Article

Bibliometric Maps of BIM and BIM in Universities: A Comparative Analysis

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Abstract: Building Information Modeling (BIM) is increasingly important in the architecture and engineering fields, and especially in the field of sustainability through the study of energy. This study performs a bibliometric study analysis of BIM publications based on the Scopus database during the whole period from 2003 to 2018. The aim was to establish a comparison of bibliometric maps of the building information model and BIM in universities. The analyzed data included 4307 records produced by a total of 10,636 distinct authors from 314 institutions. Engineering and computer science were found to be the main scientific fields involved in BIM research. Architectural design are the central theme keywords, followed by information theory and construction industry. The final stage of the study focuses on the detection of clusters in which global research in this field is grouped. The main clusters found were those related to the BIM cycle, including construction management, documentation and analysis, architecture and design, construction/fabrication, and operation and maintenance (related to energy or sustainability). However, the clusters of the last phases such as demolition and renovation are not present, which indicates that this field suntil needs to be further developed and researched. With regard to the evolution of research, it has been observed how information technologies have been integrated over the entire spectrum of internet of things (IoT). A final key factor in the implementation of the BIM is its inclusion in the curriculum of technical careers related to areas of construction such as civil engineering or architecture.

Keywords: building information modeling (BIM); legal aspects; bibliometric; sustainability; clustering

1. Introduction

The growing requirements for establishing sophisticated buildings are making AEC (Architecture Engineering and Construction) projects more complex, while technological advances are helping the participants to collaborate more effectively during the construction process. In fact, the building information model (BIM) provides an intelligent model-based process that connects AEC professionals and helps them to design, build, and operate building infrastructure [1]. This tool allows professionals to design 3D models that incorporate data associated with physical and operational properties, which will help architects, engineers, and contractors to work on a coordinated digital model, giving everyone a better insight into how their work fits in the overall project [2]. BIM systems encourage greater cooperation between stakeholders through a unique integrated model during the design and construction stages. Adopting BIM in the construction industry will lead eventually to a better planning and preparation process by detecting conflicts between elements and improving coordination. In addition, it will help reduce time costing errors and help decision makers to increase their efficiency during the construction phase, and finally will help facilities management with future changes and renovation work.

BIM is the result of an international collaborative progress starting from Japan and moving to Europe and all the way to Northern America, so the history of this concept is not attributed to one name or one place alone. Although the BIM concept has existed since the 1970s, its development went through many steps until this term was first used officially to identify this notion [3]. The first commercial software known as computer-aided manufacturing (CAM) was developed by Dr. Patrick J. Hanratty in 1957. This numerical control machining technology has progressed to become computer-aided manufacturing [4]. Then, he immersed himself in computer-generated graphics and in 1961 developed DAC (Design Automated by Computer), which became later the first system that used CAM/CAD (Computer-Aided Manufacturing / Computer-Aided Design) interactive graphics [5]. The Augmenting Human Intellect paper where the BIM foundation was first documented was published by Douglas C. Englebart in 1962. With the incorporation of object-based systems, this BIM tool allowed architects to introduce several features and specifications for a building. This new advance made the fusion of parametric manipulation and a relational database possible and as a result the 2D illustration of the current design was formed [6]. Afterwards, 3D representations were developed with the Building Description System (BDS) illustrated by Charles Eastman et al. (1975). In their publication, they describe a generic prototype of BDS and consider the perspectives of parametric design and 3D representations with a "single integrated database for visual and quantitative analysis" [7].

After two years, the requirement to integrate building elements and monitor data accuracy was considered, in order to be used as a tool for estimating structural design costs. The Graphic Language for Interactive Design (GLIDE) tool was developed to implement this utility that allows for more reliable and accurate designs. However, both BDS and GLIDE have limited themselves to including only the design stage of the project, which would not allow the immersion of the different stages of the project life cycle [8]. By the year 1984, personal computers began building modeling programs, which included the first BIM (2D CAD) software used worldwide. However, this software wasn't operational until 1986, when Robert Aish used it in large and complex projects such as the renovation of the Heathrow airport terminal [9]. In the 1990s, several companies began to develop BIM tools, such as the Lawrence Berkeley National Laboratory [10]. Autodesk also began using the BIM concept in 2002 when it purchased the Texan company Revit Technology Corporation [11]. The Graphisoft company created the teamwork concept so that team members would be able to easily share BIM data with each other [12].

The complication of buildings and structures, increased construction and the imperative need to reduce design time, the increase in international design cooperation, and other factors led to the accelerated development of computer design tools.

By the early 2000s, objects and shapes have fully incorporated different type of data in the same file, meaning the designer, contractors, engineers and the owner could all work collaboratively on one centralized collaborative model. Objects and shapes had completely incorporated different types of data into the same file, allowing the designer, contractors, engineers, and owner to work collaboratively on a centralized collaboration model. BIM platforms such as the one shown in reference [13] have been created to incorporate parametric flexibility and sculpture geometry that supports NURBS (non-uniform rational B-spline) surfaces, and provides software that larger teams of architects and engineers can use to collaborate on an integrated model based on using a coherent system rather than a set of separate drawings. The new software works with all the information concerning the construction project, while the 3D model can include architectural, structural, electrical, sanitary, plumbing, Heating, Ventilating and Air Conditioning (HVAC) installation, and fire alarm system designs. All of these layers are merged into a BIM file that can be accessed by project holders at any time and from any location [13,14]. Advanced parametric techniques are then introduced into the BIM software [15], which can process complex and contemporary architectural shapes, enabling designers to create curved and complex architectural shapes. With the advancement of computational design technologies, more unique building designs will be realized [16–21].

BIM 4D modeling is employed in combination with the Geographic information system (GIS) to create a safe execution sequence of the process in order to enhance the visual tracking of construction

supply chain management [22–24]. This can only prove that the BIM platform has a great potential to integrate various innovative operations related to construction. However, to improve the monitoring of the construction process [25,26], companies are using remote sensing technology to develop an approach called defect management for automatic quality inspection.

In the last decade, BIM technologies have improved greatly with the help of information modeling, meaning it is now possible to solve problems that were unimaginable years ago [27]. These technologies have introduced designer supervision, construction cost planning, risk management, etc. State-of-the-art architecture with unique structures and hazardous facilities, whose projects are subject to mandatory government expertise, can be addressed without great difficulty with the help of these powerful tools [28].

Northern European countries such as Finland adopted BIM regulations, e.g., Common BIM Requirement 2012 (COBIM). In 2016, the U.K became in the first country to legally mandat the use of BIM [29] for public funded projects. Germany is mandating BIM for all transportation projects so teams can collaborate and work in the same model [17,19], which will be useful in so many ways such as dealing with predictive risks and maintenance, improving g timelines and cost savings, as well as asset tracking and facilities management. Government agencies are using BIM software to plan and operate diverse forms of physical infrastructure, such as public sanitation, communication utilities, electricity grids, roads, bridges, and ports [3]. Several European and Asian countries, as well as Australia, and the USA have demanded the use of BIM in projects or have published formal standards of good practice [30]. A study at the Northumbria University campus used BIM to improve the collection of data and its accessibility for facilities management [31]. The digital representation of public infrastructure will not only help authorities to manage its current artworks but also will help them to plan better for future projects to avoid interference and unpredicted modifications.

A BIM execution plan for project implementation would help to explain the details of the necessary checklist and standards [32], such as ISO/TC 59/SC 13. These standards form the foundation for accurate and efficient communication and commerce that are required by the off-site construction industry [33]. Regrettably, this is not usually part of the contract. As such, that Northumbria University campus study had revealed insightful implications into significant legal aspects or contract provisions that need to be included in BIM contracts [34]. As an example, in the literature, it is possible to find engineering, procurement, and construction (EPC) contracting, which enables a contractor to be responsible for all works associated with the design, procurement, erection, and testing of a facility [35]. It is possible to find hydro-supported structures [36] being used as offshore wind turbines [37]. Some authors even propose the application of blockchain or smart contract [38] technologies as a possibility for this type of contract [39,40].

With the growing awareness of society and its contribution to maintaining sustainable systems, the construction industry has taken on this social concern and buildings are now designed with energy efficiency in mind. For this purpose, BEM has been combined with BIM. With this combination, the construction industry has the tools needed to solve problems related to the integrated energy analysis of buildings [41,42]. Another objective is the promotion for the construction of green buildings, the practice of building in a way that safeguards the natural environment [43].

