Olawumi and Chan, 2018). The clusters were label by loglikelihood ratio (LLR) function of the citespace software as recommended by Chen (2014).

South America

A minimum threshold of the citation was set to the 93 keywords from the documents as shown in Figure 10. The author keywords and the keyword plus are made use for the visualization. The keywords that meet the threshold and the most occurred keyword form a network as shown in figure 7 of 25 links and total link strength of 14.50. These keywords are grouped into three clusters; an item of the same colour belongs to the same cluster. The bigger the circle, the larger the number of occurrences. Cluster 0 with 11 links and 9TLS consist of 'BIM' (links = 7, TLS = 5); 'construction' (links = 2, TLS = 2); 'Design' (links = 2, TLS = 2). Cluster 1 with 12 links and 6 TLS consist of 'Last planner system' (links = 4, TLS = 2); 'Lean construction' (links = 4, TLS = 2); 'management' (links = 4, TLS = 2). Cluster 3 with 23links and 12 TLS consist of 'Building Information Modelling' (links = 9, TLS = 5); 'Performance' (links = 6, TLS = 3); 'Framework' (links = 4, TLS = 2) and 'Simulation' (links = 4, TLS = 2).

Figure 10: Co-occurring keywords network (South America)

Africa

A minimum threshold of the citation was set to the 125keywords from the documents as shown in Figure 11. The author keywords and the keyword plus are made use for the visualization. The keywords that meet the threshold and the most occurred keyword form a network of 46 links and total link strength of 17. These keywords are grouped into three clusters; an item of the same colour belongs to the same cluster. The bigger the circle, the larger the number of occurrences. The distance between the keywords represents the relatedness of these keywords to each other. Cluster 0 consist of 'Construction', 'Construction Project', 'Design, Life Cycle', 'Optimization'. Cluster 1 consist of 'Climate Change', 'Energy efficiency', 'Impacts', 'Sustainability'. Cluster 2 consist of 'Building Information', 'Demolition', 'Performance', 'System'. The top occurring words are 'Building Information Modelling' (TLS = 9, Links = 20); 'Design' (TLS = 4, Links = 12); 'Performance' (TLS = 2, Links = 7); 'Demolition waste' (TLS = 2, Links = 5); 'Sustainability' (TLS = 2, Links = 7) as shown in Figure 12.

Figure 11: Co-occurring keywords network (Africa)

Australia

A network of 40 nodes and 82 links was formed. The network has a modularity (Q = 0.4387) and the mean silhouette, S = 0.4756 representing a low homogeneity as shown in Figure 12. The high frequency keywords are BIM (frequency = 65, centrality score = 0.42); Construction (frequency = 23, centrality score = 0.18); System (frequency = 22, centrality score = 0.03); Management (frequency = 20, centrality score = 0.51); Model (frequency = 12, centrality score = 0.16). The keywords were then grouped into 6 clusters using the cluster labels by log-likelihood ratio (LLR): cluster 0 (size = 10, S = 0.66, mean year = 2012) labelled 'construction process'; cluster 1 (size = 9, S = 0.431, mean year = 2015) labelled 'infrastructure project'; cluster 2 (size = 6, S = 0.516, mean year = 2015) labelled 'framework'; cluster 3 (size = 5, S = 0.575, mean year = 2014) labelled 'ontology'; cluster 4 (size = 4, S = 0.77, mean year = 2016) labelled 'software'; cluster 5 (size = 4, S = 0.833, mean year = 2017) labelled 'contractual details' (legal framework).

Figure 12: Co-occurring keywords network (Australia)

North America

The network was formed with 110 nodes and 285 links. Modularity (Q = 0.5983) and mean silhouette, S = 0.6774 representing a high homogeneity as shown in Figure 13. High occurring words are 'Building Information Modelling' (frequency = 124, centrality score= 0.07); 'Management' (frequency = 84, centrality score= 0.20); 'Construction' (frequency = 46, centrality score= 0.12); 'Design' (frequency = 37, centrality score= 0.23); 'System' (frequency = 35, centrality score= 0.25); 'Model' (frequency = 30, centrality score= 0.22); 'Project' (frequency = 17, centrality score= 0.09); (frequency = 16, centrality score= 0.06); 'Interoperability' (frequency = 16, centrality score= 0.11). Citation burst occurred for three keywords 'Building Information Modelling' (strength = 5.7112, year = 2010 to 2012); 'Interoperability' (strength = 3.2099, year = 2011 to 2013); 'Construction' (strength = 2.8126, year = 2012 to 2013); and 'Building Information Model' (strength = 3.102, year = 2013 to 2014). The keywords were grouped into clusters: 'Building Information Modelling' (Silhouette = 0.466, size = 16, mean year = 2013); 'Building performance/ energy analysis' (Silhouette = 0.698, size = 15, mean year = 2015); 'Organization' (Silhouette = 0.527, size = 15, mean year = 2015); 'Interoperability' (Silhouette = 0.821, size = 13, mean year = 2014); 'Augmented reality' (Silhouette = 0.736, size = 12, mean year = 2015); 'Automation/Safety' (Silhouette = 0.721 size = 11, mean year = 2015); 'Organization support' (Silhouette = 0.899, size = 9, mean year = 2015); 'Comparative study' (Silhouette = 0.687, size = 7, mean year = 2016); 'Instructional need' (Silhouette = 0.897, size = 7, mean year = 2014).

Figure 13: Co-occurring keywords network (North America)

Europe

The network was formed with 129 nodes and 281 links. Modularity (Q = 0.5834) and mean silhouette, S = 0.4328 representing a low homogeneity as shown in Figure 14. High occurring words are 'Building Information Modelling' (frequency = 185, centrality score= 0.03); 'Management' (frequency = 45, centrality score= 0.12); 'Construction' (frequency =

40, centrality score= 0.17); 'Design' (frequency = 36, centrality score= 0.07); 'System' (frequency = 38, centrality score= 0.20); 'Model' (frequency = 22, centrality score= 0.06); 'Interoperability' (frequency = 20, centrality score= 0.23). Citation burst occurred for one keyword 'Building Information Modelling' (strength = 7.6546, year = 2011 to 2013). The keywords were grouped into 15 clusters, the top 9 clusters are 'BIM standards' (Silhouette = 0.632, size = 19, mean year = 2016); 'Technology adoption' (Silhouette = 0.664, size = 19, mean year = 2015); 'Semantic web technologies/Framework' (Silhouette = 0.672, size = 18, mean year = 2015); 'Construction Industry' (Silhouette = 0.667, size = 17, mean year = 2013); 'Value tracking' (Silhouette = 0.674, size = 12, mean year = 2013); 'Virtual reality' (Silhouette = 0.725, size = 12, mean year = 2015); 'Semantic enrichment' (Silhouette = 0.792, size = 10, mean year = 2017); 'Spatial planning/ data visualization' (Silhouette = 0.854, size = 8, mean year = 2015); 'Integrated design/ Energy efficiency' (Silhouette = 0.813, size = 8, mean year = 2016).

Figure 14: Co-occurring keywords network (Europe)

Asia

The network was formed with 137 nodes and 336 links. Modularity (Q = 0.5737) and mean silhouette, S = 0.551 as shown in Figure 15. High occurring words are 'Building Information Modelling' (frequency = 211, centrality score= 0.12); Construction (frequency = 57, centrality score= 0.12); 'System' (frequency = 49, centrality score= 0.12); 'Design' (frequency = 46, centrality score= 0.16); 'Management' (frequency = 46, centrality score= 0.19); 'Model' (frequency = 37, centrality score= 0.15. Citation burst occurred for one keyword 'Three-dimensional model' (strength = 3.0105, year = 2010 to 2013) 'Building Information Modelling' (strength = 6.3474, year = 2011 to 2012). The keywords were grouped into 12 clusters, the top 9 clusters are 'Procurement' (Silhouette = 0.591, size = 26, mean year = 2013); 'Safety' (Silhouette = 0.6, size = 22, mean year = 2014); 'Sustainability' (Silhouette = 0.695, size = 20, mean year = 2015); 'Facility management' (Silhouette = 0.71, size = 17, mean year = 2015); 'Tunnel construction' (Silhouette = 0.709, size = 13, mean year = 2015); 'Integrated approach/ Energy efficiency' (Silhouette = 0.741, size = 10, mean year = 2015); 'Education/Construction engineering' (Silhouette = 0.741, size = 11, mean year = 2014); 'Construction Organization/management' (Silhouette = 0.824, size = 9, mean year = 2014); 'Critical success factors' (Silhouette = 0.955, size = 6, mean year = 2017).

Figure 15: Co-occurring keywords network (Asia)

Discussion of findings

There has been an increase in the BIM publications over the years as shown in figure 2 and 3; this is also in agreement with previous findings (Yalcinkaya and Singh, 2015, Santos et al., 2017, Zhao, 2017, Hosseini et al., 2018a). However, Building Information modelling adoption and implementation rates vary across the world and the status also differs, this can be deduced from the different rate of publication in figure 2 (Jung and Lee, 2015). The dataset retrieved from the search engine of Web of Science data core shows that there is a

clear difference between the publications emanating from South America, Africa, and Australia as compared to the rest of the continents.

South America: Worthy of note is that many of the research outputs from this continent are conference proceedings or in a language other than English which was not considered in this study. This accounts for the low number (11) of publication from this region. A total of 44 authors co-author these research articles. The BIM research in is still at the early stage (Jung and Lee, 2015) and the publication network is porous with all the authors having one publication each. Despite the porosity of the network, Karoline Figueiredo (Federal University of Rio de Janeiro, Brazil) is well placed and with the highest total link strength signifying her research network to other authors. Also, most of the top authors are stationed in Brazil. 348 authors across the globe were cited from the data set (11) and the most cited are Chuck Eastman (Georgia Institute of Technology, US), Rafael Sacks (Israel Institute of Technology) and Olli Seppänen (Aalto University, Finland). Research articles (Wong and Zhou, 2015, Sacks et al., 2010a, Succar, 2009, Schlueter and Thesseling, 2009) that were most frequently cited in this region major relates to sustainability and this is in tandem with the top co-occurring words. This reflects the present focus of the researchers/research in this region.

Africa: The 17 articles retrieved from the web of science were authored by 39 authors. The BIM research in this region is also in its early stage (Abubakar et al., 2014) and Mohamed Marzouk (Cairo University, Egypt) has the highest publication and form a close cluster with the likes of Eslam Mohammed Abdelkader (Cairo University, Egypt). The authorship network shows Ajayi Saheed far away from the major cluster correlating to its interrelationship with the research cluster. Chuck Eastman (Georgia Institute of Technology, US), Mohamed Marzouk (Cairo University, Egypt), and Salman Azhar (Auburn University, US) are the most cited authors in the 17 articles analysed whilst the most cited references are Eastman et al. (2011), Pérez-Lombard et al. (2008), Schlueter and Thesseling (2009). The highly occurring keywords are also related to sustainability which reflects the focus of the research/researchers. Also, the research outputs in this region lean towards North Africa (Egypt).

