

QUANTIFYING AND MAPPING THE EVOLUTION OF A LEADER JOURNAL IN THE FIELD OF CIVIL ENGINEERING

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Abstract. *Automation in Construction* is one of the leading international journals in construction and building dating back to 1992. This study aims to quantify and visualize the evolution of *Automation in Construction* publications using bibliometric methods. Our work has two parts: 1) publication and citation statistics in terms of annual distributions, citing sources, prolific countries/regions and institutes, and highly cited papers, 2) network and science mapping analyses in terms of co-authorship network, co-citation network and thematic evolution. Two bibliometric software, VOSviewer and SciMAT, are used to help us carry out the analyses. The results suggest that *Automation in Construction* has obtained increasing influence and reputation from scientific community over the past decades. It is expected that our study has guiding significance for editors and readers of this journal through providing key insights about the evolution over time.

Keywords: *Automation in Construction*, bibliometric, publications and citations, science mapping analyses, thematic evolution.

Introduction

In the early 1990s, the building industry was on the point of a major opportunity to use modern technology, and was asked to provide facilities to house, care, and feed for people to expand and modernize industries, and create novel capabilities. With the intention to assist in this endeavor, the *Automation in Construction* (AutCon) journal was established in 1992. According to three identified functional areas, namely, Architecture and Engineering, Construction Technologies, and Maintenance and Management, the journal aimed to represent novel and exciting possibilities regarding information technologies at each stage in the life cycle of a construction project. The editorial board also reflected the distinction of different stages. Three editors managed two areas for the first three years (1992–1995): Dr. Kansel for Construction Technologies, and Prof. Wagter and Smelter for Architecture and Engineering. In 1995, Prof. Skibniewski and Prof. Kalay took over two areas and served in the position for 12 years

(1995–2007). At the end of 2007, Prof. Skibniewski became the Editor-in-Chief. During the leadership of successive Editorial Boards, AutCon has experienced considerable developments and has become one of the leading journals in the field of construction and building. According to the 2019 Journal Citation Reports (JCR), the Impact Factor (IF) of AutCon is 5.669 and ranks the 8th out of 63 journals in “Construction & Building Technology” and 7th out of 132 journals in “Engineering, Civil”.

After the first issue, AutCon has contributed nearly 3000 publications up to 2019. It is necessary to review and summarize papers of this leading journal in the civil engineering field through exploring the development skeleton and evolution. Several methods can be used to conduct a review such as traditional reviews (Navarro et al., 2020), bibliometric (Tang et al., 2020) and main path analysis (Yu & Pan, 2021; Yu & Sheng, 2020). Bibliometrics refers to the field of studying the characteristics of bibliographic

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materials using quantitative and visualization tools (Tang et al., 2020). It detects prolific countries/regions, institutes and authors, research themes, and deduces patterns over time (Singh et al., 2020a). The research object of a bibliometric study can be a discipline (Liao et al., 2019), a journal (Singh et al., 2020b; Yu et al., 2019; Zhou et al., 2019), an institute (Dees, 2015) or even an author (Hartley, 2019). Bibliometrics plays a critical role in assessing and analyzing the research developed by different actors. For a specific journal, a bibliometric study can identify its developments and evolution status, so as to provide insights for future developments. In the field of civil engineering, bibliometric methods have been increasingly used (Canas-Guerrero et al., 2013, 2014; Cobo et al., 2014; Hosseini et al., 2018; Modak et al., 2019; Vilutiene et al., 2019b; Morkūnaitė et al., 2019; Derbe et al., 2020; Wang et al., 2020a). Some journals in the civil engineering field have also been analyzed using bibliometric methods such as *Transportation Research* journals (Modak et al., 2019), *Journal of Civil Engineering and Management* (Yu et al., 2019), and *Computer-Aided Civil and Infrastructure Engineering* (Wang et al., 2020b). These bibliometric studies can provide a dynamic perspective to obtain an insight for the developments of a specific journal or the civil engineering field.

To comprehensively identify influential countries/regions, institutes, papers, and research topics from an evolving perspective, as well as encourage the scientific community in the journal field to engage further discussions, this study aims to conduct a bibliometric overview for AutCon publications from two perspectives: 1) publication and citation statistics in terms of annual distributions, sources citing AutCon publications, prolific countries/regions and institutes, and highly cited papers, 2) network and science mapping analyses in terms of co-authorship network for institutes and countries/regions, journal co-citation network and thematic evolution. Publication and citation statistics are implemented based on the Web of Science (WoS) database, one of the most widely used tool for generating citation data for research (Meho & Yang, 2007). Regarding network and science mapping analyses, we mainly use two software: VOSviewer and SciMAT. VOSviewer has good performance in visualizing academic social network such as co-word, co-citation and co-authorship networks (Bornmann & Haunschild, 2016). SciMAT can be used to identify the evolution of themes and find promising research directions. Our bibliometric work can help editors and researchers in this field know the past and current status of AutCon. Furthermore, it is hoped that our study can provide a reference for the evolution and future developments of the journal.

This rest of this bibliometric study is organized as follows: Section 1 describes the methodology. Section 2 presents basic publication and citation statistics. In Section 3, we provide network and science mapping analysis. Concluding remarks are given at the end of the study.

1. Methodology and related work

In this section, we describe the data used in this study and provide explanations about corresponding methods and software.

1.1. Data

This study focuses on AutCon studies published from 1992 to 2019 in the WoS Core Collection database and Inspec (Information service in physics, electro-technology, computer and control) database. Note that the publications from 1992–1999 were only covered in the Inspec database. Our work does not include the publications in 2020 since the volumes in 2020 have not been indexed completely by the WoS. The search query was built as: “SO = Automation in Construction NOT PY = 2020”. There are 2896 publications altogether. This number reduces to 2837 if we only consider articles (2816), proceedings papers (272) and reviews (121). Note that some publications were labeled as more than one document type simultaneously. All these records were exported in the format of plain text as the data source of bibliometric software. Note that publications from the Chinese mainland and Hong Kong are grouped under the China heading; publications from England, Scotland, Wales, and North Ireland are grouped under the UK (United Kingdom) heading. The solution is feasible as explained above.

1.2. Methods

To carry out publication and citation statistics, some indicators are used in this study, such as the total number of publications, total number of citations, average citations, and *h*-index (Hirsch, 2005). The *h*-index is an indicator to evaluate the research output of a scholar. A scholar has an *h*-index value of *h* if *h* of his/her *N* papers receive at least *h* citations and other *N-h* papers have less than *h* citations.

There are different kinds of academic social networks, such as the co-authorship network, citation network, co-citation network, and bibliographic coupling network (Kong et al., 2019). In this study, we use the co-authorship network and co-citation network. Since collaboration has become more and more popular in various disciplines, the co-authorship network is one of the most widely-used academic social network (Kong et al., 2019). In a co-authorship network, a node can be an author, an institute or a country/region, and an edge connecting two nodes refers to a collaboration relationship. CO-citation refers the relation of two publications that are cited together by another publication (Singh et al., 2020b). If two publications are frequently cited by other publications, then these two publications have similarities more or less. Researchers have used co-citation network analysis to detect new insights of research trends (Upham & Small, 2010; Rossetto et al., 2018).