Environmental sustainability concerns are frequently addressed as a complement to building design by pursuing ad hoc approaches to project implementation [44]. As a consequence, the most common problem in reaching a sustainable construction result is the lack of the right information at the right time to make crucial judgments. Furthermore, the design of these high performing buildings is a non-linear, complex, iterative, and multi-disciplinary process that requires efficient collaboration between interdisciplinary teams from the first stages to achieve sustainable outcomes [45]. Construction practitioners make extensive use of performance analysis tools to predict and quantify sustainability issues from the earliest stages of design and significantly improve quality and cost over the life cycle of a building [45]. There are very extensive and recent review studies on BIM and sustainability [46], noting that little work has been conducted about how it could be applied in refurbishment and demolition; but highlighting that BIM can improve social sustainability in two main areas: BIM provides a better facility design for a society's high standard of living. BIM transforms conventional practice, which is

often highly fragmented, into a better collaborative effort that strengthens the working relationships among project participants. And this review [46] concludes that future policies of BIM for sustainability should consider improving the interoperability issue among BIM software and energy-simulation tools.

From an engineering point of view, it is important to reflect the complexity of new ways of working. This mixed set of knowledge, skills, and attitudes is essential to strengthen productivity, entrepreneurship, and the pursuit of excellent performance in an environment increasingly based on technologically advanced and sustainable outcomes [47]. A clear example of this involves developing effective measures using a "project-based learning" technique to improve student learning outcomes for the implementation of BIM in the area of sustainability [48]. Therefore, innovative concepts such as sustainability, green concepts, planning processes, or project execution are key aspects to evaluate the key benefits of BIM, and these concepts should be integrated in order to advance their curricula [49].

In this study, there are two objectives. to the first is analyze the background of the whole work published in relation to the BIM subject as bibliometric maps of this subject, and to see which clusters this scientific field is grouped around. And the second objective, given the importance it has for sustainability, is to determine which works of BIM are used in universities to contribute to their sustainability.

The previous published studies of bibliometric analysis on BIM focus on very specific aspects. For example, a study by Badrinath et al. (2016) [33] focuses on how the BIM is taught and then used for communication and visualization. That study was based on the bibliometric analysis of 445 BIM articles, but above all it was based on double keywords not covering the whole subject, these keywords were: "academic BIM education", "BIM curriculum", and "BIM course". Although the work is interesting, it is focused on a very specific area, which is academic BIM education. It was concluded that the case studies and experiences were the dominant type of publication.

In the literature there are other works focused on bibliometric studies of the BIM, but all of them make a subjective classification, and are based on databases other than those used of this study, for example in the WoS™ Core Collection [50] or Web of Science [51]. And although some of them open an important temporal window, from 1990 to 2016 only 567 publications appeared, and the ones which analyzed the relevant topic only numbered 445 [52].

Through Scopus, it is possible to find some bibliometric work but in a very short period of time (2006–2016) [53]. Although it uses community or cluster detection, it found only 4 clusters for 1031 available studies, it is notable that this work was looking for the specific topic of BIM-based Construction Networks (BbCNs). On the subject of the research, it was discovered that collaboration was a concept researched in isolation and without strong connections to other key areas of BIM research. Other works based on Scopus are state of the art revision works [54], and the database was therefore not used only to have a list of published works, but also to develop a bibliometric analysis. However, Scopus covers a wider range of journals in the area of construction project management than the WoS and contains more recent publications than other databases [55].

2. Research Methodology

The flowchart of the research methodology is shown in Figure 1. In this study, all the publications (4307) were collected from Elsevier Scopus database. This platform is useful for bibliometric studies because it allows you to download massive information for numerous bibliometric analysis. The search was conducted in March 2019 to extract research publications that include the following citations "BIM" or "BIM in University" and "Building Information Model" or "Building Information Model in University "in the title, abstract and/or keywords within the period (2003–2018). The following search queries were used: (TITLE-ABS-KEY ({BIM} OR {Building Information Model}), and another one specific for plant: (TITLE-ABS-KEY ({BIM} OR {Building Information Model} AND{Universit*}). Thus, in the first query all the published works on BIM have been found, and the second query acts as a filter on the first, where only those works that deal with the subject of the university remain. It should be noted that the subject categories are the result of the Scopus indexation.
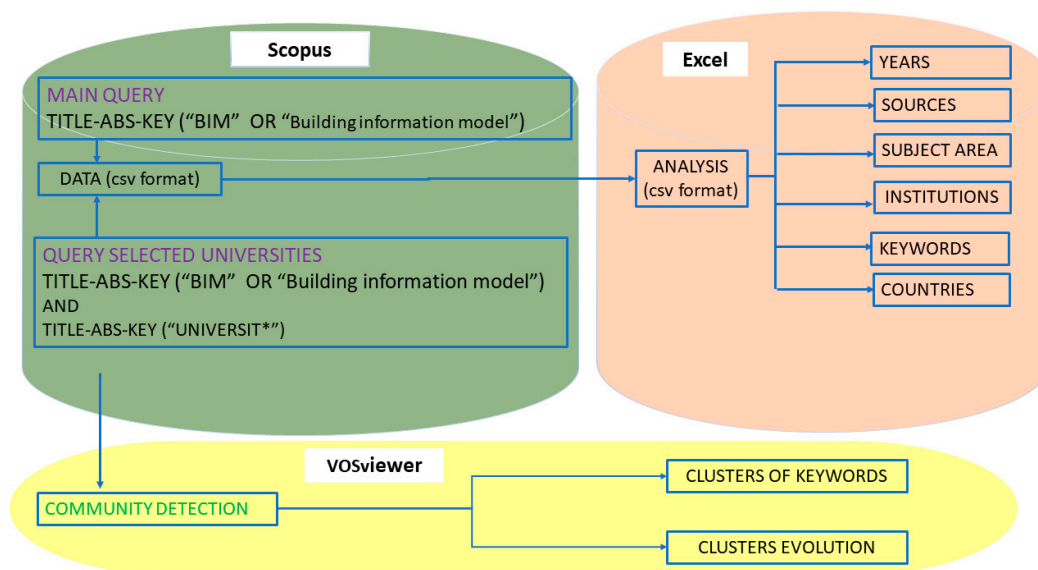
Figure 1. Flowchart of the information search and analysis.

2.1. Data Collection

The main query provides information such as the source of publications according to their authors, institutions, as well as their geographic locations. The publications acquired have been classified based on the following characteristics: the number of publications per year, distribution by subject area, document category, institution, and by country. The word frequency analysis is carried out to reflect the research field, and the core subject of BIM literature keywords are extracted and collected by filtering the main query. The records were consecutively processed using excel sheets, as well as the generation of the result corresponding graphics.

2.2. Community Detection

Community detection is a procedure that identifies geographic locations, trends, and other parameters of a large group of elements that interact with each other. This relationship between elements could vary in intensity that transcribes their dependency on each other. These multiple interdependent nodes evolve around one central core that is highly cohesive, while the density of interactivities decreases as we go far from the center. This structure is called a cluster, and the union of multiple clusters form from a complex network, which usually comes out in the form of a neural network. In this work we have proceeded by using Sw VOSviewer to detect the network community. This tool illustrates the most significant clusters based on the hierarchical connectivity algorithms [37]. This community detection software, VOSviewer, is free software available online that allows the direct import of data in the csv format exported from Scopus and also allows the figures to be exported to a large range of graphical formats. The VOSviewer delivers three displays: network visualization as clusters, overlay visualization as temporal evolution, and density visualization. In all of these cases, the parameters chosen for the analysis were: normalization method (association strength), layout (attraction 2, repulsion 0), clustering (resolution 1.00, minimum cluster size 1), and rotate (90 degrees).

