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Global bibliometric analysis of Building Information Modeling through the Web of Science Core Collection (2003-2017)

Análisis bibliométrico mundial de BIM a través de la colección principal de la Web of Science (2003-2017)

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ABSTRACT

The main objective is to perform a quantitative and qualitative analysis from the institutional point of view of the related research on Building Information Modeling (BIM) collected in the Web of Science Core Collection during the period 2003-2017. For this, all documents of the type 'article' or 'review' were reviewed and several bibliometric indicators analyzed. Similarly, the international dissemination of the research of the 16 most productive countries was analyzed, indicating the publication journals of each country and concluding that the main journals. USA is the most productive country although with a relative impact factor slightly higher than average due to the dispersion of its publications in journals of medium or low impact. It also shows how *Curtin University (Australia)* and *the Georgia Institute of Technology (USA)* have been the most productive and high impact institutions, although the outstanding rise of *Hong Kong Polytechnic University* is noted.

Keywords: BIM (Building Information Modeling), Web of Science core collection, bibliometric analysis, quantitative analysis, qualitative analysis, institutional analysis, country analysis.

RESUMEN

El principal objetivo es realizar un análisis cuantitativo y cualitativo desde el punto de vista institucional de la investigación relacionada con BIM presente en la colección principal de la Web of Science durante el período 2003-2017. Para ello, fueron revisados los registros del tipo 'artículo' o 'revisión' y se analizaron diferentes indicadores bibliométricos. La difusión internacional de investigación de los 16 países más productivos fue analizada, indicando las revistas de publicación de cada país, así como las principales revistas. Asimismo, EE.UU. es el país más productivo, aunque con un factor de impacto relativo algo mayor que la media debido a la dispersión de sus publicaciones en revistas de medio y bajo impacto, y la Universidad de Curtin (Australia) y el Instituto de Tecnología de Georgia (EE.UU.) son las instituciones más productivas y con alto impacto, sobresaliendo también la Universidad Politécnica de Hong Kong.

Palabras clave: *BIM, Web of Science colección principal, análisis bibliométrico, análisis cuantitativo, análisis cualitativo, análisis institucional, análisis por países.*

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1. INTRODUCTION

As one of the most influential innovations in the construction industry, Building Information Modeling (BIM) is able to facilitate work in different areas such as construction, industry, manufacturing and facilities management (1)(2)(3)(4). The concept of BIM was suggested by Eastman (5), and later used by Van Nederveen and Tolman (6) and Tolman (7), and can be described as an integrating technology that modifies the digital process of building representation (8).

Given the great thrust of publications related to BIM in its different areas or categories, it has been considered appropriate to carry out a bibliometric analysis different from those carried out to date, in order to extract results from an institutional point of view at both the country and research center levels of research, using the Web of Science (WoS) Core Collection database as the main worldwide database given that the main scientific journals are identified with Impact Factor (IF), and with a minimum quality level governed by the pairs review system (blind or double blind peer review).

Institutional studies of this type, where scientific publications are analyzed through quantitative and qualitative indicators, have been carried out previously (9)(10)(11). The qualitative analysis can be carried out through various indicators such as the number of citations received (12), through the h-index (13), the Eigenfactor (14), or through the IF (15), among others. However, this last method is the most widely accepted by the scientific community, despite the criticisms of its use (16)(17), since for its calculation only the last 2 years are chosen, when the tendency to change is much slower, or that a document is considered to be of higher quality the more times it is cited.

As a first approximation in the field of construction, it is convenient to indicate that there are interesting publications where bibliometric analyses of some main journals of the Journal Citation Reports (JCR) (18)(19) are carried out, or of the Spanish scientific publications in the Category 'Construction & Building Technology of the JCR (10), although not specifically BIM.

After an exhaustive revision in WoS of the publications that deal with bibliometric analysis related to BIM, some of them have been found to be very interesting. From a bibliometric review of improvements in building maintenance (20), research on BIM in China (21), or the analysis of Brazilian scientific production on BIM in the period 2000-2015 (22), passing through bibliometric analysis to identify research clusters (knowledge domains or knowledge bases) and topics in the BIM community (23), studies through co-author analysis, co-word analysis and co-citation analysis (24), bibliometric analysis to characterize the 8 emerging categories of work related with BIM as well as the most researched topics (25), studies on collaboration in BIM-based construction networks (26), analytics for mapping the managerial areas of Building Information Modeling (27) and finally conducting studies to analyze the evolution in the intellectual structure of BIM research (28).

However, there are no studies worldwide that use other quantitative and especially qualitative bibliometric indicators such as the Impact Factor, h-index or the average number of citations per document to establish ranking among countries and research centers (29)(30). There is as well no detailed analysis of the dissemination of research related to BIM, in the main international journals and for the most productive countries. Similarly, the detail of the collaboration network between countries and especially between research centers has been deepened in order to detect the three main collaborators and the percentage of their collaboration.

For all these reasons this original research, based on the largest number of records analyzed to date, is justified so that at an institutional level both countries and research centers can develop strategies within the framework of scientific technology policy and seek synergies with other institutions in order to increase the visibility and impact of their publications regarding BIM.

2. MATERIAL AND METHODS

2.1. Source of information for the extraction of scientific production

The database selected for the analysis of the scientific production on BIM was the Web of Science (WoS) 'Core Collection' of Clarivate Analytics, because although there are other alternative databases such as Scopus, Compendex or Inspec, WoS performs the Impact Factor study by analyzing its visibility, so it has been necessary to download all the impact factors of all journals for the entire time series (2003-2017).

2.2. Extraction process

In order to download all the records to be analyzed the WoS Core Collection database was searched with 4 different search chains: BIM, Building Information Modeling, Building Information Modelling, and Building Information Model, the date of the download being 4 January 2018.

In this way, 8,149 records were obtained in the entire database. Similarly, all those records that are not related to the subject were eliminated, mainly in the fields of chemistry, physics, mathematics and medicine. After this first filter, several document typologies were found (Article [1,244], Article; proceedings [28], Review [60], Proceedings Paper [1,673], Article; retracted publication [2], Retraction [1], Book review [2], Correction [7], Letter [4], Editorial material [67], News item [28], and Art Exhibit Review [1]).

The typologies found were Book, Journal and Series, and given that a qualitative analysis based on the Impact Factor is the aim of this study, only type Journal was selected. Subsequently a refinement was applied by type document (Article or Review) (documents from here on), resulting in a total of 1,332 documents [1,244 articles, 28 article proceedings, and 60 reviews] published in 263 journals by authors from 69 countries.