Australia: There are well-established authorities in this region. Xiangyu Wang (Curtin University, Australia), Bilal Succar (BIMe Initiative) and Peter Love (Curtin University) stand out of 196 authors in the authorship network signifying their influence in the region. The network is also less porous with most of the clusters being closely packed. Chuck Eastman (Georgia Institute of Technology, US), Salman Azhar (Auburn University, US), and Bilal Succar (BIMe Initiative) (from Australia and one of the influential authors in the region) are the most cited authors. Similarly, Bilal Succar's work on BIM framework (Succar, 2009), Singh et al. (2011) and Park and Kim (2013) are the most cited articles. The research trend can be deduced from the average year of occurrence of the keyword clusters; construction process (mean year = 2012), ontology (2014), Infrastructure projects (mean year = 2015), software (2016), and legal issues (2017). The trend shows an interwoven movement of viewing and researching BIM as a technology and process as against the technological imperative perspective (Merschbrock and Munkvold, 2012). Also, the legal issues related to BIM adoption and implementation is still a conundrum and receiving attention from researchers (Olatunji, 2016, Olatunji, 2011, Olatunji, 2014).

North America: The productive authors are Chuck Eastman (Georgia Institute of Technology, US), Raja Issa (University of Florida, US) and Yong-Cheol Lee (Louisiana State University) and Staub-French (University of British Columbia, Canada). Also, these authors have established clusters around them as shown in the authorship network. Michael Gallaher received citation burst between 2009 to 2012 which could be because of the work on cost of interoperability which revealed that $15.8 billion loss due to interoperability inadequacies. Similarly, Lachmi Khemlani received special attention between 2012 to 2013. The keyword clusters trend in this region includes Building information modelling (mean year = 2013), interoperability (mean year = 2014), building performance/energy analysis (mean year = 2015), and organisation (mean year = 2015). The keyword 'Interoperability' received citation burst between 2011 to 2013 which coincides with IFC2x3 Coordination View Version 2.0 (Model View Definition). Collocation of keywords also relates round BIM and interoperability, BIM for design, Simulation, Industry Foundation Classes (IFC), optimization and others.

Europe: There are many clusters in the authorship network on this continent. This relates to the numerous ongoing research in the region and this could be also be related to the United Kingdom in this continent which is a leading country in BIM adoption and implementation. Chuck Eastman (Georgia Institute of Technology, US), Salman Azhar (Auburn University, US), Bilal Succar (BIMe Initiative) are the most cited authors in this region. The citation burst received by Everett Rogers between 2015 and 2015 could be interpreted as the increase in adopting innovation diffusion theory (Rogers, 2003) to study BIM. The keyword clusters trend is BIM standard (mean year = 2016), technology adoption (mean year = 2015), Virtual reality (mean year = 2015), semantic web technologies (mean year = 2015), and Integrated design (mean year = 2016).

*Asia***:** Rafael Sacks (Israel Institute of Technology), Wang Xiangyu (Kyung Hee University, South Korea), Ghang Lee (Yonsei University, South Korea), and Jack Cheng (The Hong Kong University of Science and Technology, Hong Kong) stand out in the authorship network with clusters around. Also, Chuck Eastman (Georgia Institute of Technology, US), Salman Azhar (Auburn University, US), and Rafael Sacks (Israel Institute of Technology) are the most cited authors in this region. The keyword clusters trend is procurement (mean year = 2013), education (mean year = 2014), construction organisation/management (mean = 2014), facility management (mean year = 2015), adoption/critical success factors (mean year = 2017). The collocation of the keywords relates round BIM for construction, Implementation of BIM, and Adoption of BIM.

Table 1: Summary/Comparison of the findings

Summary and comparison of the findings

Table 1 shows a summary of the findings for easy comparison. Each of these continents has articles of 11, 17 and 85 respectively as compared to 245 from North America, 268 from Europe and 288 from Asia. This can be related to the fact that both adoption and awareness of

Building Information Modelling are still at its early stage in South America and Africa (Ogwueleka and Ikediashi, 2017, Jung and Lee, 2015). BIM originated from North America, thus, the publications have been cited the highest number of times followed by Europe which is a leading continent in the adoption of BIM. The highest number of publications was from Asia, this can be related to the increase in the level of awareness in Asian countries with emphasis on China, Malaysia, Singapore, and India (Ismail et al., 2017). Also, the productivity of these continents can be related to their h-index, North America with 34, Asia with 33, Europe with 30, Australia with 20, Africa with 6 and South America with 2. This further reinforces the different status of BIM in these continents with South America and Africa lagging, Australia and Asia are advancing, whilst Europe and North America are ahead.

There seem to be similarities in the trend of South America and Africa. The two continents are lagging in the BIM development and the research outputs lean towards a specific location. Most of the research outputs in Africa and South America are from researchers in Egypt and Brazil respectively. The top occurring keywords and top cited documents also relate round themes of adopting BIM in construction/design and sustainability. Also, Chuck Eastman is the top cited in the two continents.

There are established researchers and networks in Australia, North America, Europe, and Asia compared to Africa and South America. This may also be as a result of the digital divide between developed and developing countries. Discussion about legal issues, BIM frameworks (as reflected in the most cited documents) are still ongoing in Australia; studies of BIM at the organisation level, BIM functionalities (building performance/energy), virtual reality, and interoperability are still ongoing in North America; studies related to BIM standards, semantic enrichment, integrated design are still ongoing in Europe; whilst studies related to the implementation of BIM for procurement, safety, facility management and organisations are still ongoing in Asia. The trend of studies may be related to the fundamental work of Bilal Succar on BIM frameworks, and the trends in Europe reflects the priorities placed by the UK government and other governments in the region. Also, the studies of BIM in Europe often perceived BIM as a socio-technical system and through theoretical lenses such as innovation diffusion theory as reflected by the citation burst received by Rogers Everett. This is contrary to the findings of studies (Hosseini et al., 2018a, Oraee et al., 2017) that adopted a global view of BIM development.

The top cited authors in all the continents consist of mutual authors such as Chuck Eastman (Georgia Institute of Technology, US), Rafael Sacks (Israel Institute of Technology), Bilal Succar (BIMe Initiative), Salman Azhar (Auburn University, US). This reflects some of the influential works that are well cited from these authors and these findings are similar to that of Hosseini et al. (2018a) and Zhao (2017). Zhao (2017) opined that the diversity of the location of the top cited authors portrayed that BIM research is gaining wide proliferation across the globe. Thus, top cited authors from the continents are from diverse continents such as Asia, North America, and Australia. Also, Chuck Eastman is the most consistent author in all the continents and this is related to his fundamental ground works in BIM and often referred to as the ‘Father or Pioneer of BIM’ (Li et al., 2012, Liu et al., 2013).

Figure 16: Status of BIM research across the six continents of the world

Conclusions

In conclusion, the development of BIM research is still growing across the six continents over the last decade as reflected in the growing publications. However, the growth and development vary across boundaries as depicted in this study. South America and Africa continents are clearly lagging in the BIM research when compared to the other four continents. North America which is the origin of BIM development has clearly moved ahead. Asia is growing in its BIM adoption and research, and it leans towards implementation and adoption research. There are well-established authors and well-cited articles in Europe, North America, Australia, and Asia as against the porous domain in Africa and South America. The implication of this study is the depiction of the difference in BIM development as against the global view often presented in extant studies. This study revealed the need for more studies in Africa & South America coupled with the need to make the outputs available; also, the need for researchers in developed climes to explore new research clusters whilst adopting a socio-technical perspective.

This study has provided a useful approach to review and has presented a comparison of BIM literature from the six continents of the world. The key researchers were identified, and deductions were made from the networks about the research trends and themes as shown in table 2 and figure 16. This method can be used for review in other research domains to present a clear understanding of the research status and trend in the area.

This study covered BIM articles published in English and indexed in the web of science (WOS) database, this serves as a limitation to the study as not all BIM articles are indexed in WOS and there are BIM articles published in languages other than English. These limitations serve as fertile areas for further research as databases such as Scopus and google scholar could be used and consideration of all publications (i.e conference papers and journal articles). Also, critical reviews could be conducted in each of these continents separately to reveal deeper intellectual evolution of BIM research in each of the continents.

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REFERENCES

ABUBAKAR, M., IBRAHIM, Y., KADO, D. & BALA, K. 2014. Contractors Perception of the Factors Affecting Building Information Modelling (BIM). *Computing in Civil and Building Engineering*, 167-178.

AIBINU, A. & VENKATESH, S. 2014. Status of BIM Adoption and the BIM Experience of Cost Consultants in Australia. *Journal of Professional Issues in Engineering Education and Practice,* 140, 04013021.

AJAYI, S. O., OYEDELE, L. O., CERANIC, B., GALLANAGH, M. & KADIRI, K. O. 2015. Life cycle environmental performance of material specification: a BIM-enhanced comparative assessment. *International Journal of Sustainable Building Technology and Urban Development,* 6, 14-24.

ARAYICI, Y., COATES, P., KOSKELA, L., KAGIOGLOU, M., USHER, C. & O'REILLY, K. 2011. Technology adoption in the BIM implementation for lean architectural practice. *Automation in Construction,* 20, 189-195.

AZHAR, S. 2011. Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry. 11, 241-252.

BARLISH, K. & SULLIVAN, K. 2012. How to measure the benefits of BIM - A case study approach. *Automation in Construction,* 24, 149-159.

BASBAGILL, J., FLAGER, F., LEPECH, M. & FISCHER, M. 2013. Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts. *Building and Environment,* 60, 81-92.

BECERIK-GERBER, B., JAZIZADEH, F., LI, N. & CALIS, G. 2012. Application Areas and Data Requirements for BIM-Enabled Facilities Management. *Journal of Construction Engineering and Management,* 138, 431-442.

BRYDE, D., BROQUETAS, M. & VOLM, J. M. 2013. The project benefits of Building Information Modelling (BIM). *International Journal of Project Management,* 31, 971-980.

CHEN, C. 2014. The CiteSpace Manual. *College of Computing and Informatics*, 1-84.

EASTMAN, C., TEICHOLZ, P., SACKS, R. & LISTON, K. 2011. *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors.*, John Wiley & Sons.

GHAFFARIANHOSEINI, A., TOOKEY, J., GHAFFARIANHOSEINI, A., NAISMITH, N., AZHAR, S., OLIA, E. & RAAHEMIFAR, K. 2017. Building Information Modelling (BIM) uptake : Clear bene fi ts , understanding its implementation , risks and challenges. 75, 1046-1053.

GRAY, M., GRAY, J., TEO, M., CHI, S. C. & FIONA, Y. K. 2013. Building Information Modelling: An International survey. 5, 5-9.

GU, N. & LONDON, K. 2010. Understanding and facilitating BIM adoption in the AEC industry. *Automation in Construction,* 19, 988-999.

HARTMANN, T., VAN MEERVELD, H., VOSSEBELD, N. & ADRIAANSE, A. 2012. Aligning building information model tools and construction management methods. *Automation in Construction,* 22, 605-613.

HE, Q., WANG, G., LUO, L., SHI, Q., XIE, J. & MENG, X. 2017. Mapping the managerial areas of Building Information Modeling (BIM) using scientometric analysis. *International Journal of Project Management,* 35, 670-685.