3. Results and Discussion

3.1. Evolution of the Number of Publication Over the Years

We can observe in Figure 2 that the evolution of BIM in university publications is relatively weak compared to BIM global, which has a parabolic pattern over the period studied. The figure also shows that scientific production started to increase substantially since 2007. The total number of BIM and BIM in university publications are 4307 and 274, respectively (3.36%).
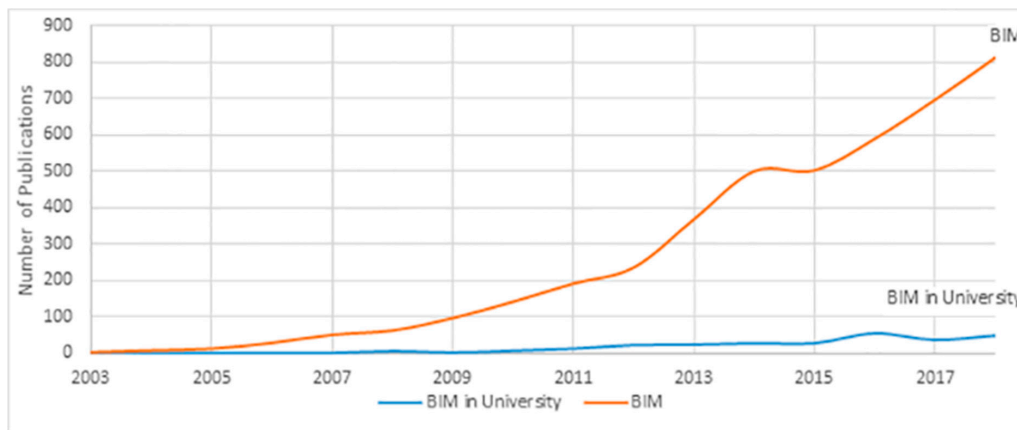
Figure 2. Evolution of the scientific production of BIM (2003–2018).

3.2. Distribution of Output in Subject Categories

Based on the Scopus classification, the distribution of publications on BIM research fields covered a total of 22 subject areas, see Figure 3. The largest number of documents corresponds to engineering (3234 records, 44%), computer science (1423 records, 20%), and business management and accounting (494 records, 7%) while the fourth largest number is for social sciences (389 records, 5%), the fifth is for mathematics (341 records, 5%) and the sixth is for environmental sciences (250 records, 3%). It is worth mentioning that a document can be related to more than one field of research at the same time. These six areas count for about 85% of all publications (Figure 3). The distribution of publications on BIM in the university research area reduced the number of subject areas, enclosing only 18 subject areas. The four first areas were the same as those showed by the global BIM research field. The first highest area according to number of publications was engineering (218 records, 43%), computer science was the second highest area (68 records, 13%), business management and accounting was the third highest (52 records, 10%), and social science was the fourth highest (48 records, 10%). Arts and humanities were in the fifth position (22 records, 4%), while energy accounted for the sixth position (17 records, 3%). BIM studies are mainly focusing on engineering and computer science, which involves architecture, mechanical structure design, and construction. It can be concluded that they are essentially the same categories that are given significance in both cases.
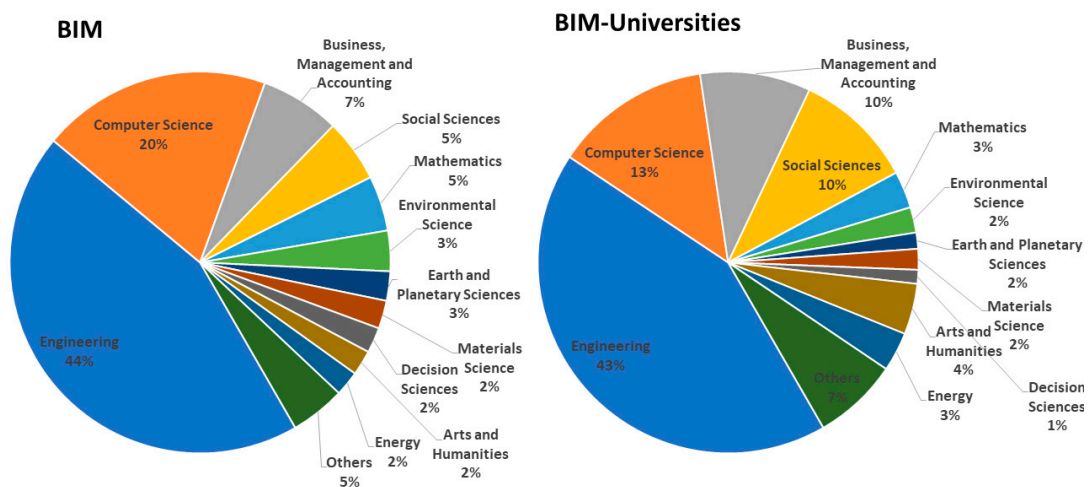

Figure 3. Distribution (%) of worldwide research of BIM and BIM in universities by subject area.

3.3. Types of Publications

The most common means used in scientific diffusion are journal articles. However, in the case of BIM, conference papers are the type of publication that counts for the biggest share with 49%, followed by scientific articles with 41% and articles in review with 3%, followed by books and book chapters with 3%. Figure 4 shows the percentage of the types of scientific production distributed on the building information model theme.
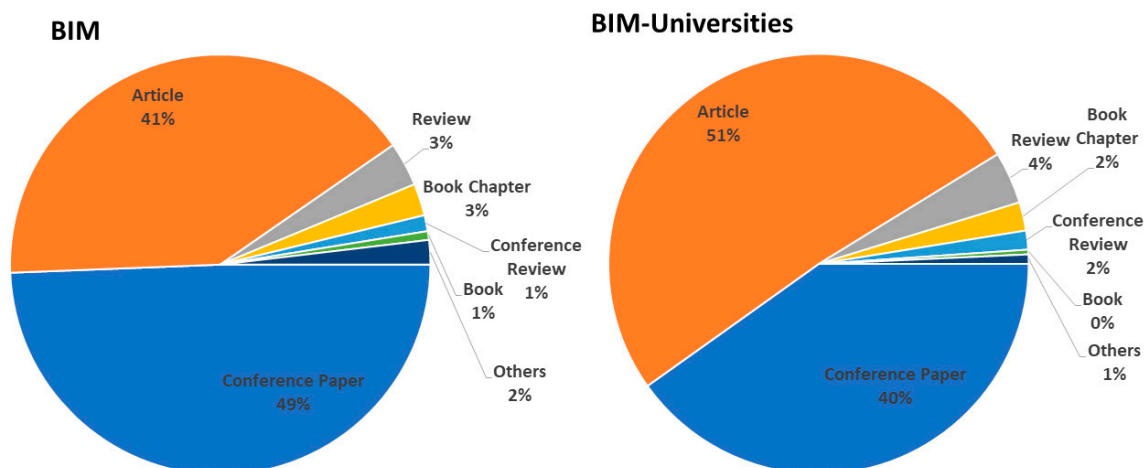

Figure 4. Distribution by publication type related respectively for global BIM and BIM in universities.

Regarding BIM in universities, scientific articles are the type of publication that counts for the largest share of BIM in university publications with 51%, followed by conference papers with 40%, articles in review with 3%, while books and book chapters had 2%. Figure 4 shows the percentages of the types of scientific production distributed on BIM in universities. It is remarkable that in the case of the universities the topic of BIM is predominant in the articles, while for BIM in general the topic is predominant in the conference papers. In general, the higher the percentage of conferences, the more novel the topic is. And when the percentage of books and book chapters is high, this indicates a topic that is scientifically established. BIM is therefore shown to be very novel, given the large percentage of conference paper in both cases.

3.4. Distribution by Countries and Institutions

If the distribution by country of the publications in BIM is represented (see Figure 5), it can be seen that the 10 highest countries are: the United States (20%), the United Kingdom (10%), China (9%), Australia (6%), South Korea (6%), Germany (5%), Canada (4%), Malaysia (3%), Italy (3%), and Taiwan (3%). It can be seen that almost 40% of publications are grouped in the first three countries.