1.3. Software

Different bibliometric software tools have been developed. A summary of 9 main software tools is provided in Table 1 (Cobo et al., 2011b).

VOSviewer (n.d., <https://www.vosviewer.com/>) is a bibliometric software for a Java environment developed by van Eck and Waltman (2010). Using VOSviewer, the co-authorship network, co-citation network and co-occurrence network can be displayed intuitively. In this study, we employ VOSviewer to conduct the co-authorship analysis and co-citation analysis.

SciMAT (Cobo et al., 2012) is a science mapping analysis software developed by the University of Granada. SciMAT has three modules: 1) a module responsible for managing the knowledge base and its entities, 2) a module dedicated to the implementation of science mapping analysis, and 3) a module to visualize the generated results. In this study, we use SciMAT to generate strategic diagrams and evolution map. Using SciMAT to analyze thematic areas, a four-stage process is required (Cobo et al., 2012):

- 1) Detect corresponding research themes treated by the research area applying a co-word analysis for each period.
- 2) Layout in a low dimensional space (strategic diagram) regarding the themes of the previous stage. Two characteristics are used to measure a theme: centrality and density. The former measures the degree of interaction of a network with other networks while the latter measures the internal strength of the network:
 - a) Motor themes in the upper-right quadrant are well developed and significant for the structuring of a research field.
 - b) Highly developed and isolated themes in the upper-left quadrant have well-developed internal ties but unimportant external ties. Hence, they are of marginal importance for a field.
 - c) Emerging or declining themes in the lower-left quadrant are unimportant and weakly-developed.
 - d) Basic and transversal themes in the lower-right quadrant are important and not well-developed.
- 3) Analyze the evolution of research themes through different investigated sub-periods, so as to mine

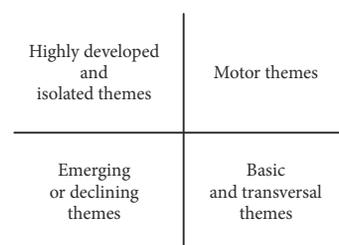


Figure 1. A strategic diagram

the thematic areas of a field, their origins and inter-relationships.

- 4) Carry out a performance analysis for different sub-periods, themes and thematic areas using impact and quantitative indicators.

In a strategic diagram, we can find four kinds of themes (see Figure 1).

Note that the data source of these two software is based on the WoS Core Collection database. Only the publications from 2000 of AutCon were collected by the Core Collection database. Therefore, network and science mapping analysis is based on the publications from 2000 to 2019. Publication and citation statistics include publications in all years.

2. Publication and citation statistics

Publication and citation statistics can identify the overall structure of a journal. In this section, we mainly present the publication and citation structures of AutCon publications in terms of annual distributions of publications and citations, citing sources, active countries/regions and institutes, and highly cited papers.

2.1. Annual distributions of publications and citations

The annual distribution of publications is shown in Figure 2. In the first four years (1992–1995), the annual numbers of publications were approximately 25. In 1996 and 1997, there was a growth because special issues were added. Between 1998 and 2011, the annual numbers of publications in AutCon presented a steady uptrend year by year. In this period, a calendar year usually published one volume

Table 1. A comparison of main bibliometric tools

Software tool	Developed year	Developed by	Analysis type
IN-SPIRE	1999	Pacific Northwest National Laboratory	Bust detection, network, temporal
CiteSpace	2004	Drexel University	Bust detection, geospatial, network, temporal
VantagePoint	2004	Search Technology, Inc.	Bust detection, geospatial, network, temporal
CoPalRed	2005	University of Granada	Network, temporal
Bibexcel	2009	University of Umeå	Network
Sci ² Tool	2009	Indiana University	Bust detection, geospatial, network, temporal
VOSViewer	2010	Leiden University	Network
SciMAT	2012	University of Granada	Network, temporal

including 5–8 issues. In 2012, the journal changed this pattern and published 8 volumes each year. This number increased to 12 in 2014 and continued until this year. In the last two years, the number of publications had a considerable growth, with the highest number of 315 in 2018.

Regarding citation counts, AutCon has a good performance. Table 2 presents the annual publication and citation structure in AutCon. Table 2 illustrates that 3.10% of all publications received more than 100 citations, 12.62% more than 50, and 58.51% more than 10. Only about 5%

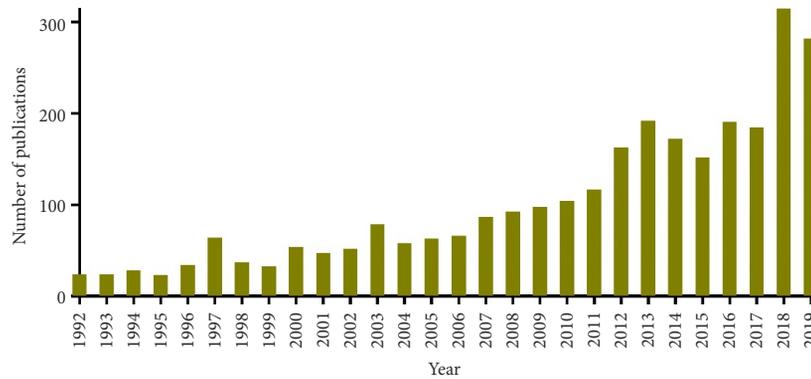


Figure 2. The distribution of publications by year

Table 2. Annual publication and citation structure in AutCon according to the WoS

Year	≥100	≥50	≥20	≥10	≥1	TD	TCD	AC	TCY	<i>h</i> -index	IF
1992	0	0	3	4	19	24	166	6.92	0	6	–
1993	0	0	0	2	19	24	75	3.13	0	5	–
1994	0	0	0	3	20	28	90	3.21	7	6	–
1995	0	0	1	5	20	23	131	5.7	6	6	–
1996	0	0	2	8	28	34	200	5.88	20	9	–
1997	0	2	9	15	50	64	564	8.81	13	13	–
1998	0	2	7	16	33	37	471	12.73	30	14	–
1999	0	2	12	17	31	33	533	16.15	24	14	–
2000	1	10	21	35	52	54	1398	25.89	56	20	–
2001	0	2	12	21	44	47	666	14.17	94	14	–
2002	1	11	29	37	50	52	1477	28.4	95	24	0.312
2003	0	7	19	35	58	79	1280	16.2	167	19	0.320
2004	4	13	31	43	57	58	2008	34.62	218	26	0.360
2005	4	12	35	47	63	63	2162	34.32	347	28	0.387
2006	7	19	38	52	65	66	2547	38.59	527	32	0.792
2007	6	20	47	71	87	87	3168	36.41	691	34	0.609
2008	7	21	54	77	92	93	3324	35.74	1067	33	1.664
2009	8	26	60	85	97	98	4247	43.34	1296	37	1.372
2010	9	30	56	89	103	104	4560	43.85	1387	40	1.311
2011	7	33	73	93	115	117	4527	38.69	1720	39	1.500
2012	8	26	81	122	160	163	4998	30.66	2475	39	1.820
2013	11	39	103	149	191	192	6550	34.11	3217	44	1.822
2014	8	27	84	135	172	172	5721	33.26	4107	39	1.812
2015	6	28	76	120	151	152	4383	28.84	5346	37	2.442
2016	1	14	73	125	188	191	3727	19.51	6108	32	2.919
2017	0	10	55	109	179	185	3130	16.92	7609	30	4.032
2018	0	4	43	119	300	315	3242	10.29	10159	25	4.313
2019	0	0	5	26	243	282	1143	4.05	12628	13	5.669
Total	88	358	1029	1660	2687	2837	66488	23.44	66488	96	
Percentage	3.10%	12.62%	36.27%	58.51%	94.71%						