HONG, Y., SEPASGOZAR, S. M. E., AHMADIAN F.F, A. & AKBARNEZHAD, A. 2016. Factors Influencing BIM Adoption in Small and Medium Sized Construction Organizations. *Proceedings of the 33rd International Symposium on Automation and Robotics in Construction (ISARC).*

HOSSEINI, M. R., MAGHREBI, M., AKBARNEZHAD, A., MARTEK, I. & ARASHPOUR, M. 2018a. Analysis of Citation Networks in Building Information Modeling Research. *Journal of Construction Engineering and Management,* 144, 04018064.

HOSSEINI, M. R., MARTEK, I., ZAVADSKAS, E. K., AIBINU, A. A., ARASHPOUR, M. & CHILESHE, N. 2018b. Critical evaluation of off-site construction research: A Scientometric analysis. *Automation in Construction,* 87**,** 235-247.

HOSSEINI, M. R., NAMZADI, M. O., RAMEEZDEEN, R., BANIHASHEMI, S. & CHILESHE, N. 2016. Barriers to BIM Adoption: Perceptions From Australian Small And Medium-Sized Enterprises (SMES). *The 40th Australasian Universities Building Education Association Conference.***,** 272-280.

IRIZARRY, J., KARAN, E. P. & JALAEI, F. 2013. Integrating BIM and GIS to improve the visual monitoring of construction supply chain management. *Automation in Construction,* 31**,** 241-254.

ISMAIL, N. A. A., CHIOZZI, M. & DROGEMULLER, R. 2017. An overview of BIM uptake in Asian developing countries. *AIP Conference Proceedings,* 1903.

JALAEI, F. & JRADE, A. 2015. Integrating building information modeling (BIM) and LEED system at the conceptual design stage of sustainable buildings. *Sustainable Cities and Society,* 18**,** 95-107.

JIN, R., GAO, S., CHESHMEHZANGI, A. & ABOAGYE-NIMO, E. 2018. A Holistic Review of off-site Construction Literature Published between 2008 and 2018. *Journal of Cleaner Production,* 202**,** 1202-1219.

JUNG, W. & LEE, G. 2015. The Status of BIM Adoption on Six Continents. *International Journal of Civil, Structural, Construction and Architectural Engineering,* 9**,** 406-410.

JUNG, Y. & JOO, M. 2011. Building information modelling (BIM) framework for practical implementation. *Automation in Construction,* 20**,** 126-133.

KARAN, E. P. & IRIZARRY, J. 2015. Extending BIM interoperability to preconstruction operations using geospatial analyses and semantic web services. *Automation in Construction,* 53**,** 1-12.

KARAN, E. P., IRIZARRY, J. & HAYMAKER, J. 2016. BIM and GIS Integration and Interoperability Based on Semantic Web Technology. *Journal of Computing in Civil Engineering,* 30**,** 04015043.

KIM, J. I., KIM, J., FISCHER, M. & ORR, R. 2015. BIM-based decision-support method for master planning of sustainable large-scale developments. *Automation in Construction,* 58**,** 95-108.

KIM, K. & TEIZER, J. 2014. Automatic design and planning of scaffolding systems using building information modeling. *Advanced Engineering Informatics,* 28**,** 66-80.

KIM, M.-K., WANG, Q., PARK, J.-W., CHENG, J. C. P., SOHN, H. & CHANG, C.-C. 2016. Automated dimensional quality assurance of full-scale precast concrete elements using laser scanning and BIM. *Automation in Construction,* 72**,** 102-114.

LEE, G., SACKS, R. & EASTMAN, C. M. 2006. Specifying parametric building object behavior (BOB) for a building information modeling system. *Automation in Construction,* 15**,** 758-776.

LI, B., FU, F. F., ZHONG, H. & LUO, H. B. 2012. Research on the computational model for carbon emissions in building construction stage based on BIM. *Structural Survey,* 30**,** 411-425.

LI, X., WU, P., SHEN, G. Q., WANG, X. & TENG, Y. 2017. Mapping the knowledge domains of Building Information Modeling (BIM): A bibliometric approach. *Automation in Construction,* 84**,** 195-206.

LIAO, L. & TEO, E. A. L. 2018. Managing critical drivers for building information modelling implementation in the Singapore construction industry: an organizational change perspective. *International Journal of Construction Management***,** 1-17.

LIU, H. L., WANG, G. B., ZHANG, L., HOU, H. & TIAN, L. 2013. Research on BIM-based Construction Project Organization Interface Management. *Applied Mechanics and Materials,* 357-360**,** 2781-2784.

LOVE, P. E. D., MATTHEWS, J., SIMPSON, I., HILL, A. & OLATUNJI, O. A. 2014. A benefits realization management building information modeling framework for asset owners. *Automation in Construction,* 37**,** 1-10.

LU, Y., WU, Z., CHANG, R. & LI, Y. 2017. Building Information Modeling (BIM) for green buildings: A critical review and future directions. *Automation in Construction,* 83**,** 134-148.

MERSCHBROCK, C. & MUNKVOLD, B. E. 2012. A Research Review on Building Information Modeling in Construction—An Area Ripe for IS Research. *Communications of the Association for Information Systems,* 31.

OGWUELEKA, A. C. & IKEDIASHI, D. I. 2017. The Future of BIM Technologies in Africa: Prospects and Challenges. *In:* WU, P., LI , H. & WANG, X. (eds.) *Integrated Building Information Modelling.* Bentham Science Publishers.

OLATUNJI, O. A. 2011. A preliminary review on the legal implications of BIM and model ownership. *Journal of Information Technology in Construction (ITcon),* 16**,** 687-697.

OLATUNJI, O. A. 2014. Views on building information modelling, procurement and contract management. *Proceedings of the Institution of Civil Engineers - Management, Procurement and Law,* 167**,** 117-126.

OLATUNJI, O. A. 2016. Constructing Dispute Scenarios in Building Information Modeling. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction,* 8**,** C4515001.

OLAWUMI, T. O. & CHAN, D. W. M. 2018. A scientometric review of global research on sustainability and sustainable development. *Journal of Cleaner Production,* 183**,** 231-250.

OLAWUMI, T. O., CHAN, D. W. M. & WONG, J. K. W. 2017. Evolution in the intellectual structure of BIM research: a bibliometric analysis. *Journal of Civil Engineering and Management,* 23**,** 1060-1081.

ORAEE, M., HOSSEINI, M. R., PAPADONIKOLAKI, E., PALLIYAGURU, R. & ARASHPOUR, M. 2017. Collaboration in BIM-based construction networks: A bibliometric-qualitative literature review. *International Journal of Project Management,* 35**,** 1288-1301.

PARK, C.-S. & KIM, H.-J. 2013. A framework for construction safety management and visualization system. *Automation in Construction,* 33**,** 95-103.

PÉREZ-LOMBARD, L., ORTIZ, J. & POUT, C. 2008. A review on buildings energy consumption information. *Energy and Buildings,* 40**,** 394-398.

PLUME, J. & MITCHELL, J. 2007. Collaborative design using a shared IFC building model Learning from experience. *Automation in Construction,* 16**,** 28-36.

POIRIER, E., STAUB-FRENCH, S. & FORGUES, D. 2015. Embedded contexts of innovation: BIM adoption and implementation for a specialty contracting SME. *Construction Innovation,* 15**,** 42-65.

PORWAL, A. & HEWAGE, K. N. 2013. Building Information Modeling (BIM) partnering framework for public construction projects. *Automation in Construction,* 31**,** 204-214.

PUOLITAIVAL, T. & FORSYTHE, P. 2016. Practical challenges of BIM education. *Structural Survey,* 34**,** 351-366.

RAHMANI ASL, M., ZARRINMEHR, S., BERGIN, M. & YAN, W. 2015. BPOpt: A framework for BIM-based performance optimization. *Energy and Buildings,* 108**,** 401-412.

ROGERS, E. M. 2003. *Diffusion of Innovations*, A Division of Macmillan Publishing Co Inc.

SACKS, R., KANER, I., EASTMAN, C. M. & JEONG, Y.-S. 2010a. The Rosewood experiment Building information modeling and interoperability for architectural precast facades. *Automation in Construction,* 19**,** 419-432.

SACKS, R., KOSKELA, L., DAVE, B. A. & OWEN, R. 2010b. Interaction of Lean and Building Information Modeling in Construction. *Journal of Construction Engineering and Management,* 136**,** 968-980.

SACKS, R., RADOSAVLJEVIC, M. & BARAK, R. 2010c. Requirements for building information modeling based lean production management systems for construction. *Automation in Construction,* 19**,** 641-655.

SANTOS, R., COSTA, A. A. & GRILO, A. 2017. Bibliometric analysis and review of Building Information Modelling literature published between 2005 and 2015. *Automation in Construction,* 80**,** 118-136.

SCHLUETER, A. & THESSELING, F. 2009. Building information model based energy/exergy performance assessment in early design stages. *Automation in Construction,* 18**,** 153-163.

SEPPÄNEN, O., BALLARD, G. & PESONEN, S. 2010. The combination of last planner system and location-based management system. *Lean Construction Journal*, 43-54.

SINGH, V., GU, N. & WANG, X. 2011. A theoretical framework of a BIM-based multi-disciplinary collaboration platform. *Automation in Construction,* 20, 134-144.

SONG, J., ZHANG, H. & DONG, W. 2016. A review of emerging trends in global PPP research: analysis and visualization. *Scientometrics,* 107, 1111-1147.

SUCCAR, B. 2009. Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in Construction,* 18, 357-375.

SUN, C., JIANG, S., SKIBNIEWSKI, M. J., MAN, Q. & SHEN, L. 2015. A Literature review of the factors limiting the application of BIM in the construction Industry *Technological and Economic Development of Economy,* 23, 764-779.

VAN ECK, N. J. & WALTMAN, L. 2010. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics,* 84, 523-538.

VAN ECK, N. J. & WALTMAN, L. 2011. Text mining and visualization using VOSviewer. *ISSI Newsletter,* 7, 50-54.

VOLK, R., STENGEL, J. & SCHULTMANN, F. 2014. Building Information Modeling (BIM) for existing buildings Literature review and future needs. *Automation in Construction,* 38, 109-127.

WALTMAN, L., VAN ECK, N. J. & NOYONS, E. C. M. 2010. A unified approach to mapping and clustering of bibliometric networks. *Journal of Informetrics,* 4, 629-635.

WANG, X., LOVE, P. E. D., KIM, M. J., PARK, C.-S., SING, C.-P. & HOU, L. 2013. A conceptual framework for integrating building information modeling with augmented reality. *Automation in Construction,* 34, 37-44.

WONG, J. & YANG, J. Research and application of Building Information Modelling (BIM) in the Architecture, Engineering and Construction (AEC) industry : a review and direction for future research. 6th International Conference on Innovation in Architecture, Engineering & Construction (AEC), Loughborough University, U.K., Pennsylvania State University, 2010. 356-365.

WONG, J. K. W. & ZHOU, J. 2015. Enhancing environmental sustainability over building life cycles through green BIM: A review. *Automation in Construction,* 57, 156-165.

XIONG, X., ADAN, A., AKINCI, B. & HUBER, D. 2013. Automatic creation of semantically rich 3D building models from laser scanner data. *Automation in Construction,* 31, 325-337.

YALCINKAYA, M. & SINGH, V. 2015. Patterns and trends in Building Information Modeling (BIM) research: A Latent Semantic Analysis. *Automation in Construction,* 59, 68-80.