BIM research has been produced in more than 160 institutions. Table 1 shows the top 20 the most productive institutions, with more than 4307 publications covering the BIM concept in the period studied. The first sixteen institutions (10% of total institutions) are from the USA, Australia, the UK, South Korea, China, Italy, Malaysia, Israel, and Germany. They are represented by the following affiliations: the Georgia Institute of technology (USA), Curtin University (UK), University of Florida (USA), University of Salford (UK), Kyung Hee University (South Korea), Pennsylvania State (USA), Hong Kong Polytechnic University (China), Politecnico di Milano (Italy), University Tongji University (China), Hanyang University (South Korea), Universiti Teknologi Malaysia (Malaysia), Cardiff University (UK), University College London (UK), Tsinghua University (China), Israel Institute of Technology (Israel), and the Technical University of Munich (Germany). Universities from the USA have the most representations with 988 publications, UK has the second highest production with 518 records, while China has the third highest rank with 460 publications. BIM in university publications have been produced in the same number of institutions as the global BIM.
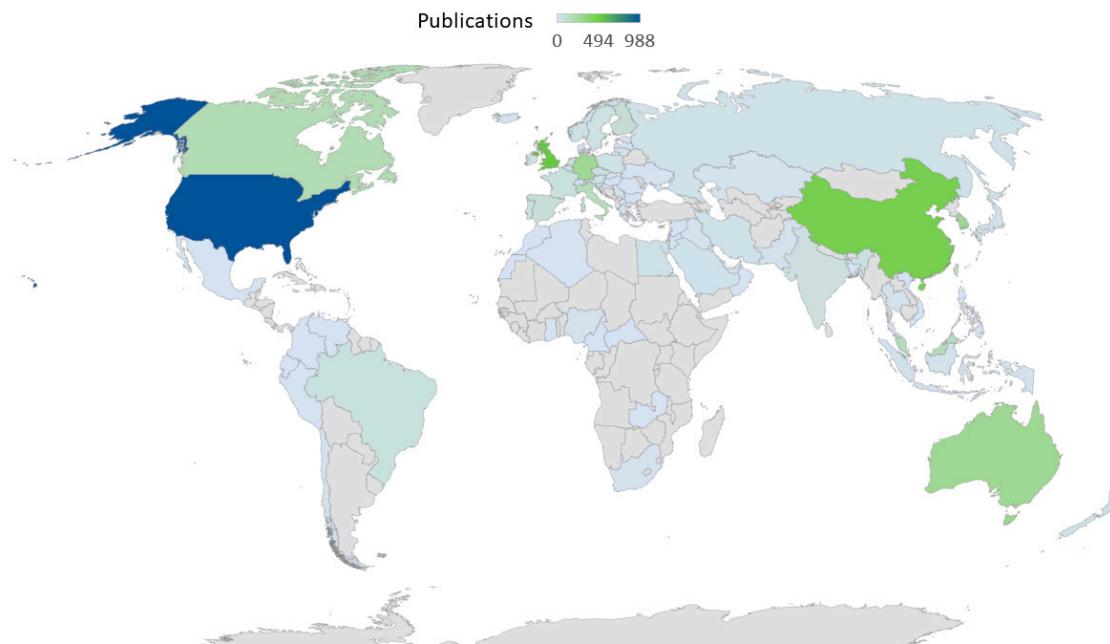
Figure 5. Distribution by countries of BIM publications.

Table 1. Classification of research institutions by record and countries.

BIM			BIM in University		
Affiliation	**Country**	**N**	**Affiliation**	**Country**	**N**
Georgia Institute of Technology	USA	101	Pennsylvania State University	USA	9
Curtin University	UK	98	Hong Kong Polytechnic University	China	9
University of Florida	USA	93	Tsinghua University	China	8
University of Salford	UK	68	Arizona State University	USA	6
Kyung Hee University	South Korea	56	Ceské vysoké ucení technické v Praze	Czech The Czech Republic	5
Pennsylvania State University	USA	55	National Taipei University of Technology	China	4
Hong Kong Polytechnic University	China	54	University of Southern California	USA	4
Politecnico di Milano	Italy	49	Vilniaus Gedimino technikos universitetas	Lithuania	4
Tongji University	China	49	Universidade de Lisboa	Portugal	4
Hanyang University	South Korea	48	Helsingin Yliopisto	Sweden	3
Universiti Teknologi Malaysia	Malaysia	47	University of Texas at San Antonio	USA	3
Cardiff University	UK	46	National Taiwan University	Taiwan	3
UCL (University College London)	UK	43	University of Salford	UK	3
Tsinghua University	China	43	University of Wyoming	USA	3
Technion—Israel Institute of Technology	Israel	42	Universitat d'Alacant	Spain	3
Technical University of Munich	Germany	41	International University of Florida	USA	3

However, the BIM in university research area had more than 274 publications in the studied period, although this number remains small in comparison to BIM global. The sixteen most productive institutions (10% of total institutions) have been developed in the following countries: the USA, the Czech Republic, the UK, China, Lithuania, Spain, Portugal, and Sweden, all of which are represented by the following universities: Pennsylvania State University (USA), Hong Kong Polytechnic University (China), Tsinghua University (China), Arizona State University (USA), Ceské vysoké Ucení technické v Praze (Czech Republic), National Taipei University of Technology (China), University of Southern California (USA), Vilniaus Gedimino technikos Universitetas (Lithuania), Universidade de Lisboa (Portugal), Helsingin Yliopisto (Sweden), University of Texas at San Antonio (U.S.A), National Taiwan University (Taiwan), University of Salford (UK), University of Wyoming (USA), Universitat d'Alacant (Spain), and the Florida International University (USA). Institutions from the USA are the most highly

represented with 79 publications, the second country had 28 publications, while Chinese universities had the third rank with 18 publications.

3.5. Relationships between Countries

Figure 6 shows the labeled clusters with the relationships between the countries of the various publications. This is generally determined by the co-authorship of articles, i.e., authors from different countries who wrote the same article. Each element represents a country and the size of these elements is determined by the total number of publications of this country. The network counts 10 communities, their rank order respectively is the USA, the UK, China, Australia, Germany, South Korea, Italy, Spain, Finland, and Taiwan. It is observed that in the clusters of these countries, there is a major correlation with nearby or neighboring countries, which is not frequently found in scientific subjects. Examples of this include the USA with Canada, China with Hong Kong, Germany with Austria or Switzerland, the UK with Ireland, Finland with Norway, or the Czech Republic with Poland.

The countries that are in the middle of the cluster are the ones who are linked with the most nodes. Language plays a key role in the interconnections between countries. The largest community is the one that evolves around the USA. These publications are written mostly in English in more than 92% of cases, although the Chinese language has also appeared in 5.5% of publications since 2006, while other languages numbered less than 1% and included Japanese, Dutch, German, Polish, Russian, Spanish, and French.
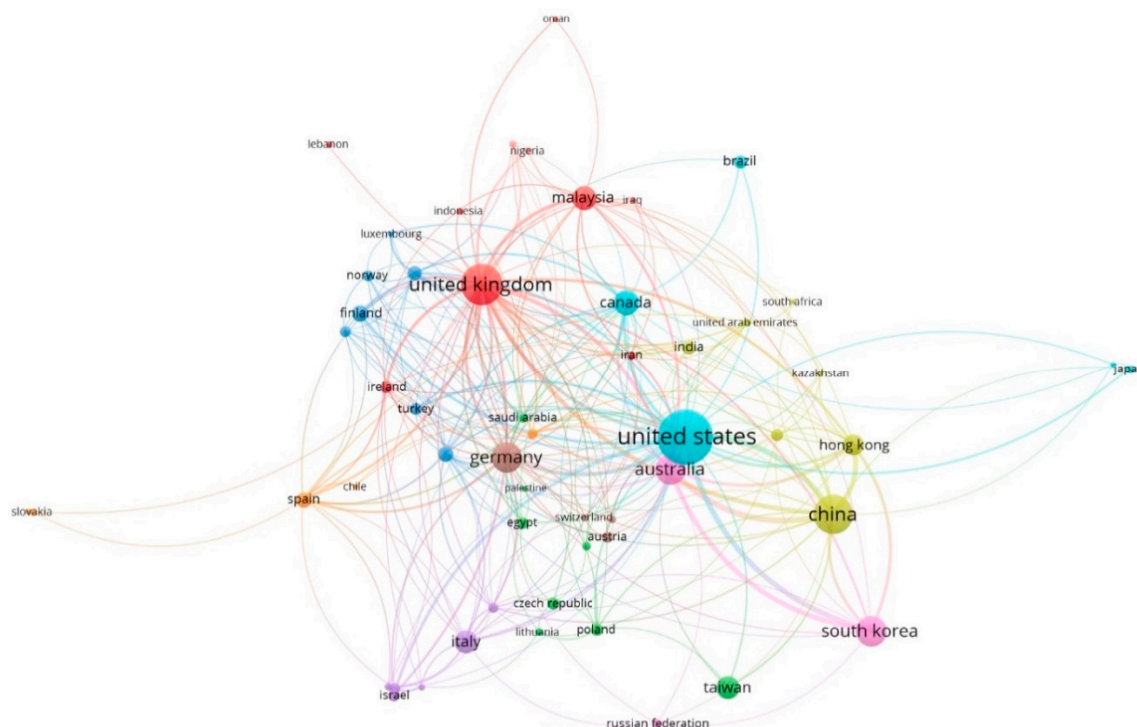

Figure 6. Countries network of BIM publications.