2.3. Construction of 'ad hoc' database for analysis

The download made it possible to save the fields indicated in the previous section for each record, making it possible to build an 'ad hoc' database with Microsoft Access 2016, which has allowed consultations to be carried out in a simple, flexible, and fast way for the different bibliometric indicators.

Thus each document is awarded to each of the countries or research centers, allowing multiple counting, provided that said country or research center appears in the *Research Address* field of the database.

Even so, and as has been verified, there are problems of normalization in WoS, since the same research center found different denominations, which forced us to check each of the records one by one in order to construct a base of refined and reliable data. In addition, some records were also found with the *Research Address* field empty, so they were eliminated from the bibliometric analysis.

2.4. Quantitative analysis

The bibliometric indicators analyzed from the quantitative point of view were:

Ndoc: Number of documents assigned to a country or research center.
Aa: Average number of authors per document corresponding to a country or research center.
Ca: Average number of research centers per document.
NC: Number of collaborative documents between research centers in the same country (national collaboration).
IC: Number of documents in international collaboration between different countries (international collaboration).
CSC: Number of collaboration documents among researchers from the same research center.
CDC: Number of collaboration documents among researchers from different research centers.

Therefore, a document signed by authors from different research centers will count equally in each country or research center.

A similar study has been carried out for each document of the author keywords, keywords plus, and the language of publication.

2.5. Qualitative analysis

The bibliometric indicators analyzed from the qualitative point of view were:

Cita: Average number of citations per document assigned to a country or research center.
h-index: Hirsch index assigned to each country or research center.
IFw & IFr: Weighted IF and Relative IF per document corresponding to a country or research center. First, and before calculating IFw and IFr, the Total Impact Factor (TIF) of a country or research center must be calculated.

To calculate TIF, the Impact Factor of the journal is assigned to each document of the country or research center in the year of publication of the document, and so on for each and every one of the documents of the country or center of research. These Impact Factors are then added up and the TIF of the country or of the research center calculated.

However, this methodological procedure for assigning qualitative indicators to a country or research center is not standardized, since as is well known the IF is a value that belongs to a journal and not a document. In a similar manner, the documents published in the same year as the IF do not relate to the articles selected to calculate the IF (two years ago), and on the other hand, in the same journal there are documents that have been cited many times and others fewer, for which reason it would not be exact to award the same citation value to all. However, it is a first approximation that can be debated. Thus, in order to obtain IFw from a country or research center, the Total Impact Factor (TIF) of that country or research center is divided by the number of documents from that country or research center.

Similarly, in order to obtain IFr from a country or research center the IFw of that country or research center is divided by the IFw of the series analyzed (in the case of countries, the series is constituted by the 33 most productive countries, and in the case of the research centers the 54 most productive), with which we can determine the relative position of each of the countries or research centers in these series. Thus, if the IFr is higher than the unit that country or research center will be placed above the value of the series, and vice versa, if it is lower than the unit, it will be positioned below.

Finally, the dissemination and internationalization of journals has been analyzed as a starting point for the qualitative analysis of scientific production.

3. RESULTS AND DISCUSSION

3.1. BIM-related documents

Once the data had been downloaded, refined and extracted, the world scientific production on BIM was classified by document type.

From Figure 1 it can be seen that from the year 2003, in which the first document on BIM indexed in WoS appears, until 2017, the evolution of the number of documents shows a slight slope of growth, but from the year 2012 is when it begins to grow remarkably, and the same happens with the authors and with the research centers that present a slope of greater growth from the year 2009. Finally, it should be noted that the citations showed a remarkable growth from 2007 to 2013, the date to from which they are decreasing as they approach the current date, and that national and international collaboration between countries also shows a slightly higher growth in national collaboration than in international collaboration.

From Figure 2, it can be observed that the average number of authors and research centers per document has always been oscillating in the time series, as well as the average number of citations per document (reaching a maximum in 2009), but with a clear downward trend since articles with more citations tend to be the oldest of the time series. The IFw has also been oscillating, although there is a clear growing trend since 2014.

In a similar manner it has been possible to identify the main journals and the number of documents of each of them, with the result that that 54 journals of the 263 found make up 75.71% of the entire sample, and that the first 5 by number of documents comprise 38.59% of the total (*Automation in Construction [20.91%], Advanced Engineering Informatics [5.26%], Journal of Computing in Civil Engineering [4.35%], Journal of Construction Engineering and Management [4.05%] and the Journal of Information Technology in Construction [3.98%]*).

On the other hand, according to the language of publication 1,290 documents were published in English [96.85% of the

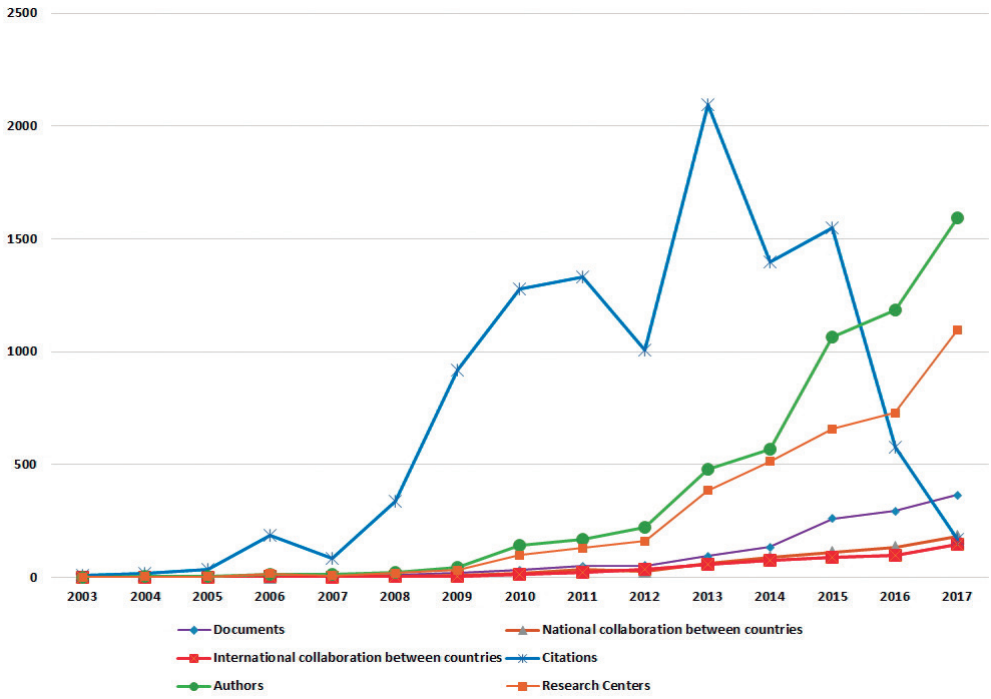

Figure 1. Evolution over time of authors, citations, documents, research centers and number of documents in national and international collaboration by country.