YI, W. & CHAN, A. P. C. 2014. Critical Review of Labor Productivity Research in Construction Journals. *Journal of Management in Engineering,* 30, 214-225.

ZHANG, S., TEIZER, J., LEE, J.-K., EASTMAN, C. M. & VENUGOPAL, M. 2013. Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules. *Automation in Construction,* 29, 183-195.

ZHAO, X. 2017. A scientometric review of global BIM research: Analysis and visualization. *Automation in Construction,* 80, 37-47.

ZHENG, X., LE, Y., CHAN, A. P. C., HU, Y. & LI, Y. 2016. Review of the application of social network analysis (SNA) in construction project management research. *International Journal of Project Management,* 34, 1214-1225.

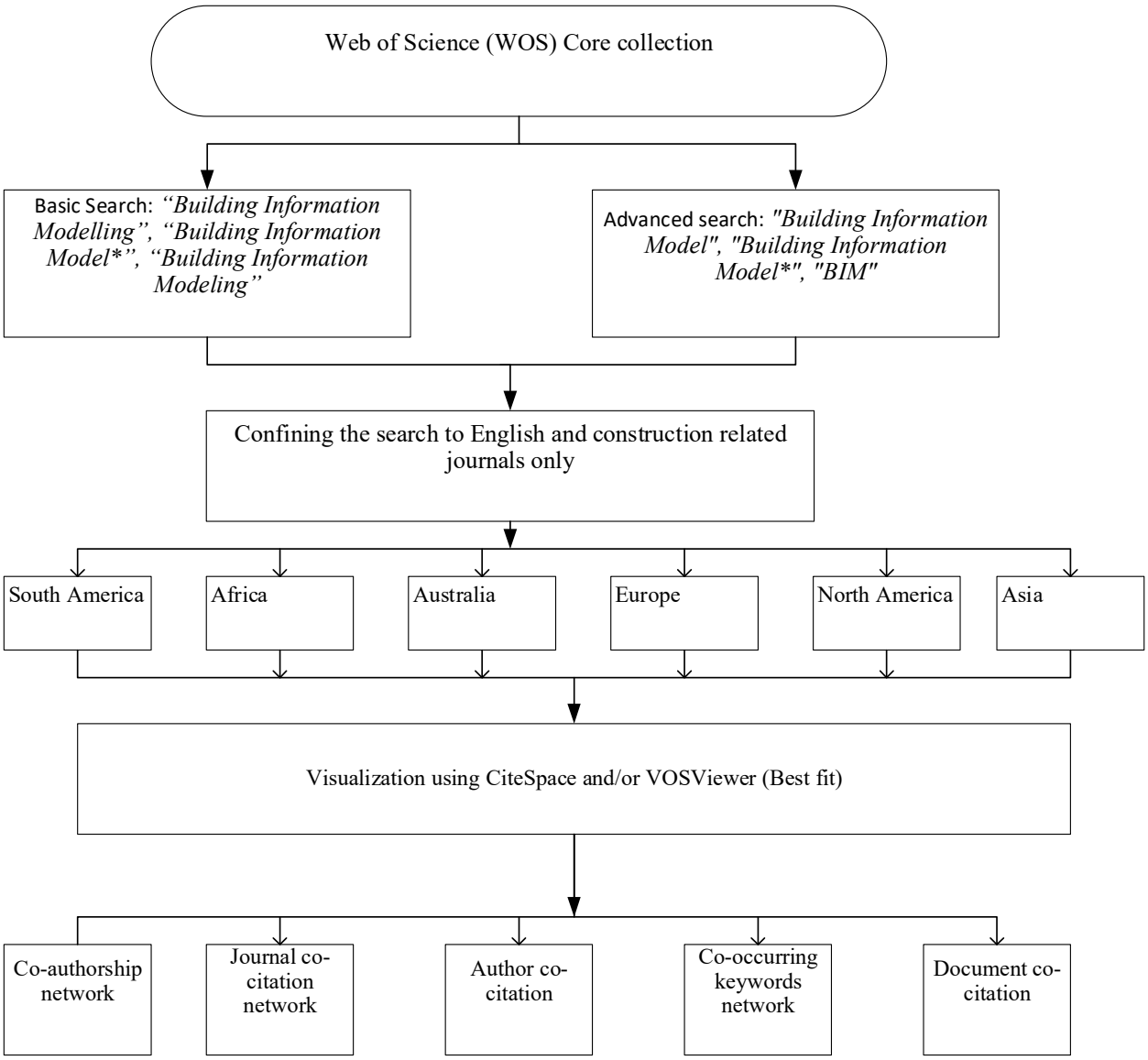

Figure 1: Outline of the research design

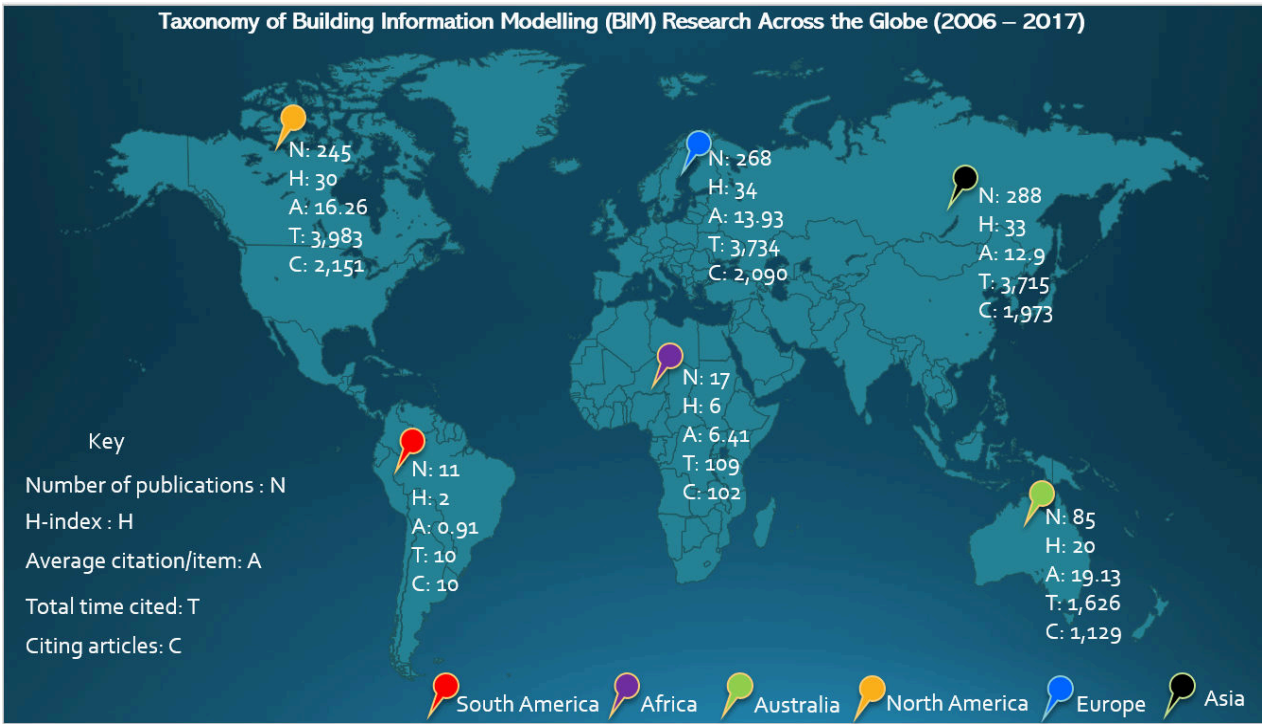

Figure 2: Data collected

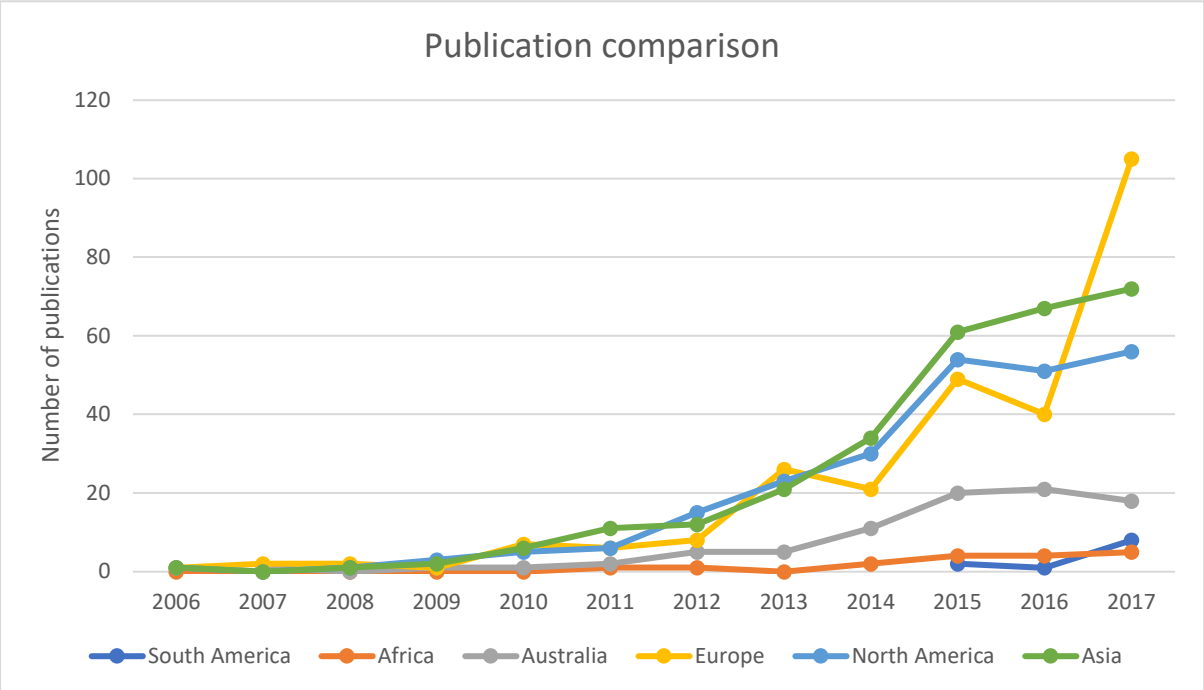

Figure 3: BIM publications from WOS 2006 - 2017

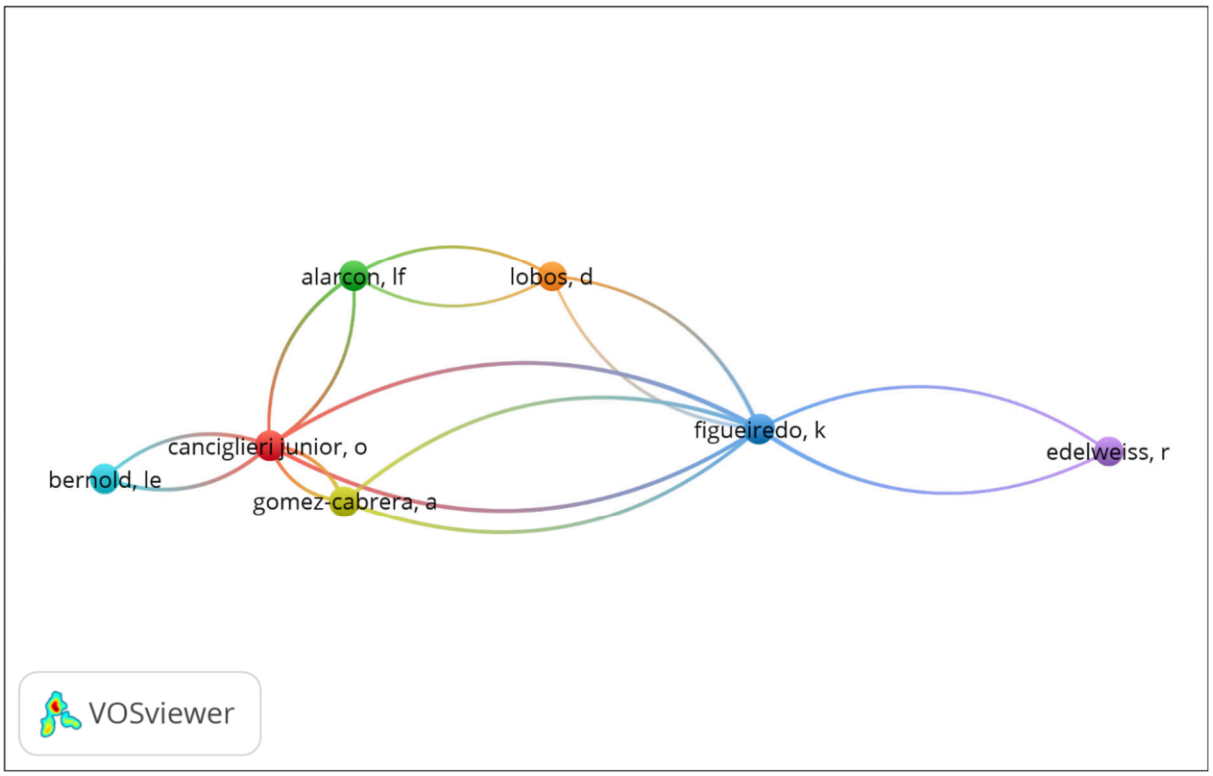

Figure 4: Co-authorship network (South America)

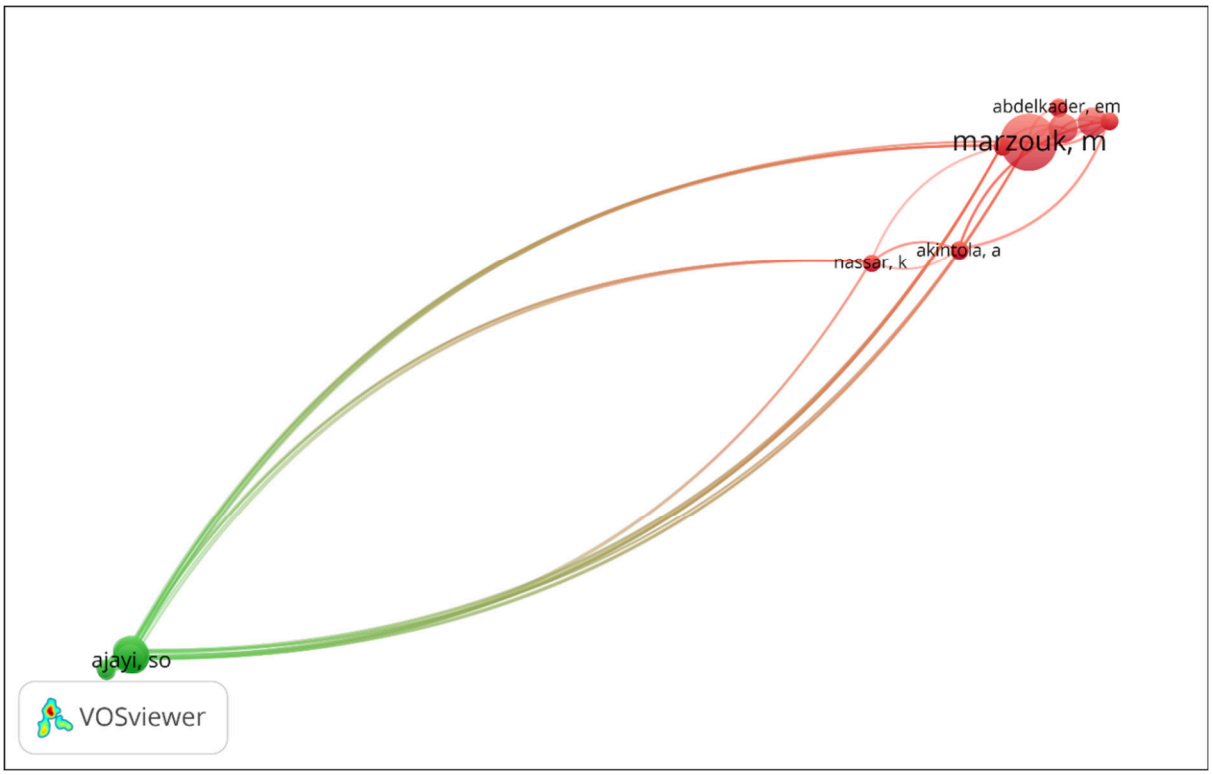

Figure 5: Co-authorship network (Africa)

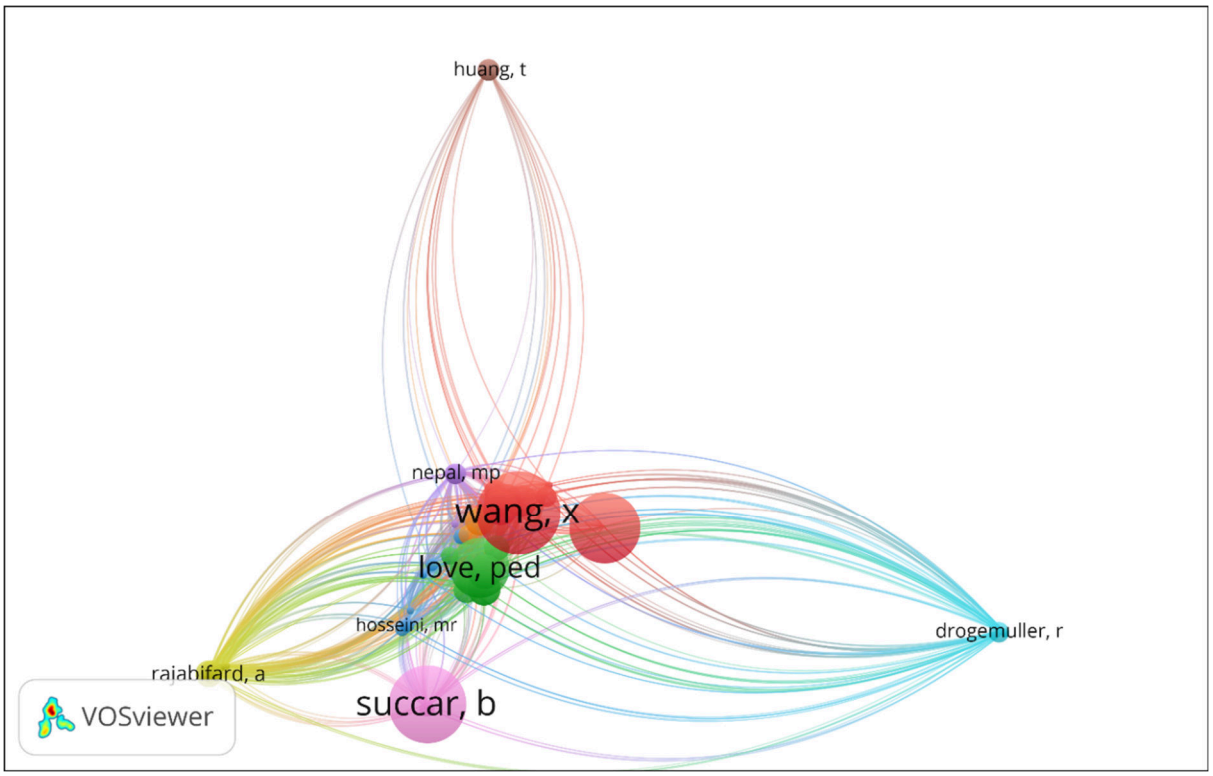

Figure 6: Co-authorship network (Australia)

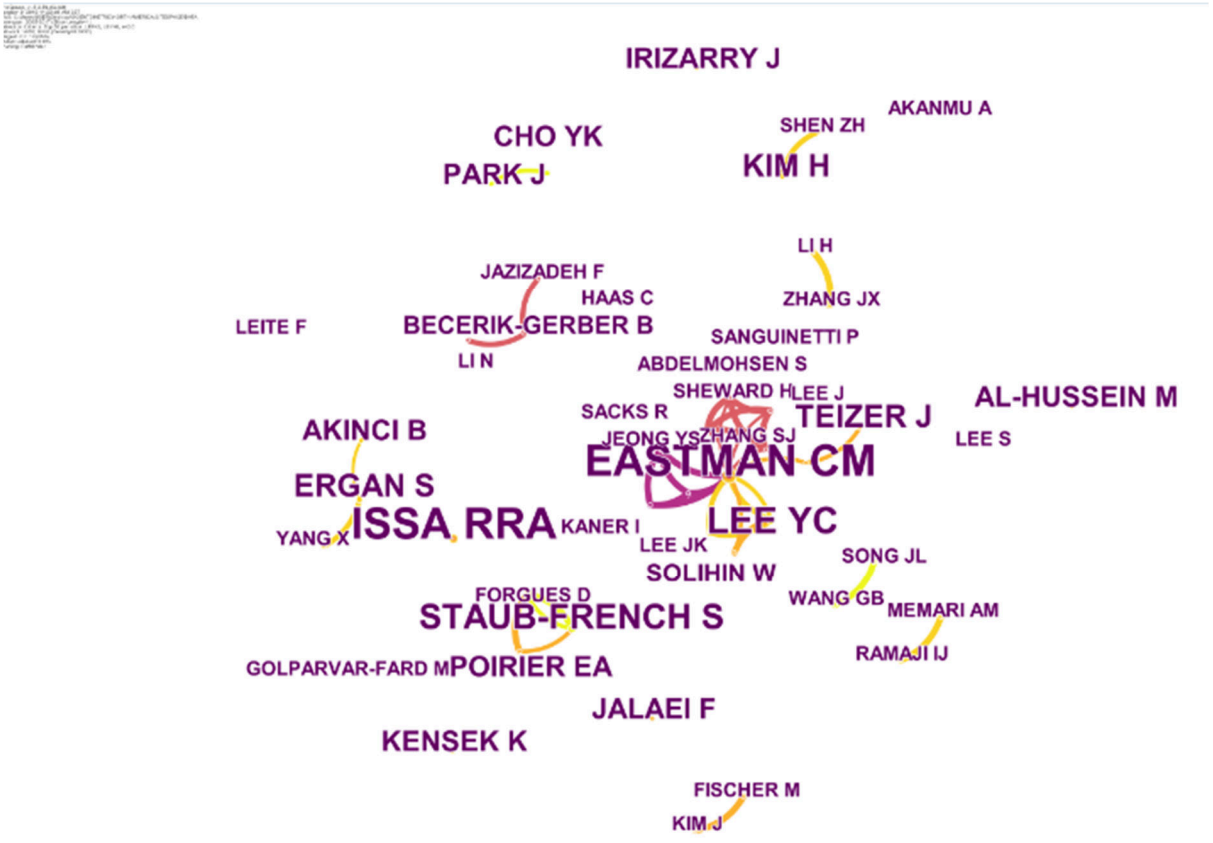

Figure 7: Co-authorship network (North America)

