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Ahmad Tajudin, I. K. Norziation, Aida Hazlin Ismail

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## Bibliometric Overview and Retrospective Analysis of Asset Management Research between 1965 and 2020

Ahmad Tajudin

Accountant General Department, Putrajaya

I. K. Norziation, Aida Hazlin Ismail

Faculty of Accountancy, Universiti Teknologi Mara Shah Alam

### Abstract

Asset management is a "joined in" organisational activity used to realise value from its controlled resources. Asset management evolved from simple maintenance, which was treated as a "necessary evil" in the 1970s, to the current position, i.e., among the core functions of organisational strategies and closely dependent technology. Studying of the asset management evolution is vital in providing valuable insights into the inclusiveness and global scope of asset management research. Thus, this study aimed to investigate the evolution and dissemination of asset management research; determine the main areas that are being debated in research on asset management; and identify the prominent authors in research into asset management and their collaborations. A bibliometric analysis was conducted comprised of 4,190 published items of literature pertaining to asset management indexed in the Scopus database in January 2021. Findings showed that asset management attracted Western scholars' attention in its early growth period, beginning from 1965. The number of publications increased steadily until the 1990s, a rise that accelerated during the 2000s. Asset management research has become well-developed, but inclusiveness has yet to be properly promoted. A positive cross-country collaboration has been achieved; however, there is a gap in asset management research in certain countries compared to the rest of the world. Future studies should explore and bridge any potential gaps in asset management development, and focus on varied asset management strategies across various countries.

**Keywords:** Asset Management, Facility Management, Maintenance Management, Bibliometric Analysis

### Introduction

Asset management is a strategic and integrated process involving various disciplines such as engineering, operations, management and maintenance, the aim of which is to gain the greatest lifetime benefits and returns on assets (Amadi-Echendu et al., 2010; Laue et al., 2014; Mirhosseini & Keynia, 2021). Asset management needs the participation of different areas, primarily human

activities, to manage individuals who control assets and incorporate asset-related policies in the operational and organisational frameworks, particularly asset maintenance (Nel & Jooste, 2016). The importance of asset management has been discussed, developed, and taken into account for several decades.

The research on asset management is rapidly developing and has inspired various approaches, framework developments, analyses and discussions. Asset management and facilities management have many similarities, especially as the function of both incorporates technical maintenance management (Mason, 2017). The functions of asset management and facilities management also include strategic planning, risk management, financial planning and control, and quality management.

Previously, studies have explored the trend of asset management research. Analysis conducted has concentrated on investigating the timeframe, and analysing different research objectives, perspectives and contributions. A study by Leiblein et al (2016) appeared as the first bibliographic review of asset management literature. The study analysed facility management, specifically in hospitals. They analysed keywords and ranked the publications based on journals. Meanwhile, Garramone et al (2020); Li et al (2019) examined asset management from different perspectives, but have yet to define whether progress is similarly shared or collaborated on worldwide. This question is important, as asset management is not a new discipline; the first reference to holistic asset management was recorded in the 1970s under the term 'terotechnology' (Konstantakos et al., 2019). Asset management also allows organisations to create, enhance and or sustain a resource with corporate governance values, ensuring the asset management paradigm shift is much broader than the scope of maintenance (Amadi-Echendu, 2004). In a competitive landscape, it is important to manage assets effectively and efficiently to achieve optimal returns and gain competitive advantages. This cannot be done by only considering the asset's entire lifetime with all the associated costs and maintenance, but instead, asset management should also be viewed from a different perspective (Campbell & Reyes, 2014).

This paper seeks to examine the scientific literature on asset management by conducting a bibliometric analysis and investigating three main research questions. These include studying how asset management research has evolved and is distributed, what major areas of asset management research are discussed, as well as who the prominent individuals in asset management research are, and their collaborations with other authors from different countries.

The above questions will be answered via several objectives

- a) To investigate the evolution and dissemination of asset management research;
- b) To determine the main areas under debate in research on asset management; and
- c) To identify the prominent authors of research on asset management and their collaborations

Therefore, it is vital to conduct this research to better understand the asset management phenomenon with regards to its global reach and collaborations. The latest data needs to be examined to aid the formulation of recommendations for future research in the development of the asset management topic.