3.6. Keyword Analysis

The keywords analysis identifies the common interests of the researchers and their work. In this section we analyze the keywords acquired from the main query as well as their frequency of appearance in every article during the period studied. If the main keywords associated with the theme of the global BIM are analyzed, those of Table 2 are obtained, where the 15 main keywords have been selected. The words of the search itself, such as BIM or Building Information Modeling or Building Information Modelling, have not been taken into account (since it is written in both forms almost equally frequently). It is noted that the general main search keywords are also the first keywords of the particular search in

universities. However, in the latter case there are, as expected, issues related to teaching: Students, Curricula, Teaching, Education, or Engineering Education.

Table 2. Main keywords related with both queries.

BIM	N	BIM in Universities	N
Architectural Design	3075	Architectural Design	168
Information Theory	1295	Information Theory	66
Construction Industry	935	Construction Industry	41
Buildings	671	Students	40
Construction	642	Buildings	39
Project Management	602	Curricula	38
Information Management	458	Project Management	37
Structural Design	458	Teaching	37
Life Cycle	377	Construction	35
Construction Projects	354	Education	35
Sustainable Development	291	College Buildings	34
Office Buildings	279	Information Management	30
Design	255	Engineering Education	27
Computer Aided Design	239	Surveys	20
Decision Making	224	Life Cycle	19

The more interesting data are the keywords College Buildings, which show that BIM is starting to also be applied for the construction of university buildings, while global BIM is mainly focused on office buildings. If a visual representation is made with clouds of the keywords, then Figure 7; Figure 8 are obtained. These figures show where a particular study has to be done for automation, sustainable development, or industry foundation classes (IFC).
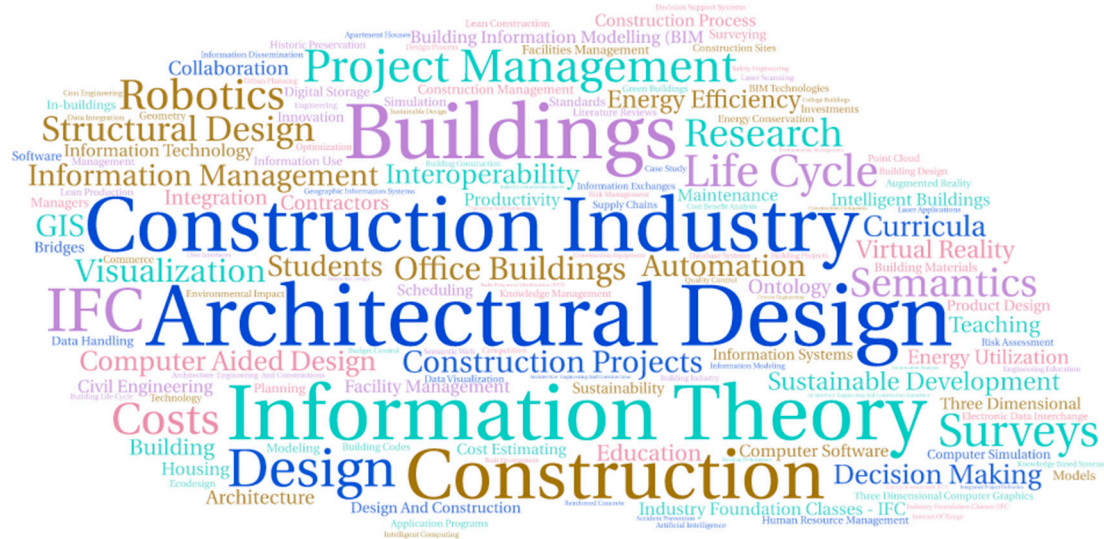

Figure 7. Word cloud of keywords related to BIM (global query).
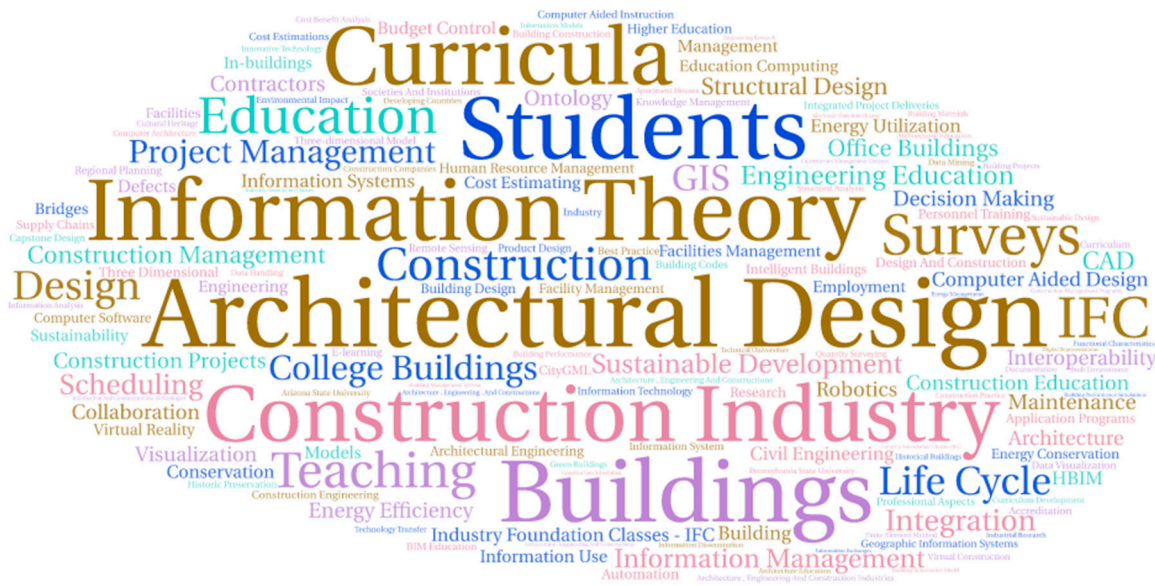
Figure 8. Word cloud of keywords related to BIM in universities.

Figure 9 shows the evolution of the following keywords: automation, sustainable development, and IFC. The three-keyword records were correlated during the greater part of the period studied. In addition, automation and sustainable development had approximately the same level of variance in the same value until 2013, when the gap started to grow wider between them. The automation record continued to increase remarkably until it reached 94 records in 2018. IFC had been scoring a lower score than sustainable development until the year 2018, when IFC obtained 53 records and sustainable development obtained 33 records.
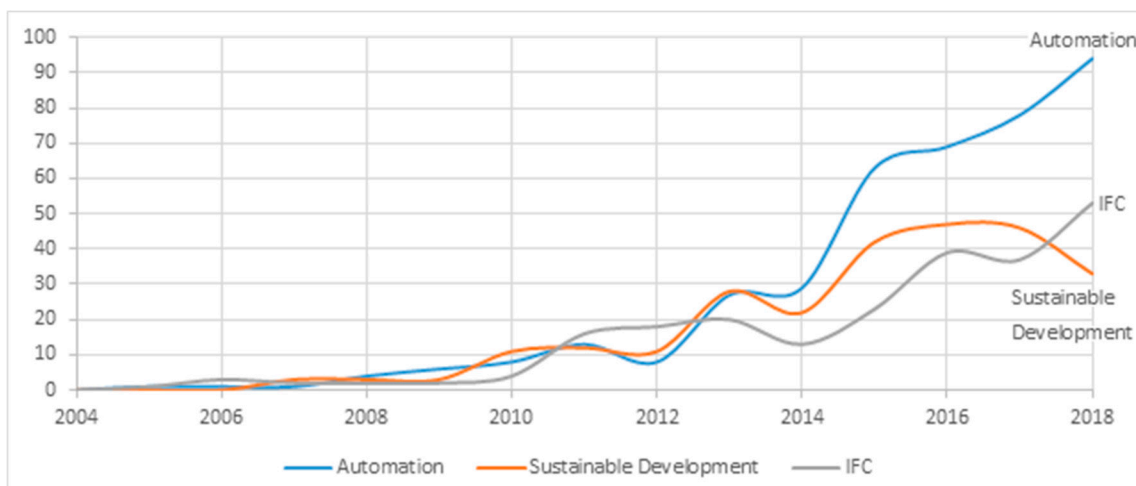

Figure 9. Countries network of BIM publishers and their community detection.