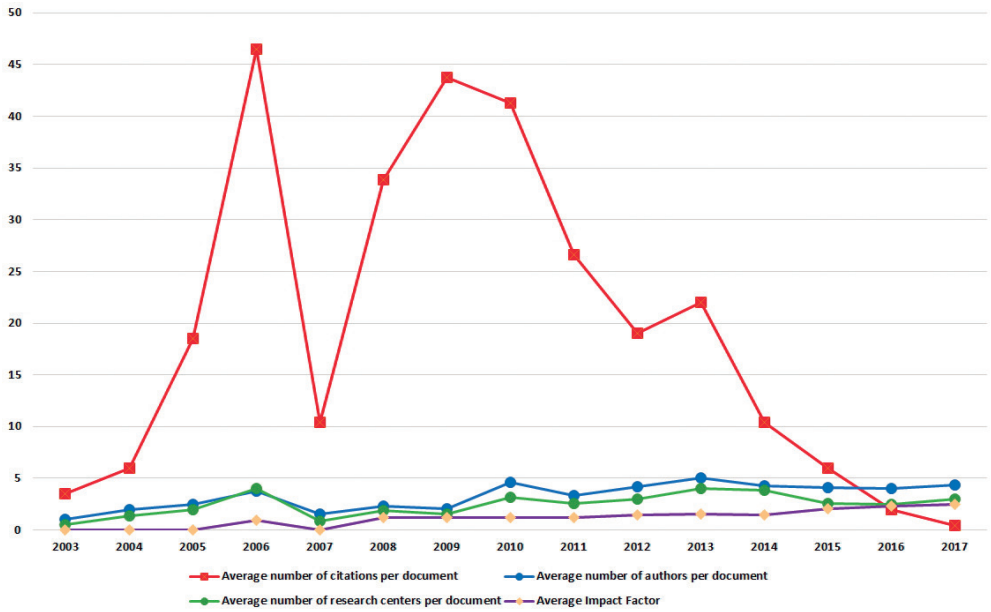

Figure 2. Average number of citations, authors, research centers per document and Average Impact Factor.

total], evidencing the opportunity of writing in that language in order to seek wide dissemination and visibility (31). They have also been published in other languages such as German [26] (in the journals *Bauingenieur, Bautechnik, Beton- und Stahlbetonbau, Stahlbau*), Spanish [5] (in the journals *Informes de la Construcción, Revista Iberoamericana de Automática e Informática Industrial, Revista Ingeniería de Construcción, Geofocus-Revista Internacional de Ciencia y Tecnología de la Información Geográfica*), Italian [4] (in the journals *Archeologia e Calcolatori* and *Geomedia*), Croatian [3] (in the *Gradevinar* journal), Turkish [2] (in the journal *Megaron*), French [1] (in the *Architecture d'aujourd hui* journal), and Russian [1] (in the journal *Mordovia University Bulletin*), which underlines the residual value of the other languages.

3.2. Trends in research

Research trends have been observed after analyzing the main keywords (author keywords and keywords plus). Thus, the 36 author keywords and 46 keywords plus most used for the time series and for each of the 4 sub-periods studied (2003-2006, 2007-2010, 2011-2014, and 2015-2017) were analyzed. The practical absence of information in the first sub-period (2003-2006) is to be ruled out as shown in Figure 1, in those four years only 11 documents were published.

Among the author keywords with more appearances, four stand out for their tendency in the ranking: *Industry Foundation Classes (IFC), Information Technologies, Interoperability,* and *Facility Management*. There are also some author keywords that have experienced a notable growth in the ranking of the sub-period 2011-2014 to 2015-2017, among which stand out *Ontology, Sustainability, Collaboration, Lean Construction, Integration, Safety, Point Cloud,* and *Green Building*. However, on the other hand there are author keywords that descend in the ranking by sub-periods in a considerable way such as *Visualization, Cloud Computing, Augmented Reality,* and *Scheduling*.

Within the keywords plus with more appearances four stand out for their tendency in the ranking: *System, Design, Management* and *Model,* which have almost always remained among the top 5 positions. Other keywords plus that stand out for the growth of their ranking between the last 2 sub-periods are: *Innovation, Adoption, Ontology*, and *Life-Cycle*. On the contrary, the keywords that lose importance are *CAD, 3D*, and *Energy*. Therefore, the author keyword and keyword plus most commonly used in both has been *Ontology*.

3.3. Research activity according to country

An analysis for the 33 countries with the highest scientific output indicating the number of documents, the percentage of documents in national and international collaboration, the average impact factor per document, the average number of citations per document, the average number of authors per document, the average number of research centers per document and the h-index has been carried out (Table 1).

From this analysis, it can be observed how the five most productive countries are: the USA [329], the Peoples Republic of China [189], England [149], South Korea [131] and Australia [117], assuming 24.70%, 14.19%, 11.19%, 9.83% and 8.79% respectively of the total production for all the countries found [69].

With regard to national and international collaboration, it has become clear that South Korea has the highest percentage [57.25%] of collaboration among research centers in the same country among the 5 most productive countries. Also, in the whole series 3 other countries stand out with respect to national collaboration, these being Lithuania [85.71%], Tai-

Table 1. Bibliometric indicators by country (2003-2017) (Top 33 most productive).