Notes: TD – Total documents; TCD – Total citations for documents published in a particular year; AC – Average number of citations by year; TCY – Total citations in that year; IF – Impact Factor.

of publications did not obtain any citation. The average number of citations (AC) for AutCon documents is 23.44. In 2000, there is a leap regarding the value of AC. The AC achieved its peak in 2010. In the following decade, the value of AC has a downward trend, which is a normal phenomenon since a paper needs 3 to 7 years to achieve its majority of citations (Wang, 2013). The number of received citations has increased significantly in the last years (see TCY) because of the powerful worldwide expansion of research. Until 2002, the annual received citations were less than 100. During the last two years, the TCY overcame a threshold 10000. This suggested that AutCon has obtained increasing reputation in scientific community. The IF can also prove this. In 2002, AutCon had an IF of 0.312. During the following several years, the IF remained stable, and started to increase in 2006. In 2008, the IF overcame a threshold 1 and kept at this level until 2014. In 2019, ActCon obtained a record of 5.669.

2.2. Sources citing AutCon publications

Analyzing the sources that cite AutCon publications is another interesting topic since it can know who are paying attention to the journal. Table 3 displays the top 30

journals, institutes and countries/regions that have papers citing AutCon publications. As the data shown in Table 3, AutCon itself is the journal with the highest number of studies citing AutCon publications. It is a common phenomenon that a journal cites itself (Tang et al., 2020) and it is logical since the material appeared in AutCon tends to influence future researches in the same journal. *Journal of Construction Engineering and Management*, *Energy Buildings* and *Journal of Computing in Civil Engineering* cite AutCon publications frequently, with 614, 476, and 467 publications, respectively. In general, construction & building journals are those that cited more AutCon documents.

Regarding institutes, the Hong Kong Polytechnic University is in the leading position, with over 700 studies citing AutCon, followed by the Tsinghua University, Tongji University and Georgia Institute of Technology. Note that two thirds of these 30 institutes come from Asia, particularly from China. Therefore, regarding countries, China is unsurprisingly the country that cites AutCon most, followed by the USA and the UK. Some small countries also have a good performance and appear in Table 3, such as Lithuania and Vietnam.

Table 3. Number of studies citing AutCon

R	Journal	TS	Institute	TS	Country/ region	TS
1	<i>Automation in Construction</i>	2062	Hong Kong Polytechnic University	767	China	7258
2	<i>Journal of Construction Engineering and Management</i>	614	Tsinghua University	358	USA	4760
3	<i>Energy and Buildings</i>	476	Tongji University	351	UK	2137
4	<i>Journal of Computing in Civil Engineering</i>	467	Georgia Institute of Technology	342	Australia	1854
5	<i>Sustainability</i>	399	Curtin University	297	South Korea	1575
6	<i>Journal of Cleaner Production</i>	344	Huazhong University of Science and Technology	273	Canada	1258
7	<i>Advanced Engineering Informatics</i>	307	National University of Singapore	271	Taiwan	1198
8	<i>Procedia Engineering</i>	303	Vilnius Gediminas Technical University	262	Spain	1156
9	<i>Sensors</i>	300	City University of Hong Kong	258	Italy	1030
10	<i>Building and Environment</i>	281	National Taiwan University of Science and Technology	254	Iran	993
11	<i>Journal of Civil Engineering and Management</i>	269	Islamic Azad University	251	Turkey	812
12	<i>Journal of Management in Engineering</i>	248	Zhejiang University	239	Germany	806
13	<i>Engineering Construction and Architectural Management</i>	240	University of Alberta	238	Malaysia	798
14	<i>Construction and Building Materials</i>	231	Harbin Institute of Technology	237	Poland	682
15	<i>IEEE Access</i>	212	Centre National de la Recherche Scientifique	232	France	673
16	<i>Lecture Notes in Computer Science</i>	212	Purdue University	232	India	596
17	<i>Applied Sciences Basel</i>	208	Chongqing University	231	Netherlands	534
18	<i>Expert Systems with Applications</i>	170	Tianjin University	219	Singapore	523
19	<i>KSCE Journal of Civil Engineering</i>	166	University of New South Wales Sydney	219	Portugal	503
20	<i>Applied Energy</i>	163	Queensland University of Technology	213	Brazil	483
21	<i>Safety Science</i>	161	Universiti Teknologi Malaysia	207	Japan	454

End of Table 3

R	Journal	TS	Institute	TS	Country/ region	TS
22	<i>International Journal of Project Management</i>	148	Dalian University of Technology	204	Sweden	365
23	<i>Computer-Aided Civil and Infrastructure Engineering</i>	144	Yonsei University	200	Switzerland	337
24	<i>Energies</i>	139	Polytechnic University of Milan	197	Lithuania	307
25	<i>Applied Mechanics and Materials</i>	137	Southeast University (China)	196	Finland	291
26	<i>International Journal of Construction Management</i>	135	Delft University of Technology	195	Greece	288
27	<i>Renewable Sustainable Energy Reviews</i>	125	University of Hong Kong	193	Belgium	264
28	<i>Remote Sensing</i>	123	Chinese Academy of Sciences	189	Saudi Arabia	243
29	<i>Journal of Building Engineering</i>	122	Hanyang University	184	Egypt	223
30	<i>Journal of Information Technology in Construction</i>	112	Concordia University	183	Vietnam	200

Note: TS – Total studies.

2.3. Prolific countries/regions and institutes

AutCon is an international journal and thus researchers from countries across the globe have published in this journal. Up to now, 73 countries have contributed papers to AutCon. Table 4 presents the top 30 prolific countries/regions in AutCon. Note that in our study, the country/region refers that where an author is working at the moment of publication. As we can see from Table 4, the USA exhibits its predominance in TD and TC with 722 publications and 19640 citations, followed by China, the UK and South Korea. Australia obtains the sixth position and shows a high productivity per inhabitant. In Table 4, there are 16 European countries, 9 Asian countries/regions, 2 North American countries, 2 Oceania countries and 1 African country. Therefore, developing countries from Africa and South America still have a long way to go. Some small countries with a population of less than 5 million also appear in Table 4, such as New Zealand, Slovenia and Ireland. If we normalize TD and TC against population, those developed countries/regions with small sized population showed their advantages, such as Taiwan, Australia, Israel and Finland. Several developing counties/regions are also on the list, such as China, Iran, Turkey, Egypt, and Malaysia. With the development of scientific activities in these developing countries/regions, especially Asian countries, it is expected that the number of publications from these countries/regions will increase in the future.