The major topics in Table 3 and Figure 10 constitute the structure of BIM. Management is the first topic that most relevant keywords evolve around, while the technology of BIM plays a crucial role in improving the interaction between different contributors and the ways in which they manage various aspects of the project development and BIM implementation during the building life cycle.

Table 3. Main keywords used by the communities detected in the topic BIM.

Cluster	Color	Main Keywords	Topic
1	Red	Construction management —Collaboration –Information technology—Bim adoption	Construction management
2	Green	Interoperability-Facility management—Industry foundation classes —Internet of Things	Documentation and Analysis
3	Blue	Architecture—Virtual Reality—Education—GIS	Architecture and Design
4	Orange	Lean construction—Implementation—Adoption —Benefits	Construction/Fabrication
5	Yellow	Energy efficiency—sustainable design—Leadership in Energy and Environmental Design—energy simulation—Building performance	Operation and maintenance

Figure 10 illustrates numerous keyword clusters in the form of a neural network with different colors, where the co-occurrence of keywords occurs at least 5 times. Each node is a keyword, and the link thickness between nodes represents the degree of connection. The BIM keywords analysis has identified six communities using a community detection algorithm and Table 2 shows their main clusters by their order of importance. The most significant clusters besides building information model are construction, interoperability, virtual reality, architecture, collaboration and construction management, visualization, and automation. These communities provide a general indication of the fields that are related to BIM, which are diverse and technology oriented.
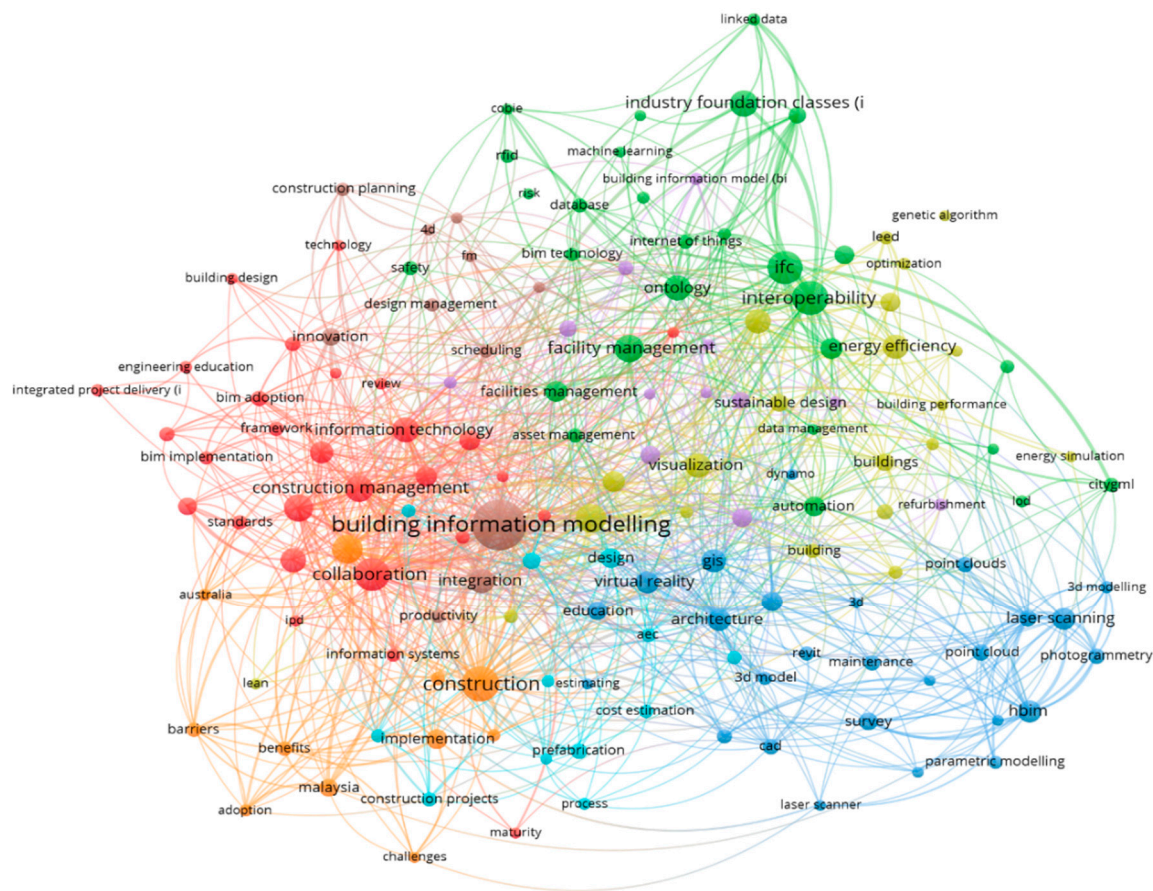

Figure 10. Keywords co-occurrence network related to BIM worldwide.

Analyzing the first cluster, in red in Figure 11, where only keywords with a minimum of 15 co-occurrences have been highlighted, it can be seen that it is related to construction management, collaboration, information technology, and BIM adoption. This shows that BIM is not only useful for geometric modeling of a building's performance but can also assist in the management of construction projects [56]. Some works highlight the synergy between facility management and BIM as a basis for multidisciplinary collaboration [57]. Within this community or cluster, the information technology that is developing object-oriented Computer Aided Design (CAD) tools compatible with BIM can be found, such as analysis tools, model verifiers, and facility management applications [58]. It should be remembered that the main difference between BIM technology and conventional 3D CAD is that the latter describes a building through independent 3D views, such as plans, while BIM uses all the information related to the building, including its physical and functional characteristics and information about the project life cycle, in a series of "smart objects" [59].

The second cluster, in green in Figure 12, where only keywords with a minimum of 15 co-occurrences have been highlighted, is shown to be associated with interoperability, facility management, industry foundation classes, and IoT. BIM is an expansive area of knowledge inside the architecture, engineering and construction industry [60]. An example of this is building automation, e.g., for on-site assembly services in prefabricated buildings with IoT, where the IoT-enabled platform can provide various decision support tools and services to different stakeholders [61]. As an example of industry foundation classes, it is possible to find works where various standards have been published, leading up to the 10-year development of industry foundation classes [62].

The cluster related to architecture, cluster 3 with the color blue in Figure 13, where only keywords with a minimum of 15 co-occurrences have been highlighted, has architecture; virtual reality, education, and GIS as the main related keywords. BIM offers the potential to achieve a lower project cost, increase productivity and quality, and reduce project turnaround time [58]. There are several great examples in the literature of the integration of architecture and GIS showing benefits such as reusability and extensibility [63]. Virtual reality is relevant because it allows us to make a 3D reconstruction of architecture appearance [64]. Both areas are very important in teaching, e.g., for the teaching of architecture through augmented reality [65,66].

The orange cluster four in Figure 14, is mainly related to the keyword's lean construction, implementation, and adoption benefits, cost/benefit analysis, awareness raising, and education and training, all of which are important activities to address the challenges of BIM usage. From the analysis of numerous works related to BIM, it was inferred that the benefit of BIM most frequently relates to cost reduction and control throughout the project life cycle, but significant time savings were also reported. The costs of BIM focused primarily on the use of BIM software [67]. Of course, the benefits are proportional to the form of implementation of the BIM [68].