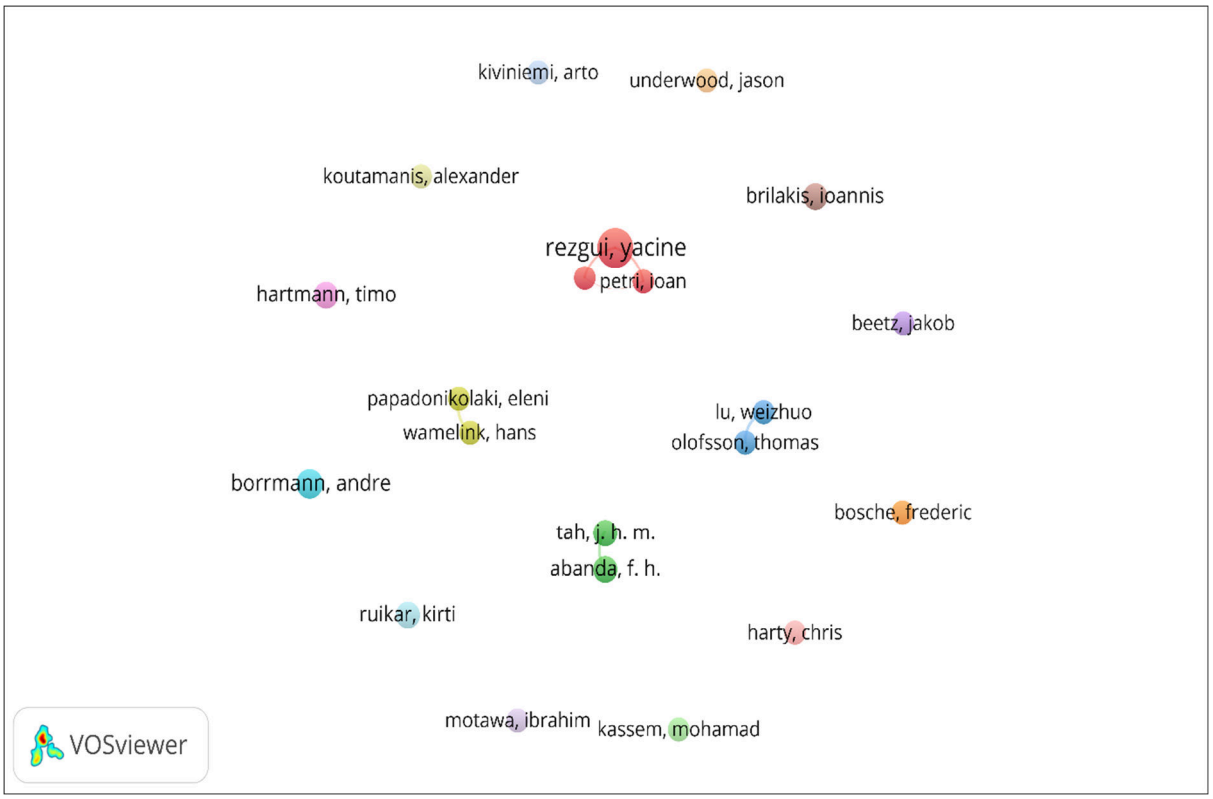

Figure 8: Co-authorship network (Europe)

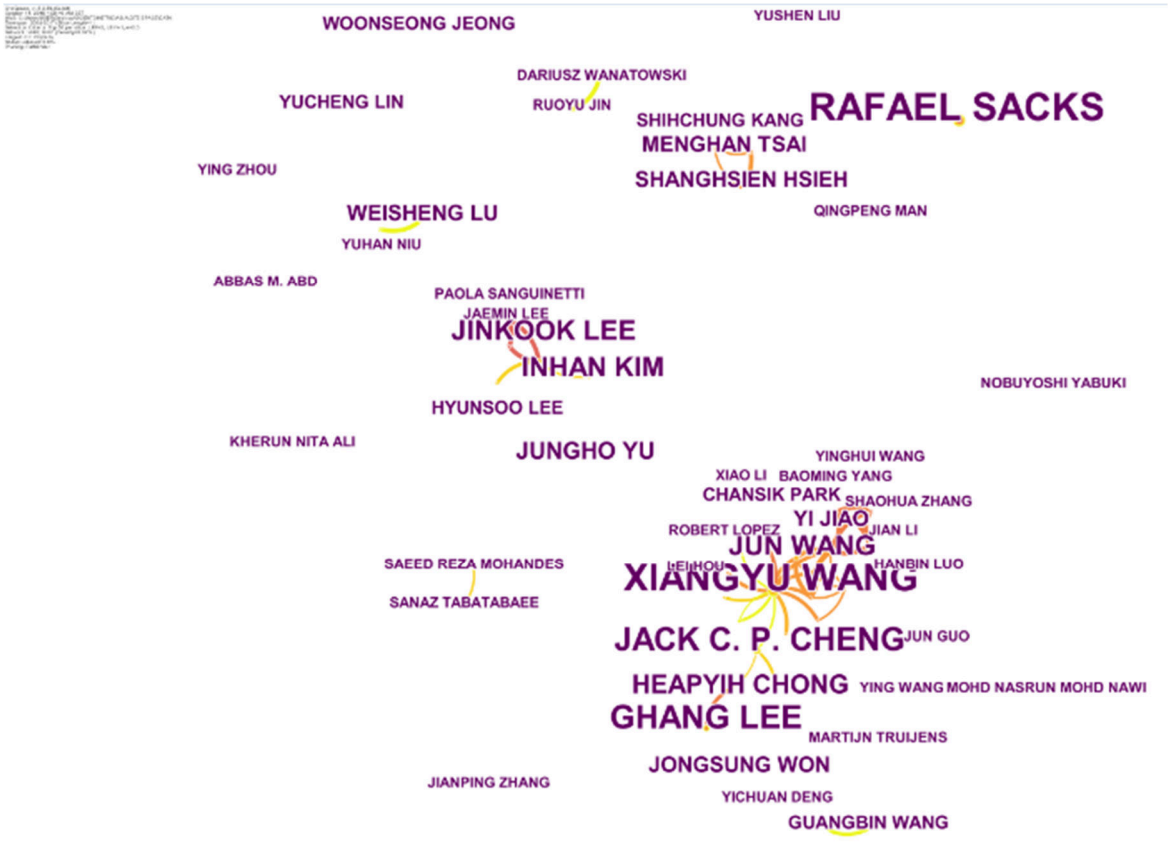

Figure 9: Co-authorship network (Asia)

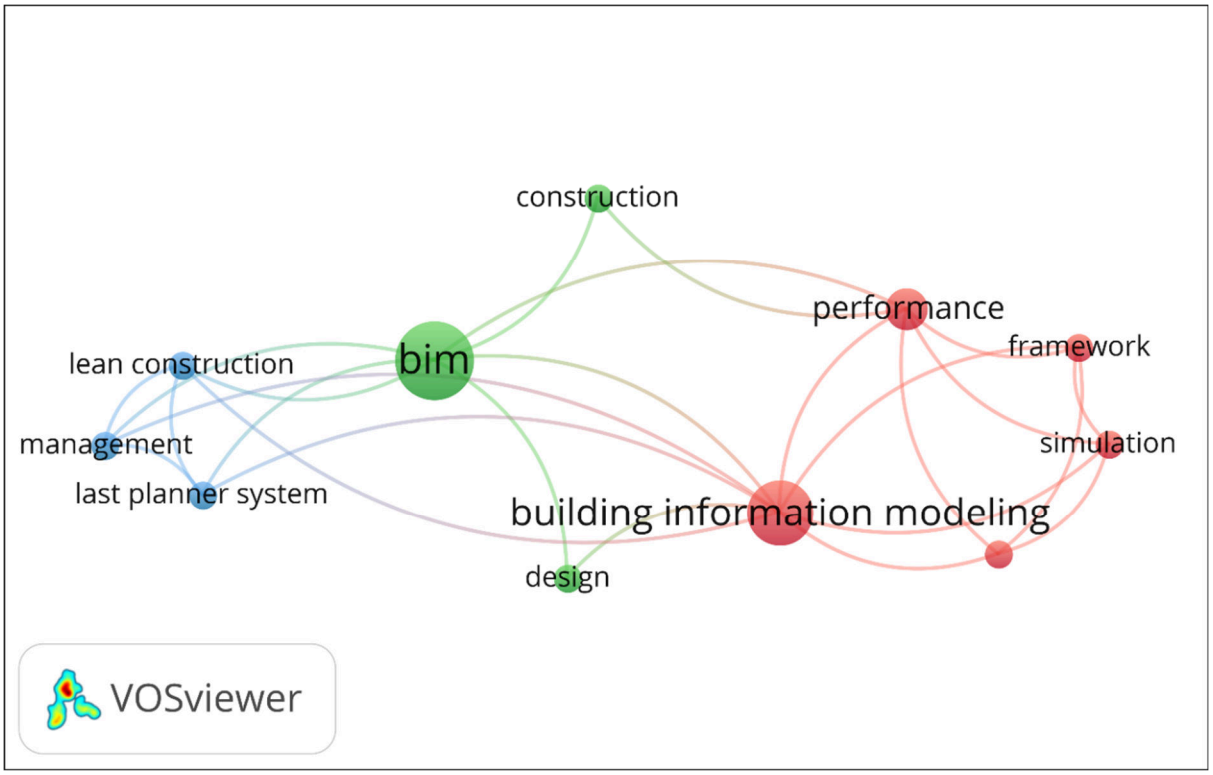

Figure 10: Co-occurring keywords network (South America)