Regarding institutes, Table 5 presents the most active institutes with additional indicators such as the TD, TC, AC, *h*-index and number of documents reaching the citation threshold 100, 50, and 20, respectively. Furthermore, we also provide the world ranks of these institutes according to the Academic Ranking of World Universities (ARWU) and the Quacquarelli Symonds (QS) World University Rankings. The objective is to show that researchers from top institutes across the globe have contributed publications in AutCon. As we can see from Table 5, among these 30 institutes, seven are from China, six are from the

USA, and four are from South Korea. The Hong Kong Polytechnic University is in the leading position with 162 publications and 4946 citations, followed by the Georgia University of Technology and National Taiwan University of Science and Technology. Note that the Carnegie Mellon University has the best performance regarding the AC, which suggests that the publications from this university have significant influence. We can find that several institutes are not in the top 500 according to ARWU and QS rankings, such as Concordia University and University of Salford. Hence, from this perspective, AutCon is diverse and has influence not only in leading universities over the world.

2.4. Highly cited papers

Since its establishment, AutCon has contributed many highly influential papers to construction and building research. The top 10 highly cited papers are analyzed in detail.

Table 6 lists the top 10 most cited papers of all time appeared in AutCon according to the WoS. Additional indicators for the top 10 highly cited papers are also provided, such as the number of institutes (NI), number of countries/regions (NC/R) finishing the paper, document type (DY) and citations/year (C/Y).

The most cited paper was written by Volk et al. (2014) with 556 citations. This study provided a state-of-the-art review of building information modeling implementation and research in existing buildings based on 180 publications. According to the ISO 29481-1:2010(E) standard (International Organization for Standardization, 2010) and Vilutiene et al. (2019a), the building information modeling can be defined as “a shared digital representation of physical and functional characteristics of any built object which forms a reliable basis for decisions”. Furthermore, this paper is also one of the latest papers among top 10 highly cited papers (published in 2014). Hence, it is expected that this review will receive more citations in the future.

Table 4. The top 30 prolific countries/regions

Rank	Country/region	TD	TC	AC	<i>h</i> -index	Pop	TD/Pop	TC/Pop	≥100	≥50	≥20
1	USA	722	19640	27.20	67	326,767	2.21	60.25	32	112	295
2	China	552	13273	24.05	60	1,400,050	0.39	9.48	19	84	209
3	UK	292	7622	26.10	47	66,573	4.39	114.49	14	46	114
4	South Korea	270	6736	24.95	42	51,269	5.27	131.39	10	37	105
5	Taiwan	245	5677	23.17	41	23,694	10.34	239.60	3	27	102
6	Australia	209	6377	30.51	43	24,772	8.44	257.43	8	40	94
7	Canada	185	4460	24.11	37	36,954	5.01	120.70	7	23	68
8	Spain	92	1990	21.63	25	46,397	1.98	42.89	2	7	33
9	Netherlands	71	981	13.82	17	17,084	4.16	57.42	1	3	12
10	Germany	69	1982	28.00	20	82,293	0.84	24.08	2	7	20
11	Singapore	66	1402	21.24	20	5,791	11.40	242.06	2	8	20
12	Israel	60	1684	28.07	20	8,453	7.10	237.18	5	12	21
13	Poland	60	758	12.63	15	38,104	1.57	19.89	0	2	11
14	Japan	59	840	14.24	16	127,185	0.46	6.60	0	4	14
15	Italy	55	787	14.31	15	60,482	0.91	13.01	0	2	13
16	Portugal	46	1104	24.00	18	10,291	4.47	107.28	1	6	16
17	France	42	876	20.86	15	65,233	0.64	13.40	2	3	14
18	Finland	37	836	22.59	14	5,542	6.68	150.85	2	6	12
19	Iran	35	524	14.97	13	82,012	0.43	6.39	0	2	9
20	Turkey	34	903	26.56	17	81,917	0.42	11.02	1	6	16
21	Switzerland	31	603	19.45	11	8,544	3.63	70.58	1	3	6
22	Egypt	29	577	19.90	13	99,376	0.29	5.81	0	4	10
23	Sweden	26	527	20.27	12	9,983	2.60	26.00	0	3	10
24	Belgium	22	495	22.50	12	11,498	1.91	43.05	0	3	8
25	Malaysia	19	344	18.11	10	32,042	0.59	10.74	0	1	6
26	New Zealand	18	321	17.83	8	4,749	3.79	67.59	0	3	4
27	Slovenia	18	278	15.44	10	2,081	8.65	133.59	0	1	5
28	Austria	15	102	6.80	6	8,751	1.71	11.66	0	0	2
29	Ireland	15	292	19.47	8	4,804	3.12	60.78	1	1	4
30	Greece	14	229	16.36	9	11,142	1.26	20.55	0	0	5

Notes: TD – Total documents; TC – Total citations; AC – Average number of citations; Pop – Population in thousands; TD/Pop – Total documents by person multiplied by one million; TC/Pop – Total citations by person multiplied by one million.

Table 5. Top 30 prolific institutes

Rank	Institute	TD	TC	AC	<i>h</i> -index	≥100	≥50	≥20	Country/ region	ARWU	QS
1	Hong Kong Polytechnic University	162	4946	30.53	42	6	34	80	China	201–300	75
2	Georgia University of Technology	85	4176	49.13	38	11	26	53	USA	101–150	80
3	National Taiwan University of Science and Technology	72	1783	24.76	25	1	6	34	Taiwan	901–1000	267
4	Tsinghua University	70	1951	27.87	24	4	13	27	China	43	15
5	Huazhong University of Science and Technology	54	1259	23.31	19	2	8	19	China	101–150	396
6	City University of Hong Kong	52	1173	22.56	19	1	8	19	China	201–300	48
7	Curtin University	52	1628	31.31	23	4	12	26	Australia	201–300	217
8	National Taiwan University	49	1108	22.61	18	1	7	18	Taiwan	151–200	66
9	University of Alberta	48	684	14.25	15	0	2	10	Canada	101–150	119
10	Concordia University	46	938	20.39	17	1	5	12	Canada	801–900	477