The last cluster, in yellow in Figure 15, where only keywords with a minimum of 15 co-occurrences have been highlighted, focuses on the keywords: Energy efficiency, sustainable design, leadership in energy, environmental Design, energy simulation, and building performance. For a sustainable building, the use of its energy always involves customers and designers [69]. This includes important aspects of environmental design, e.g., to determine what the forecast CO_2 emissions are from the building and whether it will meet the performance criteria [70]. It should be noted that retrofitting of existing buildings offers significant opportunities for reducing global energy consumption and greenhouse gas emissions [71,72]. Therefore, a model based on BIM that can enhance the post-occupancy assessment processes and meet the industry standards for sustainable buildings would be useful.
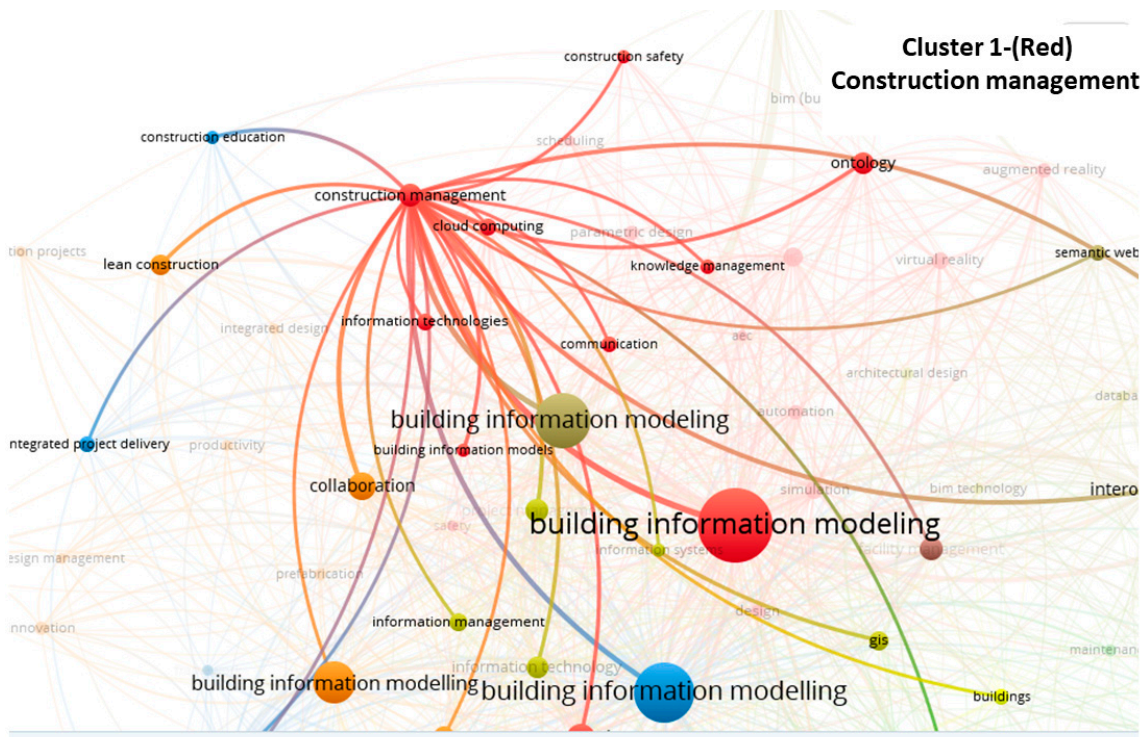
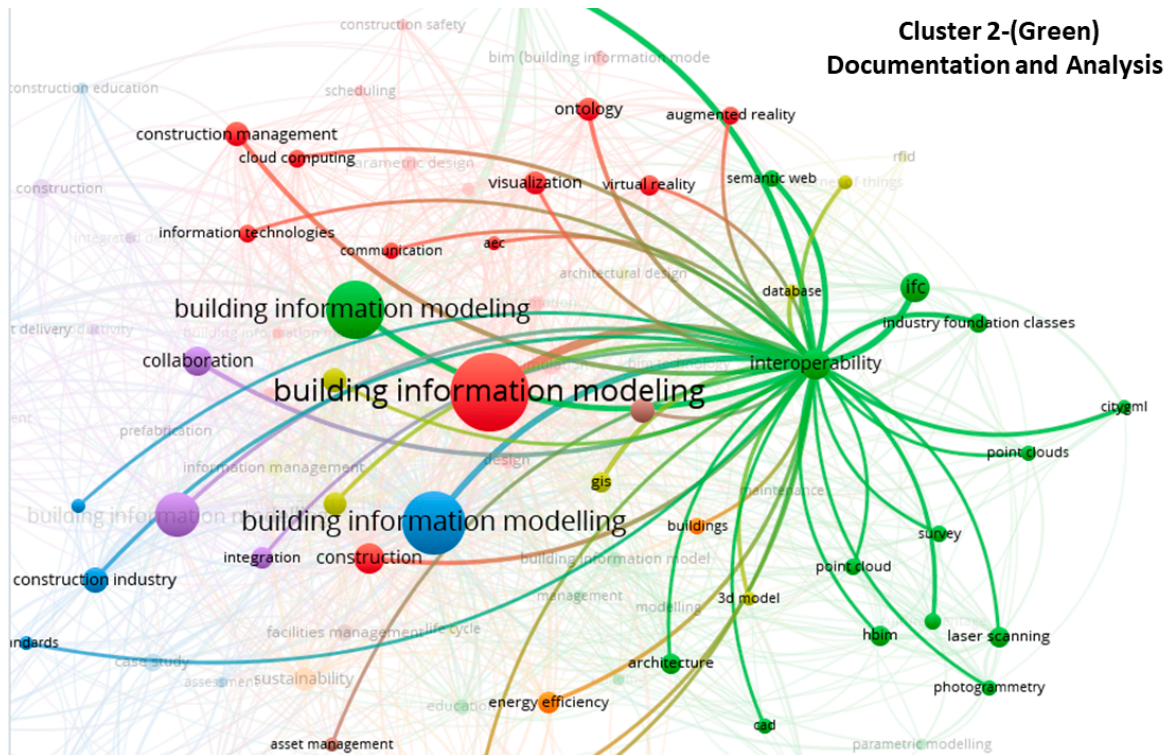**Figure 11.** Keywords co-occurrence for cluster 1 (Construction management).

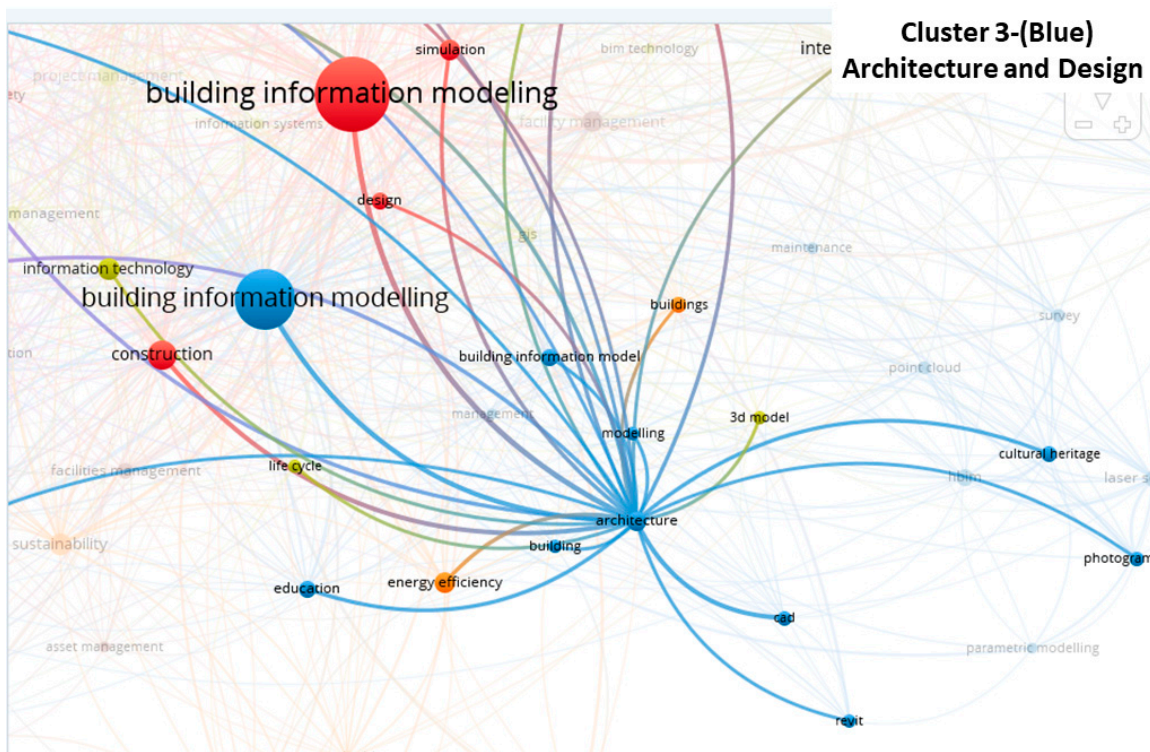**Figure 12.** Keywords co-occurrence for cluster 2 (Documentation and Analysis).