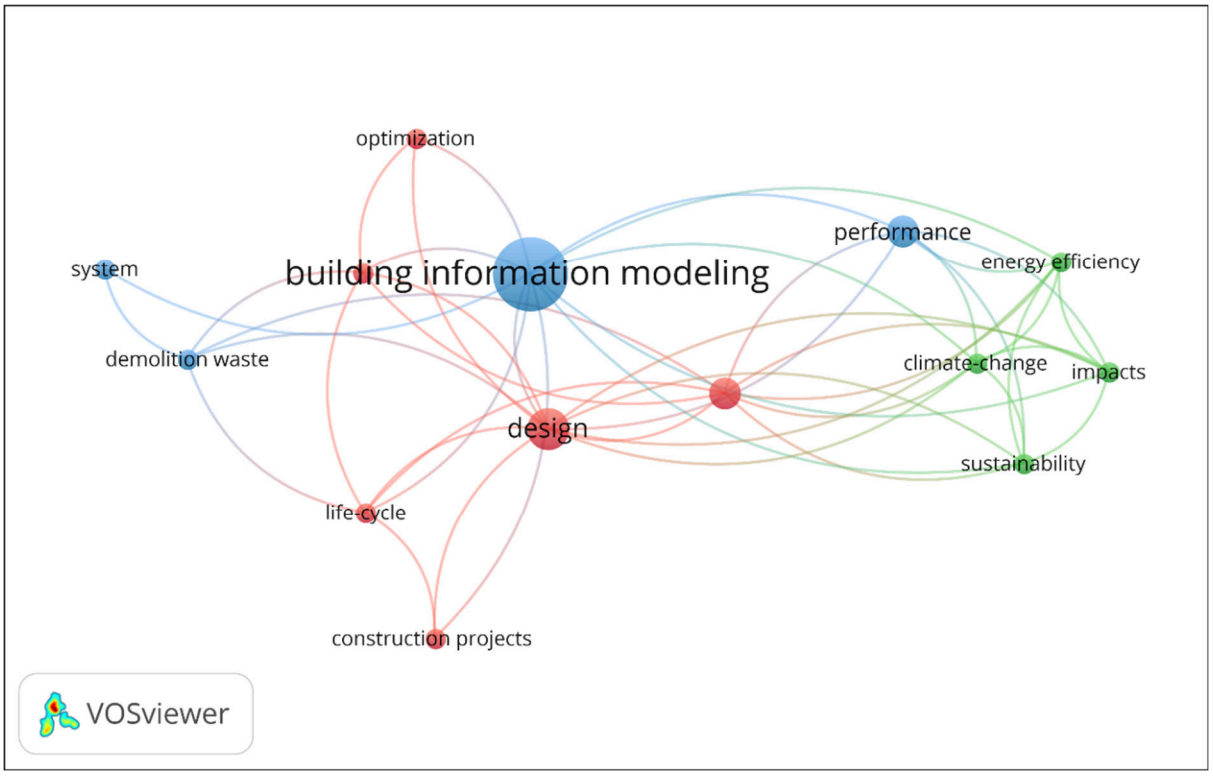

Figure 11: Co-occurring keywords network (Africa)

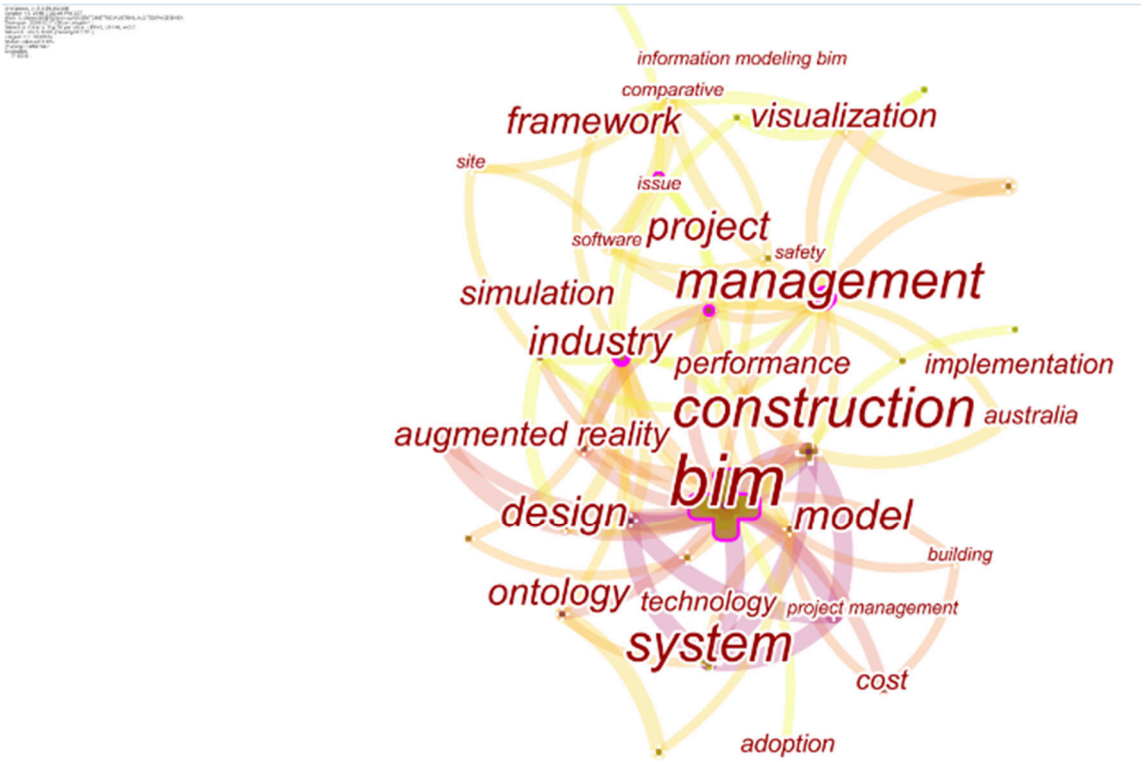

Figure 12: Co-occurring keywords network (Australia)

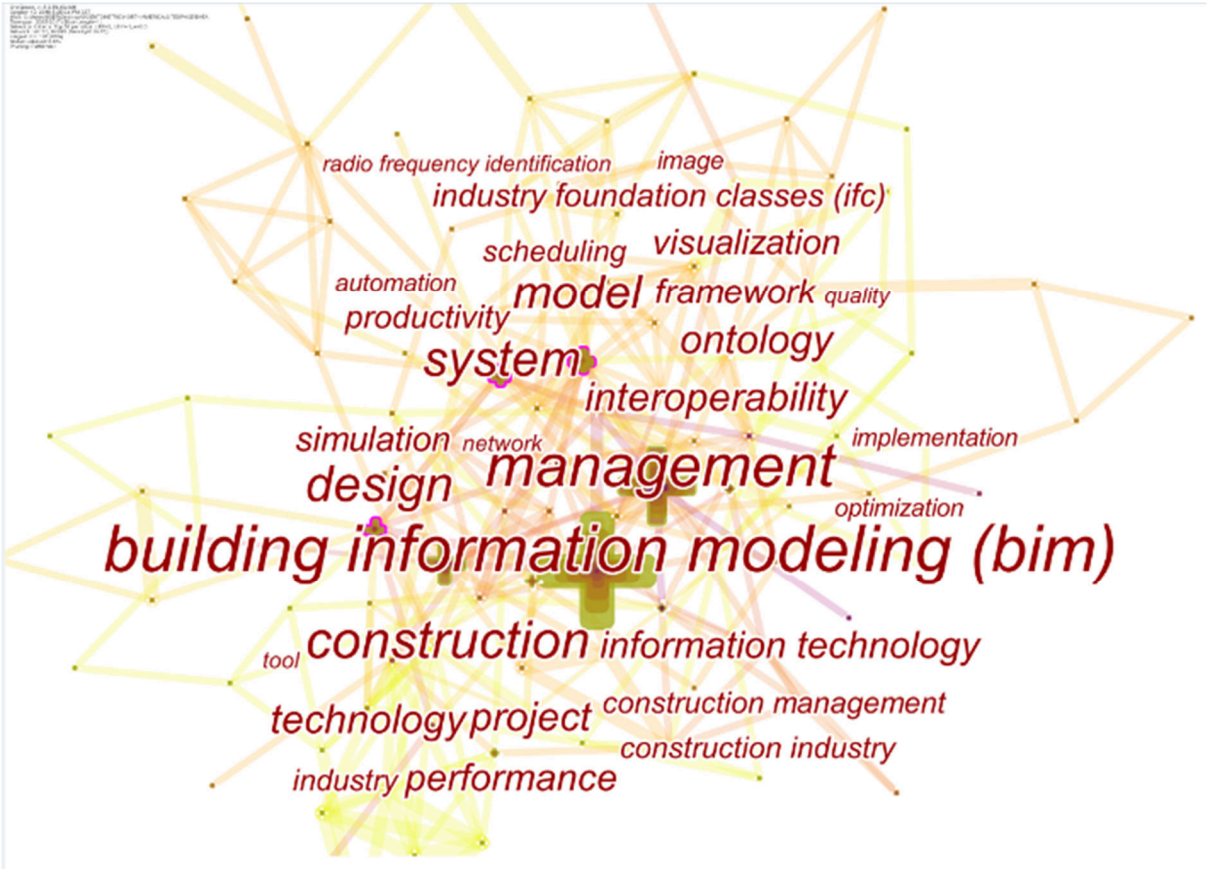

Figure 13: Co-occurring keywords network (North America)

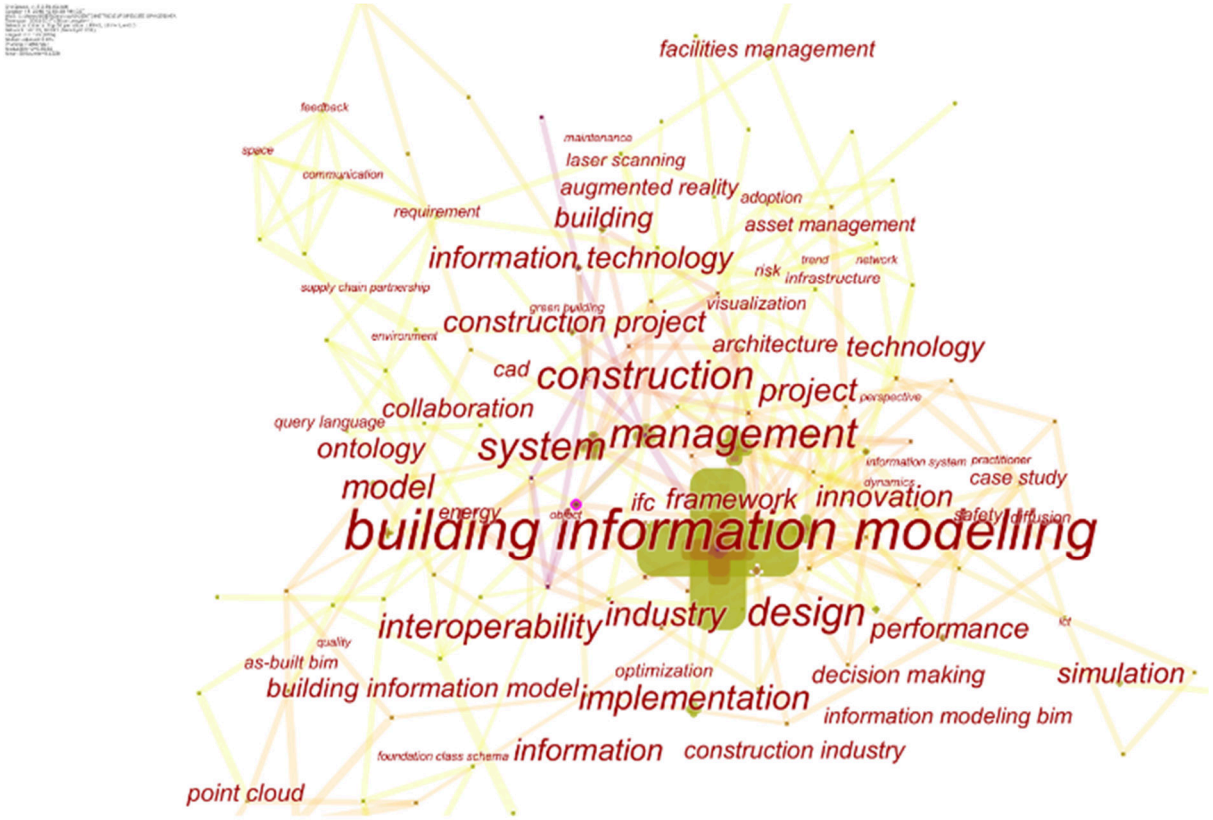

Figure 14: Co-occurring keywords network (Europe)