End of Table 5

Rank	Institute	TD	TC	AC	<i>h</i> -index	≥100	≥50	≥20	Country/ region	ARWU	QS
11	Yonsei University	41	911	22.22	17	0	8	15	South Korea	201–300	85
12	Kyung Hee University	40	1299	32.48	20	3	7	20	South Korea	301–400	236
13	University of Michigan	38	1031	27.13	17	3	5	15	USA	20	21
14	Loughborough University	36	1610	44.72	23	2	12	25	UK	701–800	226
15	The University of Hong Kong	36	1110	30.83	18	2	7	16	China	101–150	22
16	University of Illinois at Urbana-Champaign	36	1087	30.19	20	1	9	20	USA	38	82
17	Hanyang University	35	935	26.71	14	2	3	10	South Korea	301–400	146
18	National University of Singapore	33	523	15.85	14	0	2	8	Singapore	67	11
19	Purdue University	33	756	22.91	16	1	2	12	USA	72	109
20	University of Waterloo	33	1083	32.82	17	4	8	16	Canada	151–200	166
21	Carnegie Mellon University	32	1733	54.16	18	6	12	15	USA	95	51
22	Zhejiang University	29	861	29.69	16	0	7	16	China	70	53
23	University of Salford	28	1217	43.46	20	3	8	20	UK	–	801–1000
24	University of Texas at Austin	28	812	29.00	16	1	6	11	USA	45	71
25	Queensland University of Technology	27	862	31.93	17	1	7	13	Australia	301–400	217
26	National Chiao Tung University	26	545	20.96	13	0	2	9	Taiwan	501–600	240
27	Seoul National University	26	364	14.00	12	0	1	6	South Korea	101–150	37
28	Israel Institute of Technology	26	1115	42.88	15	5	9	12	Israel	85	291
29	Tongji University	26	428	16.46	10	0	3	5	China	201–300	256
30	University of Lisbon	26	546	21.00	13	0	3	8	Portugal	151–200	357

Notes: TD – Total documents; TC – Total citations; AC – Average number of citations; ARWU – Academic Ranking of World Universities; QS – Quacquarelli Symonds World University Rankings.

Table 6. The top 10 most cited documents in AutCon according to the WoS

Rank	Title	NI	NC/R	DY	Citations	C/Y
1	Building Information Modeling (BIM) for existing buildings – literature review and future needs (Volk et al., 2014)	1	1	Review	556	79.43
2	Building information modelling framework: A research and delivery foundation for industry stakeholders (Succar, 2009)	2	1	Article	480	40.00
3	Automatic reconstruction of as-built building information models from laser-scanned point clouds: A review of related techniques (Tang et al., 2010)	4	1	Review	375	34.09
4	The gap between predicted and measured energy performance of buildings: A framework for investigation (de Wilde, 2014)	2	1	Article	334	47.71
5	Building information modeling (BIM) and safety: Automatic safety checking of construction models and schedules (Zhang et al., 2013)	3	2	Article	294	36.75
6	Understanding and facilitating BIM adoption in the AEC industry (Gu & London, 2010)	2	1	Article	288	26.18
7	Mobile 3D mapping for surveying earthwork projects using an Unmanned Aerial Vehicle (UAV) system (Siebert & Teizer, 2014)	2	2	Article	286	40.86
8	Developments in construction-scale additive manufacturing processes (Lim et al., 2012)	1	1	Article	262	29.11
9	Building information model based energy/exergy performance assessment in early design stages (Schlueter & Thesseling, 2009)	1	1	Article	258	21.50
10	Automatic creation of semantically rich 3D building models from laser scanner data (Xiong et al., 2013)	3	2	Article	252	31.50

Notes: NI – Number of institutes; NC/R – Number of countries/regions; DY – Document type; C/Y – Citations/Year.

The second most cited work was written by Succar (2009) and has received 480 citations. This paper also focused on building information modeling. It discussed some publicly available international guidelines and introduced the framework of building information modeling. Note that Tezizer Jochen has three publications in the list and four authors including Gu Ning, Huber Daniel, Akinci Burcu, and Lee Jin-Kook have two publications.

Among top 10 highly cited papers, only 3 were international collaboration papers. Hence, for influential studies of AutCon, the inter-country/region collaboration is not significant. Furthermore, 3 papers were finished by a single institute. Regarding the document type, 8 are articles and 2 are reviews. Although some literature (Miranda & Garcia-Carpintero, 2018; Zahedi & Haustein, 2018) suggested that review papers tend to obtain more citations than regular articles, reviews have few advantages in AutCon. 8 papers were published in the 2010s and the rest were published in the 2000s. Note that none publication in the last half decade was included. It is logical since a paper usually needs a period of 3 to 7 years to reach its majority of citations (Liao et al., 2019). Therefore, publications in recent years still need time to catch up.

3. Network and science mapping analysis

To know the collaboration status of AutCon publications, journals that are most related to AutCon, research topics and evolution of themes, this section carries out network and science mapping analyses for AutCon publications.

3.1. The co-authorship network

Since the last century, scientific collaboration has gradually become a mainstream scientific knowledge pattern in various fields (Kong et al., 2019). Because of the subject specialization, co-authorship is one of the most extensive and practical way of scientific collaboration (Tang et al., 2018; Liao et al., 2019; Zhou et al., 2020). This section presents the country/region co-authorship network and institute co-authorship network regarding AutCon publications.

To display the main structure of institute co-authorship network, all institutes are filtered by a minimum threshold of 9 publications in AutCon, which results in 99 institutes. Among them, some are not connected to each other. Finally, using the VOSviewer software package, the institute co-authorship network with 92 identified nodes is demonstrated in Figure 3. According to the clustering process embedded in VOSviewer, we obtain 16 clusters. The largest cluster in red color contains 24 items, mainly from South Korea. The Yonsei University, Kyung Hee University, Hanyang University and Seoul National University are active nodes in this cluster. In Figure 3, the biggest node is the Hong Kong Polytechnic University, which echoes the content of Table 5. The Hong Kong Polytechnic University has several major cooperative partners such as the Queensland University of Technology, Huazhong University of Science and Technology, Tsinghua University, City University of Hong Kong, and Curtin University, with a link strength of 14, 12, 13, 10, and 7, respectively.