Country	Ndoc	NC (%)	NC	IC (%)	IC	IFw	IFr	Cita	Aa	Ca	h-index
United States of America (USA)	329	40.43	133	36.17	119	1.55	1.08	12.55	3.08	3.25	37
People's Republic of China	189	41.80	79	43.39	82	1.57	1.09	6.48	3.65	3.70	21
England	149	25.50	38	34.23	51	1.75	1.23	14.70	3.34	3.45	23
South Korea	131	57.25	75	36.64	48	1.44	1.00	9.24	3.40	3.42	21
Australia	117	37.61	44	40.17	47	1.59	1.10	13.97	3.76	3.96	24
Germany	85	55.29	47	30.59	26	1.61	1.12	13.81	3.14	3.43	17
Canada	65	52.31	34	26.15	17	1.38	0.96	10.84	3.38	3.60	14
Taiwan	52	80.77	42	9.62	5	1.13	0.79	4.15	3.12	3.16	10
Spain	38	71.05	27	15.79	6	1.22	0.85	11.12	3.71	3.72	9
Italy	37	35.14	13	5.41	2	1.29	0.89	2.40	3.54	4.36	5
Netherlands	36	36.11	13	30.56	11	1.78	1.25	11.17	3.33	3.94	8
Israel	32	37.50	12	46.88	15	1.83	1.27	22.04	3.31	3.22	14
Malaysia	28	17.86	5	14.29	4	1.56	1.08	3.22	3.93	3.67	4
Finland	25	32.00	8	28.00	7	1.57	1.09	26.87	2.92	2.93	11
France	23	30.43	7	39.13	9	1.80	1.25	9.06	4.35	4.73	8
Turkey	21	19.05	4	52.38	11	1.79	1.24	13.00	2.86	2.79	9
Egypt	17	58.82	10	17.65	3	1.23	0.85	4.77	2.53	2.15	6
Sweden	16	25.00	4	31.25	5	1.50	1.04	11.56	2.31	2.50	8
New Zealand	15	6.67	1	40.00	6	2.29	1.59	2.14	4.40	6.29	4
Wales	15	46.67	7	26.67	4	1.70	1.18	7.00	3.67	3.80	5
Portugal	15	80.00	12	6.67	1	1.00	0.69	19.17	2.67	2.45	9
Singapore	15	33.33	5	33.33	5	1.60	1.11	9.00	3.20	3.10	6
Scotland	14	21.43	3	35.71	5	1.83	1.27	20.38	2.43	2.83	9
Japan	14	21.43	3	42.86	6	1.60	1.11	7.56	3.14	3.20	6
Norway	11	18.18	2	18.18	2	1.50	1.04	12.00	2.73	2.75	5
Ireland	11	36.36	4	36.36	4	1.86	1.29	24.88	3.91	3.71	7
Slovenia	10	70.00	7	10.00	1	1.00	0.69	20.25	2.90	3.17	6
Belgium	9	11.11	1	66.67	6	2.00	1.39	7.71	4.67	4.50	3
Austria	9	66.67	6	22.22	2	1.29	0.89	2.38	3.78	3.14	4
Iran	7			42.86	3	2.33	1.62	4.00	4.29	4.67	4
Lithuania	7	85.71	6	14.29	1	1.14	0.79	1.29	3.86	3.43	3
Nigeria	7			42.86	3	2.00	1.39	9.00	5.57	7.00	3
Chile	7	14.29	1	42.86	3	1.75	1.22	0.75	2.57	3.00	2

wan [80.77%] and Egypt [80.00%], although with a number of documents much smaller than the five most productive countries.

Regarding international collaboration, the Peoples Republic of China [43.39%] and Australia [40.17%] stand out, although there are other countries such as Belgium [66.67%], Turkey [52.38%] and Israel [46.88%] which stand out from among the whole series.

Regarding IFr, it is worth mentioning that of the five most productive countries only England stands out with a value of 1.23, South Korea being the country with the lowest value [1.00], although all have values above unity. On the other hand, there are other countries that stand out such as Iran [1.62] and New Zealand [1.59], although the number of documents from these countries is not comparable to the first five, because it is much more difficult to maintain the same value as these countries when the number of documents is very high.

Regarding the average number of citations per document, only England [14.70], Australia [13.97] and the USA [12.55] stand out, with the Peoples Republic of China being the one with the lowest value [6.48]. To the contrary, there are other countries that stand out such as Finland [26.87], Ireland [24.88] or Israel [22.04].

It has also been possible to analyze the average number of authors per document, underlining the fact that almost all countries have values that range between 3 and 5, highlighting Sweden as the country with the lowest value of the whole series [2.31].

Finally, the h-index is analyzed in which the USA stands out with a value of 37 among the five most productive countries. This shows the quality of the publications of that country, presenting such a large number of the articles cited. However, this result must be qualified because the number of US documents [329] is much higher than the rest. Thus, if the ratio of this indicator is set against the number of documents the USA and the Peoples Republic of China would occupy the last places in this indicator, highlighting countries such as Ireland, Scotland, Slovenia and Portugal, although as mentioned before it is much more difficult to maintain the same ratio as these countries when the number of documents is very high.

Also, the scientific production disaggregated by sub-periods has been studied. We can see how the 5 most productive countries are generally maintained within the first 5 positions, with the USA always in first place. On the other hand there are other countries that are rising in the ranking notably like Italy, Malaysia, New Zealand and Singapore, if the last two sub-periods are examined, and on the contrary other countries like Japan, Scotland, Portugal and Slovenia have descended in their positions considerably.

3.4. Research activity according to research center

The search for research centers in the *Research Address* field of the *ad hoc* built database has demanded an immense effort. Each of them has had to be revised because the standardization errors existing in WoS need to be taken into account, since a good number of research centers presented different denominations. Also, the 54 research centers ordered by scientific production, once the normalization problems discussed above had been solved, have been analyzed (Table 2).

Institutional analysis shows how the five most productive research centers by number of documents are *Curtin University [55], the Georgia Institute of Technology [54], Hong Kong Polytechnic University [28], the Technion Israel-Institute of Technology [26]* and *Yonsei University [25]*, assuming the assumption of 4.13%, 4.05%, 2.10%, 1.95% and 1.88% respectively of the total scientific production.

With regard to collaboration with researchers from the same research center, it has become clear that within the 5 most productive research centers the *Technion-Israel Institue of Technology* stands out with more than 80% of its scientific production [38.46%], but it is above all in the *University of Vigo* [88.89%] and the *University of Alberta* [80%] where the percentages are greater than the other research centers studied.

In a similar vein, regarding collaboration with researchers from other international research centers the *Hong Kong Polytechnic University* stands out with 75% of its scientific production, and *Curtin University* with 70.91%. The remaining research centers which stand out with more than 80% of their scientific output include the *City University of Hong Kong* [91.67%], the *University of Toronto* [91.67%], the *Korea Institute of Construction Technology* [90.00%], the *University of Michigan* [88.24%], the *University of Colorado* [83.33%], the *University of Waterloo* [83.33%], *Carnegie Mellon University* [82.35%] and the *Huazhong University of Science and Technology* [81.25%].