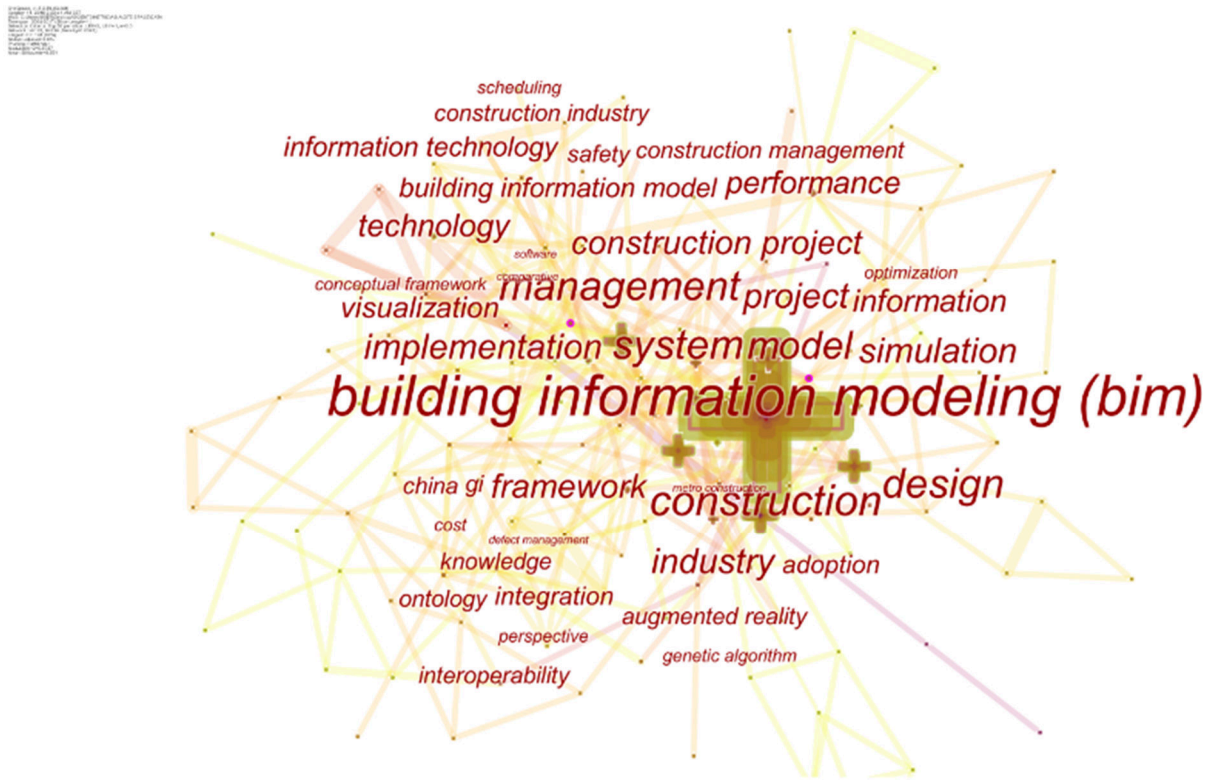

Figure 15: Co-occurring keywords network (Asia)

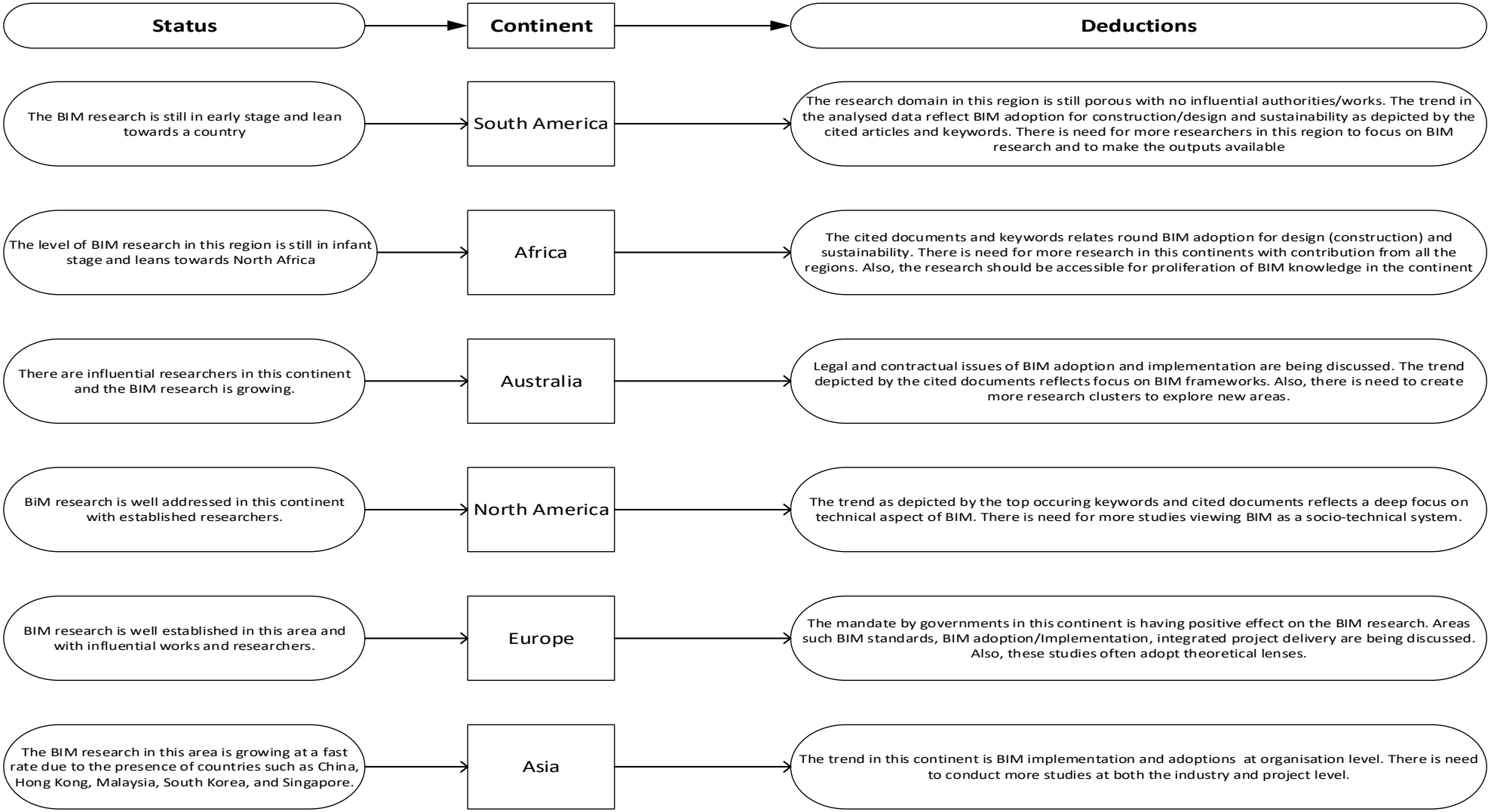

Figure 16: Status of BIM research across the six continents of the world

Continent	Publications	Top authors in each continent	Top keywords	Cited Documents	Top cited authors in each continent
South America	Number: 11 H Index: 2 Total citation: 10	Karoline Figueiredo (Federal University of Rio de Janeiro, Brazil) Assed Haddadd (Federal University of Rio de Janeiro, Brazil) Mariana Palumbo (Federal University of Fluminense, Brazil)	'BIM' 'Construction' 'Design' 'Performance' 'Management'	Wong and Zhou (2015) Sacks et al. (2010a) Succar (2009)	Chuck Eastman (Georgia Institute of Technology, US) Rafael Sacks (Israel Institute of Technology) Olli Seppänen (Aalto University, Finland)
Africa	Number: 17 H Index: 6 Total citation: 109	Mohamed Marzouk (Cairo University, Egypt) Eslam Mohammed Abdelkader (Cairo University, Egypt) Akintola Akintoye (Leeds Beckett University, UK/ University of Cape Town, South Africa	'Building Information Modelling' 'Design' 'Performance' 'Demolition waste' 'Sustainability'	Eastman (2016) Pérez-Lombard et al. (2008) Schlueter and Thesseling (2009)	Chuck Eastman (Georgia Institute of Technology, US) Mohamed Marzouk (Cairo University, Egypt) Salman Azhar (Auburn University, US)
Australia	Number: 85 H Index: 20 Total citation: 1,626	Xiangyu Wang (Curtin University, Australia) Bilal Succar (BIMe Initiative) Peter Love (Curtin University)	'Construction process' 'Infrastructure project' 'Framework' 'Ontology' 'Software' 'Contractual details'	Succar (2009) Singh et al. (2011) Park et al. (2017)	Chuck Eastman (Georgia Institute of Technology, US) Salman Azhar (Auburn University, US) Bilal Succar (BIMe Initiative)
North America	Number: 245 H Index: 30 Total citation: 3,983	Chuck Eastman (Georgia Institute of Technology, US) Raja Issa (University of Florida, US) Yong-Cheol Lee (Louisiana State University)	'Building Information Modelling', 'Building performance/energy analysis', 'Organization', 'Interoperability', 'Augmented reality', 'Organization support'	Zhang et al. (2013) Xiong et al. (2013) Barlish and Sullivan (2012)	Chuck Eastman (Georgia Institute of Technology, US) Salman Azhar (Auburn University, US) Burcin Becerik-Gerber (University of Southern Carolina)

Europe	Number: 268 H Index: 34 Total citation: 3,734	Yacine Rezgui (Cardiff University, UK) Borrman Andre (Technical University of Munich, Germany) Hartmann Timo (Technical University of Berlin, Germany)	'BIM Standards', 'Technology adoption', 'Semantic web technologies', 'Construction Industry', 'Value tracking', 'Virtual reality', 'Semantic enrichment', 'Spatial planning', 'Integrated design'	Volk et al. (2014) Bryde et al. (2013) Sacks et al. (2010b)	Chuck Eastman (Georgia Institute of Technology, US) Salman Azhar (Auburn University, US) Bilal Succar (BIMe Initiative)
Asia	Number: 288 H Index: 33 Total citation: 3,715	Rafael Sacks (Israel Institute of Technology) Wang Xiangyu (Kyung Hee University, South Korea) Ghang Lee (Yonsei University, South Korea)	'Procurement', 'safety', 'Sustainability', 'Facility management', 'Tunnel construction', 'Integrated approach', 'Education', 'Construction organisation/management', 'Critical success factors'	Zhang et al. (2013) Singh et al. (2011) Jung and Joo (2011)	Chuck Eastman (Georgia Institute of Technology, US) Salman Azhar (Auburn University, US) Rafael Sacks (Israel Institute of Technology)

Table 1: **Summary and comparison of the findings on BIM research across the six continents of the world**