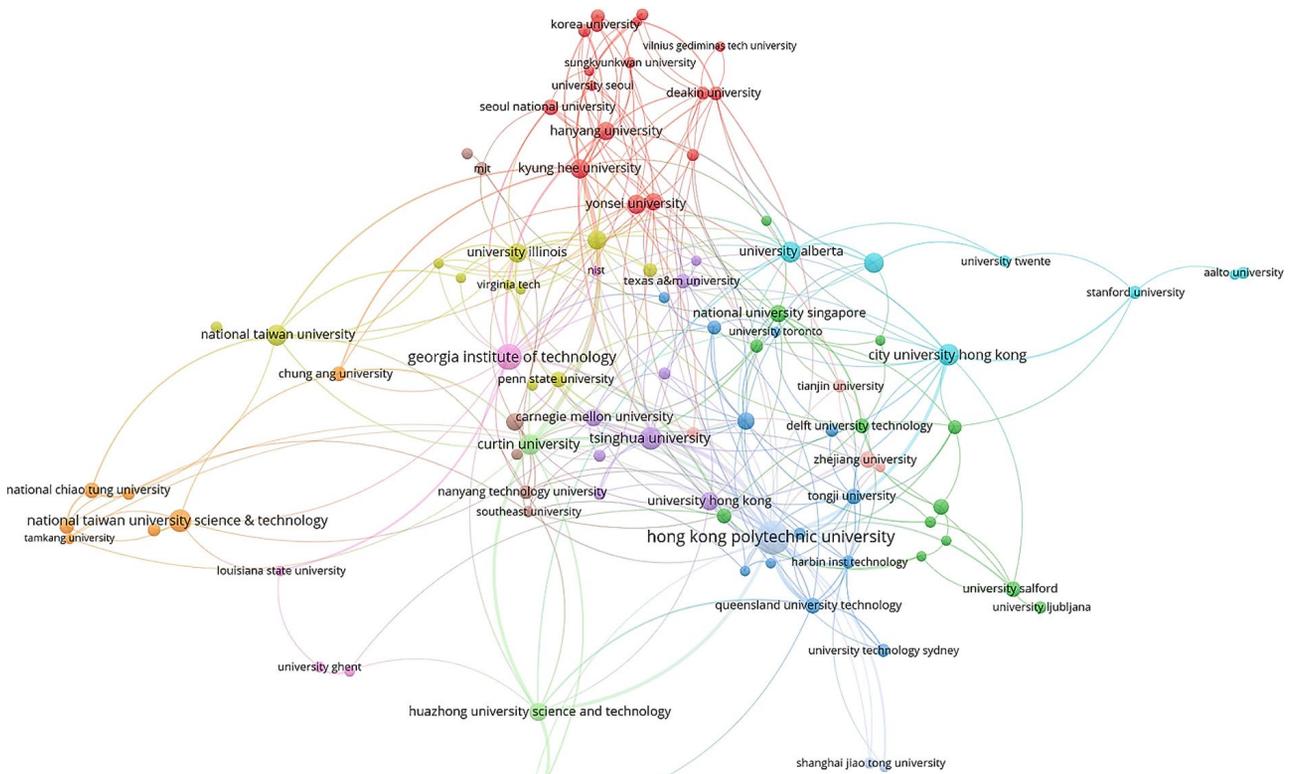


Figure 3. The institute co-authorship network

The thickest line connects the Kyung Hee University and Curtin University, which suggests the deep collaborative relationship between these two universities.

We construct the country co-authorship network in Figure 4. The whole network has 69 nodes. However, Bahrain, Jordan, Serbia, Slovenia and South Africa did not have collaboration with other countries/regions. Therefore, Figure 4 consists of 64 nodes. As shown in Figure 4, the USA and China are two biggest nodes. The link strength of these two countries is 59. The thickest line is constructed by China and Australia. 76 papers were finished in the form of collaboration between these two countries. Main cooperative relationships include the Queensland University of Technology-Hong Kong Polytechnic University (14), Curtin University-Huazhong University of Science and Technology (13), and Curtin University-Hong Kong Polytechnic University (7). Two major partners of the USA are China and South Korea, and three major partners of China are Canada, the USA and the UK. This denotes that the geographical location is not the determining factor that influences international collaborations.

3.2. The journal co-citation network

To detect the relationships of AutCon with other journals, this section conducts the journal co-citation analysis. Journal co-citation analysis, as a branch of co-citation analysis, has been widely used to reveal the underlying relevance and structure of papers between journals (Yang et al., 2019). The more frequently two journals are co-cited, the stronger is their linkage (Wang et al., 2020a). According to VOSviewer, AutCon publications have 65920 different references from 29781 journals. The journal co-citation network of AutCon publications is shown in Figure 5.

In Figure 5, only the journals cited at least 20 times are displayed. The size of a node represents the cited frequency and the thickness of the line denotes the relationship strength between two journals. It is obvious that AutCon is the largest node in Figure 5. As stated in Section 2.2, it is logical that a journal cites itself. Except for AutCon, *Journal of Construction Engineering and Management*, *Journal of Computing in Civil Engineering*, and *Advanced Engineering Informatics* are top journals that are cited by AutCon publications, with 2272, 2130, 1902, and 1291 times, respectively. Many other journals also played critical roles, such as *Energy and Buildings*, *Building and Environment*, *Journal of Information Technology in Construction*, and *Computer-Aided Civil and Infrastructure Engineering*. A majority of these top journals belong to “Engineering, Civil” and “Construction & Building Technology” in the WoS category.

3.3. The evolution of AutCon themes

To discover the main topics and thematic areas of AutCon publications, in this section, we use the SciMAT software to carry out conceptual bibliometric analyses based on co-word bibliographic networks (Laengle et al., 2020). The author keywords are used, which are the refinement of a theme and can represent authors’ understanding of their studies (Tang et al., 2018, 2020). In a research field, frequently used author keywords are usually associated with an important research topic (Uddin & Khan, 2016). Before analysis, a normalization process is given, in which singular and plural forms of keywords are joined. The keywords with different forms but with the same meaning are joined. To carry out the thematic evolution analysis of the journal, we divide the data into four consecutive sub-periods: 2000–2004, 2005–2009, 2010–2014, and 2015–2019.