Regarding IFr, it is worth mentioning that of the five most productive research centers *Curtin University* [1.51] and *Hong Kong Polytechnic University* [1.47] stand out, although all of them have values higher than unity. Of the other research centers the *RAPIDS-Construction Safety & Technology Laboratory* [2.63] stands out, followed by the *City University of Hong Kong* [1.98], the *University of Michigan* [1.74], the *Korea Institute of Construction Technology* [1.67], *the Ruhr-University Bochum* [1.65], the *Delft University of Technology* [1.63], the *University of Hong Kong* [1.57] and *Birmingham City University* [1.52], although as already mentioned a larger number of documents, makes it more difficult to maintain a good IFr value.

Regarding the average number of citations per document (Cita), the *Technion-Israel Institute of Technology* [25.70] and the *Georgia Institute of Technology* [21.18] stand out among the 5 most productive research centers, and among the others we can highlight the *RAPIDS-Construction Safety & Technology Laboratory* [34.00], the *University of Salford* [31.25], *Carnegie Mellon University* [30.07], *Heriot-Watt University* [24.33], and *Aalto University* [22.57].

The average number of authors per document (Aa) was also analyzed, showing that almost all research centers have values that oscillate between 3 and 5, highlighting *Cairo University* as the institution with the lowest value of the whole series [2.40].

Finally, we analyzed the h-index in which the *Georgia Institute of Technology* [16] and *Technion-Israel Institute of Technology* [14] stand out among the five most productive research centers, which shows the quality of their publications when

Table 2. Bibliometric indicators by research centers (2003-2017) (Top 54 most productive).

Research Center	Country	Ndoc	CSC (%)	CSC	CDC (%)	CDC	IFw	IFr	Cita	Aa	Ca	h-index
Curtin University	Australia	55	14.55	8	70.91	39	2.47	1.51	12.00	4.29	4.45	13
Georgia Institute of Technology	USA	54	20.37	11	62.96	34	2.36	1.43	21.18	3.54	3.83	16
Hong Kong Polytechnic University	China	28	10.71	3	75.00	21	2.42	1.47	8.83	4.46	4.54	9
Technion - Israel Institute of Technology	Israel	26	38.46	10	50.00	13	2.00	1.23	25.70	3.46	3.42	14
Yonsei University	Korea	25	28.00	7	68.00	17	2.05	1.24	10.71	3.88	3.91	9
Pennsylvania State University	USA	24	8.33	2	54.17	13	2.07	1.26	4.60	3.04	2.86	5
Hanyang University	South Korea	22	22.73	5	72.73	16	2.11	1.28	12.05	3.73	3.53	8
Tsinghua University	China	21	47.62	10	47.62	10	1.74	1.05	13.15	4.00	3.89	9
University of Salford	England	20	10.00	2	50.00	10	2.25	1.36	31.25	3.40	3.58	11
University of Hong Kong	China	20	15.00	3	70.00	14	2.59	1.57	3.00	4.45	4.82	5
Tongji University	China	17	11.76	2	76.47	13	2.40	1.46	6.40	4.12	4.33	6
Carnegie Mellon University	USA	17	5.88	1	82.35	14	2.23	1.35	30.07	3.41	3.38	7
University of Michigan	USA	17	5.88	1	88.24	15	2.88	1.74	12.50	3.94	4.00	8
National Taiwan University	Taiwan	16	62.50	10	37.50	6	1.75	1.06	4.56	3.56	3.56	5
Stanford University	USA	16	18.75	3	75.00	12	2.07	1.26	15.07	3.75	3.71	8
Loughborough University	England	16	18.75	3	25.00	4	2.00	1.21	12.00	3.69	3.57	6
University of Illinois	USA	16	12.50	2	68.75	11	2.00	1.21	13.23	2.50	2.50	8
Hong Kong University of Science and Technology	China	16	18.75	3	62.50	10	2.15	1.31	6.77	3.38	3.54	5
Huazhong University of Science and Technology	China	16	18.75	3	81.25	13	2.31	1.40	8.88	4.06	4.06	6
Technical University of Munich	Germany	15	40.00	6	33.33	5	2.38	1.44	14.64	3.27	3.63	8
Cardiff University	Wales	15	46.67	7	26.67	4	1.80	1.09	7.00	3.67	4.00	5
Texas A&M University	USA	15	33.33	5	53.33	8	2.08	1.26	10.08	3.33	3.38	7
University of British Columbia	Canada	15	33.33	5	40.00	6	1.56	0.95	14.82	3.20	3.22	8
Delft University of Technology	Netherlands	15	13.33	2	46.67	7	2.67	1.63	6.11	3.60	4.33	5
University of Southern California	USA	15	33.33	5	40.00	6	1.73	1.06	13.64	2.80	3.00	7
University of Florida	USA	15	13.33	2	60.00	9	2.27	1.38	8.64	2.67	2.64	7
Northumbria University	England	14	7.14	1	35.71	5	2.00	1.23	6.67	3.21	4.00	6
University of Melbourne	Australia	13	76.92	10	15.38	2	1.17	0.71	5.67	3.31	3.50	5
Chung-Ang University	South Korea	13	30.77	4	69.23	9	1.83	1.11	17.92	3.69	3.75	9
Birmingham City University	England	13	7.69	1	53.85	7	2.50	1.52	5.13	3.62	3.50	3
University College London	England	13	38.46	5	30.77	4	1.44	0.88	2.56	2.77	3.11	4
Kyung Hee University	South Korea	12	33.33	4	41.67	5	2.33	1.41	7.44	3.75	4.11	5
University of Waterloo	Canada	12	8.33	1	83.33	10	2.22	1.35	6.82	4.00	4.00	6
Queensland University of Technology	Australia	12	33.33	4	50.00	6	1.89	1.15	10.70	3.25	3.67	6
University of Toronto	Canada	12	8.33	1	91.67	11	2.00	1.23	5.33	3.67	3.56	4
University of Texas	USA	12	25.00	3	58.33	7	2.30	1.41	6.20	3.00	3.30	3
City University of Hong Kong	China	12			91.67	11	3.27	1.98	6.45	4.67	4.64	5
University of Colorado	USA	12			83.33	10	2.67	1.63	2.50	3.58	3.67	4
RAPIDS - Construction Safety & Technology Laboratory	Germany	11	9.09	1	72.73	8	4.33	2.63	34.00	3.45	4.67	8
University of Technology of Malaysia	Malaysia	11			18.18	2	2.00	1.21	1.00	4.27	4.00	2
Aalto University	Finland	11	45.45	5	18.18	2	1.57	0.95	22.57	2.82	2.86	6
Ruhr-University Bochum	Germany	10	20.00	2	80.00	8	2.71	1.65	4.40	3.30	3.71	4
University of Alberta	Canada	10	80.00	8	10.00	1	1.33	0.81	3.56	2.80	3.00	3
Kwangwoon University	South Korea	10	60.00	6	40.00	4	1.80	1.09	7.30	3.20	3.20	5
Eindhoven University of Technology	Netherlands	10	40.00	4	50.00	5	2.40	1.47	11.22	3.70	4.00	4
Virginia Tech	USA	10	20.00	2	70.00	7	2.00	1.23	11.22	3.00	3.13	6
Korea Institute of Construction Technology	South Korea	10	10.00	1	90.00	9	2.75	1.67	7.70	3.50	3.75	5
Cairo University	Egypt	10	60.00	6	40.00	4	1.40	0.85	4.30	2.40	2.40	5
Heriot-Watt University	Scotland	9	33.33	3	33.33	3	1.75	1.07	24.33	2.56	3.00	7
Politecnico Milan	Italy	9	44.44	4			1.00	0.61	4.25	3.89	4.33	3
University of Vigo	Spain	9	88.89	8	11.11	1	1.11	0.67	4.89	4.11	4.11	5
Oxford Brookes University	England	9	33.33	3	33.33	3	1.40	0.85	12.00	3.44	4.00	5
Concordia University	Canada	9	22.22	2	44.44	4	1.33	0.82	13.00	3.11	3.00	6
National University of Singapore	Singapore	9	22.22	2	44.44	4	1.83	1.12	5.83	3.33	3.50	4