Figure 13. Keywords co-occurrence for cluster 3 (Architecture and Design).
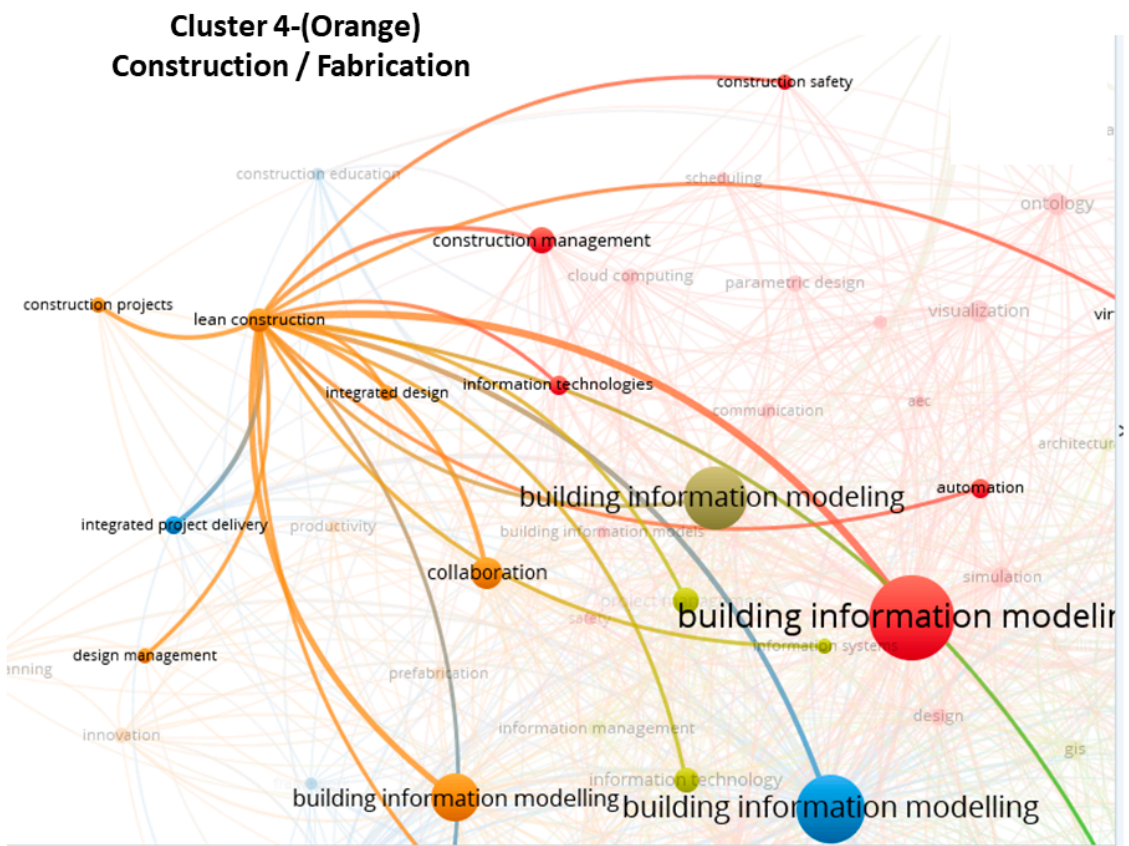

Figure 14. Keywords co-occurrence for cluster 4 (Construction / Fabrication).

Figure 15. Keywords co-occurrence for cluster 5 (Operation and maintenance).

Figure 16. Evolution BIM research (2014–2017).

The network analysis illustrates the evolution of BIM within the period from 2014 to 2017 (Figure 16). It shows that all the major clusters spread from the central communities that represent BIM in different designations, while this analysis also reveals the structure of the current network and the composition of the future trends.

Of the whole studied period of BIM research, i.e., from 2003 to 2018, the period with the highest rate of evolution in BIM research found is from 2014 to 2017. In those years, the keywords were (indicated by purple in the year 2014): cad, parametric design, information technology, built heritage or integrated project delivery. In the years 2015–2016 (indicated in green) the main keywords were: lean construction, GIS, facility management, energy efficiency, or sustainability. The end of the evolution period (yellow, the year 2017) is shown by frequent keywords used: social network analysis, IoT, safety, SMES as the acronym for Small and Medium-sized Enterprises, and higher education. This evolution shows how information concepts and technologies have been incorporated into the research of the BIM as the IoT, obtaining importance in the curricula of students of higher education in careers such as engineering and architecture as a key factor for BIM implementation [73–75].

4. Discussion

Countries like China, the UK, Canada, South Korea, Germany, the USA, Australia and Italy are among the top publishers of both BIM global and BIM in universities. The geographic location plays a major role in the composition of most of the clusters. The UK's cluster is larger than more than six countries outside of the European continent combined. In addition, China is the leader in research about BIM within the Asian continent. The collaborating work of authors shapes the bibliometric map of BIM through numerous parameters, while citation network analysis of the cited references indicates a wide range of subjects in this field of research such as computer science, engineering, business, management and accounting. These different subjects show the diversity of this research area. The keywords analysis provided a list of diverse words related to themes like architectural design, construction management, interoperability, lean construction, virtual reality, visualization, robotics and sustainability development. The extensive amount of data that is generated to improve the facilities management requires multidisciplinary applications of BIM. Therefore, the use of advanced technology is emerging in order to be able to respond properly to market challenges. BIM applications are moving towards IoT, safety, digitalization, smart building, social network analysis, and point cloud. Thus, automation will play a significant role either in providing a highly accurate 3D model for the existing buildings, or in providing a system that measures, collects, and analyzes data of the key performance metrics based on the IoT concept. Furthermore, a digitally empowered framework will enable the decentralization of facilities management for single or multiple buildings [20,21], and could provide a finished product to end-users for cognitive building operation. In term of safety, professionals and researchers are working to develop an approach to integrate the risk factor in building an information model. The tool will be able to detect and quantify automatically any potential risk within the construction site and the life cycle of the project [17,19,26]. Several studies have applied social network analysis (SNA) to investigate major risks related to the act of building and to identify the network structure of all the contributor relationships [26]. Other research suggests using risk factors integration from an online application called the Safety in Design Risk Evaluator, which measures risks at the item-level in multistory buildings with a 4D building information model and a construction timetable [31]. Therefore, BIM trends as many other concepts are mainly heading towards the adoption of digital technologies, big data, IoT, smart models, and machine learning. The expertise areas extracted from the co-occurrence network include interoperability, IFC, lean construction, BIM implementation, energy efficiency and BIM education. Most of these fields are technology based, which has led to a fast-growing knowledge of BIM and its sub-areas that we can see in the evolution pattern. Therefore, BIM education should be constantly upgraded to deliver a valuable knowledge of this dynamic platform.

BIM should be understood as cycle where are all the phases related to the building industry. These phases are: programming, conceptual design, analysis, documentation, fabrication, construction, construction logistics or management, operation and maintenance, demolition, and renovation. The clusters obtained in the previous section reflect almost all of these phases of the BIM, but the cluster of demolition and renovation are missing. This gap in BIM research is already pointed out by some recent works [76]. This shows that these two fields of research within the BIM; although they are currently not fully developed.

5. Conclusions

This bibliometric approach can meaningfully contribute to the ongoing manual review of BIM. Conference papers are the main source of scientific publications, followed by scientific article and reviews. Experts and researchers mostly contribute to expanding BIM literature through these channels, and the rest are published through book chapters, conference reviews and article publications. The scientific contribution in this study refers to 4307 articles associated with BIM, where only 6.4% of these articles related are to BIM in universities and 46% is published in just three countries, which are the USA, UK, and China. The bibliographic records provide users with necessary data about the affiliation of different articles. Furthermore, four out of sixteen universities are present for both of the research topics BIM and BIM in universities. Georgia Institute of Technology and Pennsylvania State University are the leaders in this emerging area of research. It is also observed that the countries that made the usage of BIM mandatory in the regulation of construction are the ones which have the most interest in researching and developing this concept. The five clusters obtained in BIM research are those of the cycle in which all phases related to the construction industry are found: construction management, documentation and analysis, architecture and design, construction / fabrication, and operation and maintenance (related to energy or sustainability). However, the clusters of the last phases such as demolition and renovation are not present, which indicates a field that still needs to be developed and researched. With regard to the evolution of research, it has been observed how information technologies have been integrated with IoT. Finally, a key factor in the implementation of the BIM is its inclusion in the curriculum of technical careers related to construction such as civil engineering or architecture. Therefore, in order to remain up to date and meaningful, education in construction needs to take advantage of the opportunities and overcome the challenges presented by BIM. This bibliometric analysis provides a general overview of the subject in order to concentrate on the strategies that are still relevant and to open up promising new lines of research. This work opens new perspectives for the use of the BIM in universities, which has been found to be less extensively covered than BIM at a global level.

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