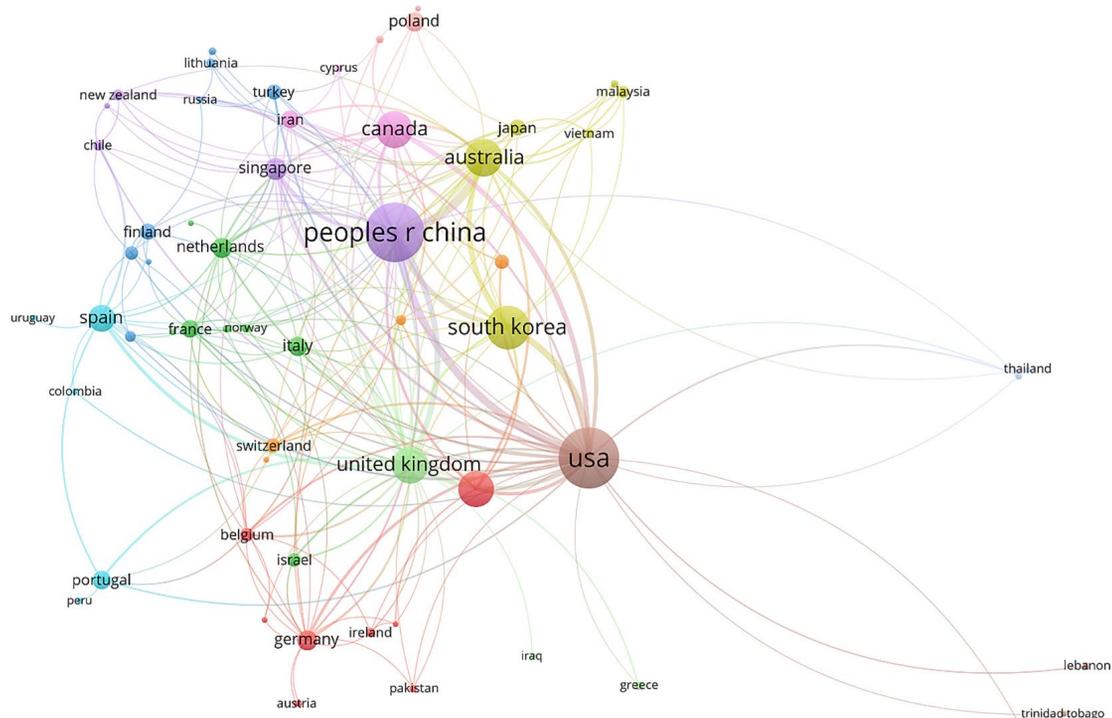


Figure 4. The country/region co-authorship network

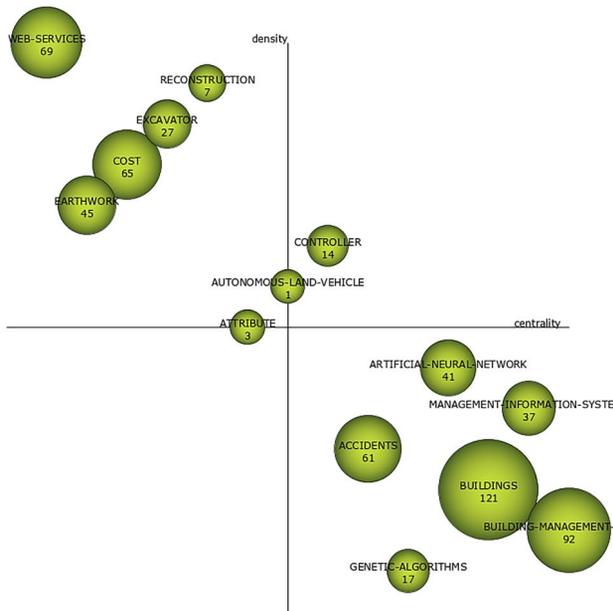


Figure 6. The strategic diagram of the sub-period 2000–2004

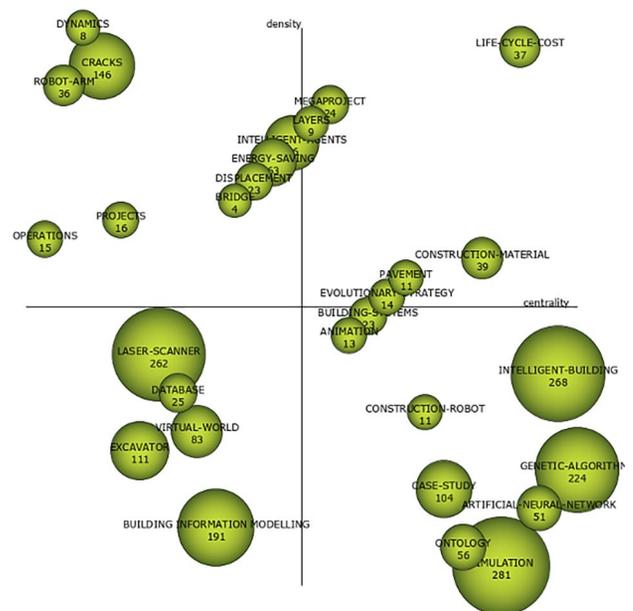


Figure 7. The strategic diagram of the sub-period 2005–2009

Table 8. Performance measures of themes in the sub-period 2005–2009 (Threshold: 2)

Theme name	Number of documents	Number of citations	<i>h</i> -index
Genetic algorithms	7	224	6
Simulation	6	281	6
Intelligent building	3	268	3
Building information modeling	3	191	3
Virtual world	3	83	3
Laser scanner	2	262	2
Case study	2	104	2
Excavator	2	111	2
Ontology	2	56	2
Artificial neural network	2	51	2
Construction material	2	39	2
Life cycle cost	2	37	2
Robot arm	2	36	2
Projects	2	16	2
Operations	2	15	2

Table 9. Performance measures of themes in the sub-period 2010–2014 (Threshold: 2)

Theme name	Number of documents	Number of citations	<i>h</i> -index
Building information modelling	23	1082	17
Simulation	15	364	9
Decision support systems	5	105	5
Energy saving	5	275	5
Artificial neural network	4	87	4
Representation	4	74	3
Uncertainty	3	24	3
Dynamics	2	39	2
Social network	2	31	2
Life cycle cost	2	42	2
Measurement	2	349	2
Safety risk	2	133	2
Construction professional	2	141	2
HAVC system	2	39	2
Database	2	8	2

The third sub-period (2010–2014). In this sub-period, we find more themes (37) than previous two sub-periods based on a total of 739 documents. According to Figure 8 and Table 9, we can observe that *Building information modeling* has the best performance with more than 1000 citations. Some novel themes also have a good performance, such as *Decision support systems*, *Measurement*, and *Safety risk*.

The fourth sub-period (2015–2019). In the last sub-period (see Figure 9 and Table 10), the theme *Building information modeling* continued to maintain its dominant position. Although in this sub-period, only 20.57% (230) of documents were associated with some Artificial neural network theme, there are a large number of themes because of the high number of documents.

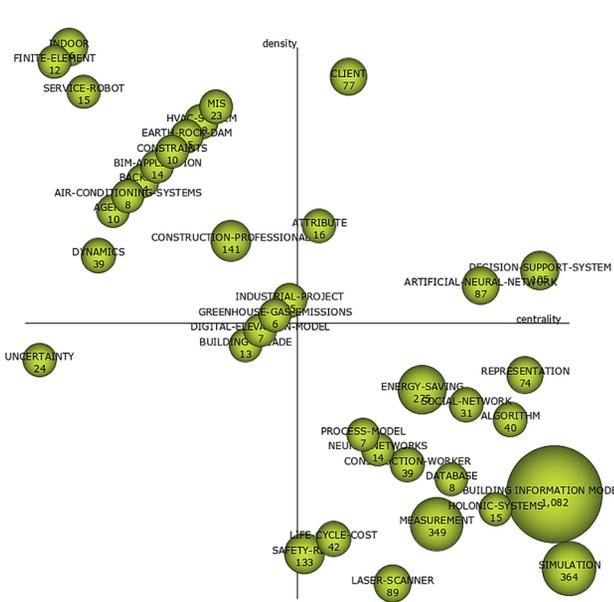


Figure 8. The strategic diagram of the sub-period 2010–2014

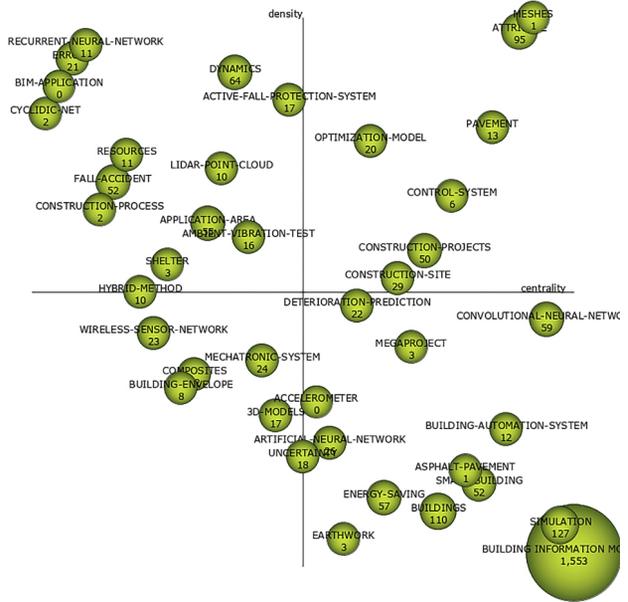


Figure 9. The strategic diagram of the sub-period 2015–2019

Table 10. Performance measures of themes in the sub-period 2015–2019 (Threshold: 3)