presenting a large number of cited articles. However, and as previously mentioned regarding countries, if the ratio of this indicator is set against the number of documents only the *Technion-Israel Institute of Technology* would fall within the first 7, notably highlighting *Heriot-Watt University*, the *RAP-IDS-Construction Safety & Technology Laboratory*, *Chung-Ang University*, *Concordia University*, *Oxford Brookes University*, the *University of Vigo* and the *University of Salford*.

On the other hand, very interesting related information can be obtained, analyzing the scientific production by sub-periods. Thus, it is noted that *Curtin University* and the *Georgia Institute of Technology* have always occupied the first two positions, and in particular the *Hong Kong Polytechnic University* has risen to the 3rd position. However, within the first 5 the *Technion-Israel Institute of Technology* has been descending considerably in the ranking for scientific production. Of the other research centers it should be noted that there are research centers with notable growth such as the *University of Hong Kong,* the *Hong Kong University of Science and Technology, Tongji University, Birmingham City University,* and the *University of Toronto*. On the other hand, other research centers have declined significantly in scientific production such as *Heriot-Watt University, Cairo University,* the *Queensland University of Technology, Carnegie Mellon University,* the *University of Texas,* the *National Taiwan University* and the *University of Salford*.

Finally, taking into account the most important qualitative indicators (IFw, Cita and h-index), we could highlight the research centers that exceed the average values of the series. To do this, the average of these values is calculated for the 54 most important research centers by number of documents and then it is verified which research centers present the three indicators at the same time with values higher than average. Thus, they include: *Curtin University,* the *Georgia Institute of Technology, Hangyang University,* the *University of Salford, Carnegie Mellon University,* the *University of Michigan,* the *Technical Univesity of Munich* and the *RAP-IDS - Construction Safety & Technology Laboratory*.

3.5. National and international collaboration networks between countries and research centers

After analyzing national and international collaboration, it has been possible to search the database to determine the international relationship between the 3 main collaborators by number of collaborations, establishing the percentages through the number of documents collaborated upon. In the same way, the national and international relationship between research centers was defined, and therefore the collaboration networks at national and international level. Also, the international collaboration network among the 33 countries with the highest scientific output has been analyzed.

From the analysis of international collaboration between countries it is first of all worth noting that the USA is the first country with the most productive international collaboration, highlighting South Korea with 72.92% of its scientific production, Canada with 64.71%, Turkey with 63.64 % and Israel with 60%. Similarly, and in the opposite direction, the US collaboration with South Korea represents 29.41% of its scientific production, with the Peoples Republic of China 28.57%, and with Germany 11.76%.

Among the rest of the 5 most productive countries the strongest collaboration relationship is between South Korea and the USA, representing 72.92% of South Korea's scientific production, followed by Australia's relationship with China [63.83%], and China´s with the USA [41.46%].

It has also been possible to verify how the collaboration between USA and the 'Four Asian Tigers' (South Korea, Taiwan, Sigapore and Hong Kong) is very scarce or practically nul, except in the case of South Korea with 29.41%.

Among the other countries analyzed, and among the 33 most productive countries, international collaboration between countries with 100% collaboration stands out, such as Italy with England or the Netherlands, Malaysia with Australia, Portugal with Belgium, Norway with Australia, Ireland with England, Slovenia with the USA, Lithuania with Syria, and Chile with England.

On the other hand, from the analysis of collaboration between the 38 research centers with the highest scientific output it can be said that by analyzing the first 3 collaborators of the 5 most productive research centers, we observe how there is an appreciable collaboration between 2 of them (the *Georgia Institute of Technology* and the *Technion Israel-Institute of Technology*), a low collaboration ratio of *Hong Kong Polytechnic University* and also *Yonsei University*, and no relationship of *Curtin University* with any of the remaining 4. The latter generally presents a low international collaboration, and practically does not collaborate with any of the 15 most productive research centers, which demonstrates a high rate of collaboration of researchers from the same center or from different research centers in the same country of origin (Australia).

Also noteworthy is the collaboration of some research centers which, although they are not among the 10 most productive, do present percentages of collaboration over 25% with their first country of collaboration for a number of documents. These include *Tongji University* with *Hong Kong Polytechnic University* [53.85%], the *National Taiwan University* with *Curtin University* [50%], *Loughborough University* with *University College London* [25%], the *Hong Kong University of Science and Technology* with *Pennsylvania State University* [30%], the *Huazhong University of Science and Technology* with *Curtin University* [53.85%], the *University of Southern California* with *Tsinghua University* [66.67%], *Chung-Ang University* with *Curtin University* [33.33%], the *University of Waterloo* with the *University of Toronto* [80%], the *University of Toronto* with the *University of Waterloo* [72.72%], and the *City University of Hong Kong* with the *University of Hong Kong* [45.45%], maintaining this relationship reciprocally.

The four research centers in Hong Kong always have among their three main collaborators one of these institutions, as well as the three Chinese universities which also collaborate with them.

3.6. Internationalization and dissemination of journals

Interesting observations can be extracted in Table 3. It presents the percentage of documents published in each of the 25 journals with the highest scientific output for each of the

16 most productive countries, among all the documents published by each journal, and in parentheses the percentage of all the scientific production of each country in the journals, as long as it is equal to or greater than 10% of the total scientific production of the country in the entire time series (2003-2017). Therefore, given that in a document there may be authors from different countries, this document will be computed equally in each one of them. Of these, 19 have an impact factor for the entire time series (2003-2017).

From this analysis it is deducted that only one journal presents publications from the 16 most productive countries except one (Austria): *Automation in Construction*. This becomes, therefore, the main journal in which issues are published related to BIM worldwide. Furthermore, it has an impact factor during all the years of the time series.

On the other hand, it is striking that there are journals that bring together 100% of their scientific production with authors from the same country. This is the case of *Agro Food Industry Hi-Tech* with the Peoples Republic of China, *Bautechnik* with Germany, the *Journal of Asian Architecture and Building Engineering* with South Korea, and *Jurnal Teknologi* with Malayia. This can favor inbreeding at the

Table 3. Percentage of documents published in top 25 journals of the 16 countries with the highest production.

Journal	Australia	Canada	England	Finland	France	Germany	Israel	Italy	Malaysia	Netherlands	Peoples R. China	South Korea	Spain	Taiwan	Turkey	USA
Automation in Construction	14.13 (41.8)	5.95 (31.4)	10.78 (32.6)	3.35 (60)	2.60 (43.8)	4.09 (15.1)	4.09 (40.7)	1.86 (33.3)	0.74 (22.2)	1.86 (20.8)	17.10 (28.6)	14.87 (32.5)	2.97 (24.2)	3.72 (21.3)	1.86 (33.3)	27.88 (29.8)
Advanced Engineering Informatics		16.18 (21.6)	10.29	1.47	1.47	20.59 (19.2)	7.35 (18.5)	1.47		7.35 (20.8)	4.41	8.82	1.47	1.47	2.94 (13.3)	29.41
Journal of Computing in Civil Engineering	3.70	11.11 (11.8)	5.56			5.56	3.70			1.85	7.41	12.96	3.70	5.56	3.70 (13.3)	51.85 (11.1)
Journal of Information Technology in Construction	3.77	7.55	20.75	3.77		13.21	1.89		1.89	3.77	9.43	1.89				33.96
Journal of Construction Engineering and Management	9.30		6.98			4.65	6.98 (11.1)				18.60	9.30		4.65		58.14 (10)
Journal of Management in Engineering	4.17		8.33	4.17							25.00	16.67			4.17	62.50
Engineering Construction and Architectural Management	23.81		23.81	4.76					14.29	4.76	14.29					14.29
Energy and Buildings			10.00			5.00		5.00			15.00		5.00	10.00		30.00
Journal of Civil Engineering and Management			5.00	5.00							10.00	5.00		30.00 (12.8)		15.00
Agro Food Industry Hi-Tech											100.0 (11.2)					
KSCE Journal of Civil Engineering											11.76	76.47 (10.6)		5.88		17.65
Journal of Professional Issues in Engineering Education and Practice	12.50						6.25				6.25	12.50				68.75
Bautechnik						100.00 (20.55)										
Journal of Asian Architecture and Building Engineering												100.0 (12.2)				6.67
Building Research and Information	7.14	7.14	35.71			14.29	7.14			14.29	7.14	7.14				7.14
Built Environment Project and Asset Management	28.57		42.86						7.14	7.14	7.14					7.14
Architectural Design			30.77								7.69					53.85
Architectural Engineering and Design Management	7.69		38.46					7.69		7.69	7.69					15.38
Building and Environment	7.69	7.69				7.69		7.69			15.38	7.69			7.69	30.77
Jurnal Teknologi			7.69						100.0 (48.1)						7.69	
Construction Management and Economics	8.33	8.33	33.33	25.00 (13.6)						8.33						
International Journal of Project Management	8.33		25.00			8.33				16.67	41.67	16.67	8.33			
Sustainability	8.33		8.33								33.33	50.00			8.33	41.67
Buildings	9.09	9.09	9.09	9.09										9.09		45.45
Journal of Cleaner Production	18.18		9.09								36.36					

(The values in parentheses correspond to the percentage of production for each country of its total scientific production).

time of publication of documents for researchers in the country of the journal, not being a good indication of quality. The same happens with the *KSCE Journal of Civil Engineering* of Korea and the *Journal of Professional Issues in Engineering Education and Practice* of the USA, since they concentrate percentages higher than 65% of publications whose authors are from their respective countries.

In these cases, it is clear how the country of the journal is the country of most of the authors of its publications, monopolizing a high percentage and still presenting Impact Factor in the last year studied, 2016. This indicates a low international diffusion, generally associated with a low impact factor or less than the average, except for *Jurnal Teknologi,* which does not show an Impact Factor.

Analyzing the countries with the highest scientific output, it is interesting to highlight that: the USA is the country with the majority of authors in 11 journals (*Automation in Construction, Advanced Engineering Informatics, Journal of Computing in Civil Engineering, Journal of Information Technology in Construction, Journal of Construction Engineering and Management, Journal of Management in Engineering, Energy and Buildings, Journal of Professional Issues in Engineering Education and Practice, Architectural Design, Building Environment,* and *Buildings*); The Peoples Republic of China is in 2 journals (the *International Journal of Project Management* and the *Journal of Cleaner Production*); England is in 5 journals (*Engineering Construction and Architectural Management, Building Research and Information, Built Environment Project* and *Asset Management, Architectural Engineering and Design Management*, and *Construction Management and Economics*), South Korea is in 2 journals (the *KSCE Journal of Civil Engineering*, and *Sustainability*), and Taiwan is in the *Journal of Civil Engineering and Management*.

On the other hand, analyzing the 25 journals with the highest scientific output it turns out that those that have a high 5-year Impact Factor such as the *Journal of Cleaner Production, Energy and Buildings, Building and Environment, the International Journal of Project Management, Automation in Construction, Building Research and Information*, and *Advanced Informatics Engineering*, tend to aid those countries which publish in them in obtaining an IFw higher than the average, and similar high percentages of publication of countries in journals with a medium or low IFw could explain the bad behavior of the IFw in those countries.