Theme name	Number of documents	Number of citations	<i>h</i> -index
Building information modelling	60	1553	21
Simulation	14	127	7
Convolutional neural network	5	59	4
Artificial neural network	4	26	3
Buildings	4	110	3
Construction projects	3	50	3
Building automation system	3	12	3
Smart building	3	52	3
Uncertainty	3	18	2
Energy saving	3	57	3
Errors	3	21	3

Generally, we can find that in all four sub-periods, basic and transversal themes received more citations and impacts. It is reasonable that these themes are more likely to obtain citations and attention. This shows that the identification of these basic and transversal themes is consistent (Cobo et al., 2011a).

We have analyzed the themes in each sub-period, next, we further discuss the thematic evolution of AutCon.

In each sub-period, the keywords are different in terms of lexicography or quantity. That is, the journal terminology evolves through the period using various keywords to describe the content of it. Therefore, through the pe-

riod, some themes disappeared and some new themes appeared. On another note, some keywords appeared during several consecutive or all sub-periods and some keywords only appeared in some sub-periods. Figure 10 presents the evolution status of keywords in AutCon publications. A circle represents a sub-period and the number in it denotes the number of keywords. The arrow between two circles represents the number of shared keywords and the inclusion index (Cobo et al., 2011a) (in parentheses). The inclusion index is calculated according to:

$$\text{Inclusion index} = \frac{\#(U \cap V)}{\min(\#U, \#V)}, \quad (1)$$

where *U* represents each detected theme in a sub-period and *V* represents each detected theme in the next sub-period. “#” denotes the number of themes.

The arrow pointing upward denotes the keywords did not appear in the next sub-period and the arrow pointing downward indicates the new keywords in the sub-period (Cobo et al., 2011a). For instance, the second sub-period has 138 keywords, in which 86 keywords remain in the third sub-period and 52 keywords are not kept in the third sub-period. From Figure 10, we can find that the number of keywords in each sub-period and the number of shared keywords between consecutive sub-periods increase dramatically.

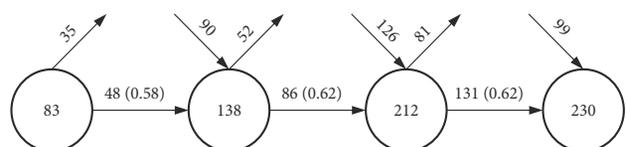


Figure 10. The overlapping map of four sub-periods

Table 11. Performance measures of detected thematic areas

Theme name	Number of documents	Number of citations	Number of periods
Building information modelling	86	2826	3
Simulation	35	772	3
Energy saving	9	395	3
Genetic algorithms	8	241	2
Buildings	8	231	2

The thematic evolution of AutCon publications is displayed in Figure 11. A solid line indicates that the connected themes share the same name and a dotted line denotes that the linked themes have keywords different from the name of the themes. The size of the sphere reflects the number of documents of each theme, and the thickness of the line is proportional to the inclusion index. As we can see from Figure 11, the themes are of high degree of inter-connection. Several main thematic areas and their corresponding performance measures are provided in Table 11. Analyzing Figure 11 and Table 11, we can find that the AutCon themes presents great dispersion, given that many identified themes are isolated. As we can see, *Building information modeling* is the most talked about topic in AutCon publications. Furthermore, this area evolves in an increasing way (see Figure 12). Half of the top 30 most cited papers focused on this topic (see Table 6). It is expected that the journal would continue to focus on this area. Other focused topics include simulation, energy saving and genetic algorithms (Ponz-Tienda et al., 2013).

Conclusions

The objective of this paper was to trace the evolution status of the journal "Automation in Construction". This study provided a bibliometric overview for AutCon publications between 1992 and 2019. Our work was mainly based on two parts: 1) publication and citation statistics and 2) network and science mapping analyses. The main findings of this study can be summarized as follows:

1. AutCon is one of the most influential journals in the field of building, construction and civil. The result showed that AutCon has a significant increase regarding publications and citations in the last decade. This suggested that AutCon received increasingly wide attention and reputation from scientific community.
2. The USA was the most prolific country with the highest number of publications, citations and h-index, followed by China and the UK. Some developing countries/regions also appeared in the top 30 list. It is expected that other developing countries/regions will increase their influence in AutCon. The top institutes contributing to the journal were the Hong Kong Polytechnic University and Georgia University of Technology. AutCon has a diverse distribution regarding countries/regions and institutes.

3. Inter-institutional and inter-country/region collaboration were popular in this journal. Furthermore, AutCon also had strong connections with the journals in engineering, construction and building. AutCon publications mainly cited publications from *Journal of Construction Engineering and Management*, *Journal of Computing in Civil Engineering*, and *Advanced Engineering Informatics*. *Journal of Construction Engineering and Management*, *Energy and Buildings*, and *Journal of Computing in Civil Engineering* cited AutCon publications more frequently.
4. A majority of highly cited papers focused on building information modeling. It is expected that this topic will still maintain its heat in the future. Expect for building information modeling, we observed that AutCon publications presented low cohesion. This reflects that the journal published refereed material on all aspects and the scope of AutCon is broad including the use of information technologies in design, engineering, construction technologies, and management of constructed facilities (Boscardin et al., 2019; Yepes et al., 2015).
5. Based on the thematic evolution analysis, we found that the building information modeling run through the development of the journal. We also identified several emergent themes that attracted the interest of the community such as the use of convolutional neural network and artificial neural network in civil engineering field.

Future research directions of AutCon could focus on energy saving materials and smart buildings. Traditional construction mode consumes a lot of energy and pollutes the environment seriously, and the accumulated contradictions and problems are becoming increasingly prominent. It is a general trend to vigorously promote green building materials, reduce building consumption and environmental pollution. Furthermore, emerging deep learning and neural network methods are worthy to be investigated in construction automation such as predicting or assessing problems.

This study also has limitations. A bibliometric study provides an overview regarding a specific time period. The data are dynamic and the results may change over time. It is hoped that our study will help editors and readers of this journal. In the future, it is important to continue to attract high level work to publish in this journal. The journal can invite experts in the fields that are consistent with the topic of AutCon to contribute submissions. Simultaneously, it is suggested that editors pay attention to the academic research trends of related subjects and organize the research results published in time. Through our study, readers can also know topics that have potential to publish in this journal.

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