Among the 16 most productive countries we can see how the USA publishes mainly in three journals: *Automation in Construction* [29.8%], the *Journal of Computing in Civil Engineering* [11.1%] and the *Journal of Construction Engineering and Management* [10%], with a total of 50.9% of all its scientific production; The Peoples Republic of China publishes mainly in two journals: *Automation in Construction* [28.6%], and *Agro Food Industry Hi-Tech* [11.2%], giving a total of 39.8% of its scientific production; England publishes mainly in the journal *Automation in Construction* [32.6%], and South Korea publishes mainly in three journals: *Automation in Construction* [32.5%], the *Journal of Asian Architecture and Building Engineering* [12.2%], and the *KSCE Journal of Civil Engineering* [10.6%]. %), totalling 55.3% of its scientific production; Australia publishes mainly in the journal *Automation in Construction* [41.8%]; Germany publishes mainly in three journals: *Bautechnik* [20.6%], *Advanced Engineering Informatics* [19.2%] and *Automation in Construction* [15.1%], with a total of 54.9% of its scientific production; Canada publishes mainly in three journals: *Automation in Construction* [31.4%], *Advanced Engineering Informatics* [21.6%), and the *Journal of Computing in Civil Engineering* [11.8%], a total of 64.8% of its scientific production; Taiwan publishes mainly in two journals: *Automation in Construction* [21.3%], and the *Journal of Civil Engineering and Management* [12.8%], a total of 34.1% of its scientific production; Spain publishes mainly in the journal *Automation in Construction* [24.2%]; Italy publishes mainly in the journal *Automation in Construction* [33.3%]; The Netherlands publishes mainly in two journals: *Automation in Construction* [20.8%], and *Advanced Engineering Informatics* [20.8%], a total of 41.6% of its scientific production; Israel publishes mainly in two journals: *Automation in Construction* [40.7%], and *Advanced Engineering Informatics* [18.5%], a total of 59.2% of its scientific production, Malaysia publishes mainly in two journals: *Automation in Construction* [22.2%], and *Jurnal Teknologi* [48.1%], a total of 70.3%; Finland publishes mainly in two journals: *Automation in Construction* [60%], and *Construction Management and Economics* [13.6%], a total of 73.6%, France publishes mainly in the journal *Automation in Construction* [43.8%], and Turkey publishes mainly in three journals: *Automation in Construction* [33.3%], *Advanced Engineering Informatics* [13.3%] and the *Journal of Computing in Civil Engineering* [13.3%], with a total of 59.9% of all its scientific production.

4. CONCLUSIONS

In this article an in-depth bibliometric analysis of all the BIM-related records present in WoS Core Collection database in the 2003-2017 time series has been carried out. A total of 1,332 records of the article and review typology (documents) were analyzed in order to obtain a series of quantitative and qualitative bibliometric indicators which would help to obtain an overview of everything published in this period regarding BIM. The information obtained in this research is very useful from the institutional point of view, since it will help countries and research centers to develop strategies to strengthen their scientific policies and to increase the visibility of their research, establishing a ranking among countries and research centers with higher scientific production.

From the quantitative point of view, several indicators have been obtained for each year of the time series such as the number of documents, citations, authors, research centers, the number of documents in collaboration between authors from the same country (national collaboration), the number of documents in collaboration between authors from different countries (international collaboration), the number of documents between researchers of the same research center and the number of documents between authors from different research centers. Similarly, the most frequent author keywords and keywords plus have been obtained for each of the 4 sub-periods into which the time series was divided, which indicates the trends in research in the time series.

From the qualitative point of view, various indicators such as the average number of citations, the average number of authors, the average number of research centers and the average Impact Factor have been obtained by document and for each year of the time series. Moreover, for each country and

research center the average Impact Factor, the relative Impact Factor and the h-index have been obtained.

Analyzing the quantitative results it can be observed that the growth trend of the theme is smooth, considering that in the 15 years of the time series only 1,332 documents of the type article or review were published. These are the documents from which the Impact Factor is obtained, which means an average of only 89 documents per year. However, a notable growth is observed from the year 2012, also for the number of authors and research centers.

The documents we found had been published in 263 journals, with English being the main communication language. Of these the journal *Automation in Construction* brings together almost 21% of all scientific production, highlighting others such as *Advanced Engineering Informatics,* the *Journal of Computing in Civil Engineering*, and the *Journal of Construction Engineering and Management*.

On the other hand, research trends have been studied through the analysis of author keywords and most frequent keywords plus. Thus, it has been observed that among the author keywords four stand out for their position in the ranking, such as *Industry Foundation Classes (IFC), Information Technologies, Interoperability* and *Facilities Management*.

Within a geographical and institutional context 69 countries have participated in all the scientific production unloaded, among which the USA stands out with 329 documents, followed by the Peoples Republic of China, England, South Korea, and Australia, highlighting South Korea in national collaboration, and the Peoples Republic of China and Australia in international collaboration.

The qualitative assessment of these countries has been carried out through the analysis of the relative Impactor Factor (IFr), and of the h-index. Thus, among the 5 most productive countries England stands out with the highest IFr, the USA with the highest h-index, and Australia as the country with the best relationship between the h-index and the number of documents. In addition, it can be observed that almost all the G8 countries (USA, Canada, Germany, Italy, France, England, Japan and Russia), except Japan and Russia, are among the 15 most productive countries. The 'Four Asian Tigers' '(Hong Kong, Singapore, South Korea and Taiwan) do not stand out, except for South Korea.

Among the 54 most important research centers there are 12 centers from the USA, five of them among the 15 most productive, 7 from the Peoples Republic of China (although 4 are from Hong Kong - Special Administrative Region of China), 6 from England, 5 from South Korea, 3 from Australia, and 3 from Germany.

Regarding research centers, the consolidation of *Curtin University* and the *Georgia Institute of Technology* in the first two positions by number of documents is noteworthy, although it is also worth mentioning the rapid growth of research centers in Hong Kong, in particular *Hong Kong Polytechnic University,* highlighting the *Technion Israel-Institute of Technology*) and the *Georgia Institute of Technology* as being the most productive in international collaboration.

Regarding the most important qualitative bibliometric indicators (IFr, Cita and h-index), certain research centers have stood out with values above the average, such as *Curtin University,* the *Georgia Institute of Technology, Hangyang University,* the *University of Salford, Carnegie Mellon University,* the *University of Michigan,* the *Technical Univesity of Munich,* and the *RAPIDS - Construction Safety & Technology Laboratory*.

On the other hand, it is confirmed that journals with a low impact factor publish articles from countries with lower scientific production, presenting a high percentage of articles that come from a single research center and with much less international diffusion.

An analysis of the dissemination of research has also been carried out through the 25 journals with the highest scientific output for each of the 16 most productive countries. For this, we have obtained, on the one hand, the percentage of articles from each country in each journal, and on the other hand, the percentage of scientific production of each country in each journal. As a main conclusion, it has been found that only the journal *Automation in Construction* presents publications of all that countries.

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