The remainder of this paper will discuss the literature review, which is followed by a description of the research methods and results. The following sections contain a discussion of different considerations and issues to acknowledge when answering the research questions listed above.

### **Literature Review**

This section outlines the literature on asset management, including the evolution and the gaps within bibliometric reviews of asset management research.

### **Asset Management**

Asset management is a "joined in" activity of an organisation used to realise value from its controlled resources. According to Publicly Available Specification 55 (PAS 55), asset management can be defined as "... systematic and coordinated activities and practices through which an organisation optimally and sustainably manages its assets and asset systems, their associated performance, risks and expenditures over their life cycles for the purpose of achieving its organisational strategic plan". The United States Department of Transport described asset management as a comprehensive process for cost-effective asset maintenance, upgrading and operations. Asset management can be regarded as a combination of engineering fundamentals, organisational processes and economic theory. Therefore, within the organisational structure, asset management needs the participation of different areas, primarily human activities, to manage individuals who control assets and incorporate asset-related policies into operational and organisational frameworks, particularly asset maintenance (Nel & Jooste, 2016).

Managing assets allows an organisation to create, enhance, and sustain its business as it can increase the economic productivity (Sara et al., 2021) and allow the organisation to save money for long term (Mastroianni et al., 2021). The critical process in managing assets is to maintain them so that their function remains. A study by Schraven et al (2011) indicates that a key challenge to achieving effective asset management is the establishment of an alignment between asset objectives, situation and intervention, the formulation of asset objectives, and the management of multiple actors with different interests.

The focus of asset management is the efficient management of an asset's life cycle, from acquisition to use, maintenance, and disposal. The emphasis is not on the revenue it might create for an organisation, but the results, risks and costs involved in reaching the best solutions (Hastings, 2015; Schuman & Brent, 2005).

Generally, asset management activity begins with planning to acquire assets and ends when the asset is disposed of; the asset's whole life should be monitored. This activity is known as the life cycle, which manages all assets in their lifespan, and includes creating, establishing, exploiting and, finally, divesting of an asset (Amadi-Echendu, 2004).

### **Evolution of Asset Management**

Asset Management is a term that has been used in organisations and presents different meanings, depending on where it is used (Alfatih et al., 2015). As in other disciplines, an organisation faces challenges in managing its assets. Asset management sometimes conflicts with the intention to acquire assets; to generate future economic benefits or for the services potentially directly attributable to flow to the organisation, assets have to respond to the economy, politics, and society (MPSAS17). This indicates that managing an asset involves multiple parties, not just "doing things"

with assets. Asset management must be a collaborative process of understanding and using assets as valuable sources of value and service delivery mechanisms (IAM, 2015).

Asset management is not a recent discipline, but it has been reinforced, and it is continuously evolving (Amadi-Echendu et al., 2010; Wijnia, 2016). According to Konstantakos et al. (2019), the first use of the term holistic asset management was recorded in the 1970s under the name of terotechnology. Terotechnology is a combination of the accessibility of the system approach and numerate techniques, applied together to enable the manufacturing engineer to consider situations a step further by overcoming various user issues. It should also be concerned with identifying the degree of reliability of the issue (Harvey, 1977). This discipline was based on sound fundamentals, conventional reliability and sustainability practices to encourage industrial profitability.

Later, in the 1980s, technology was created, particularly in information systems, and resulted in the asset management discipline scope being strengthened with the introduction of software systems and predictive maintenance techniques. This technology allowed organisations to adopt the systematised orientation of asset management and simulate the core function activities they conducted.

Further, asset management emerged under the modern paradigm of "Enterprise Asset Management" in the 1990s. The major drivers of this phase were to minimise the corrective time frame by conducting root-cause failure analysis, introducing mature and effective software systems, and implementing risk-based safety strategies.

Holistically, a higher level of asset management maturity and convergence emerged in 2000. Organisations strived to manage assets to gain the greatest possible lifetime effectiveness, utilisation, and returns by collaborating with third parties, such as vendors and clients, to create a holistic, strategic process that integrated finance, management, engineering, operations and maintenance processes (Pais et al., 2020). The asset management process should be used in complete life cycles of assets - design, acquisition, operation, maintenance, and disposal and in risk-based management of assets and related human resources to achieve even greater value. The holistic approach helps organisations to leverage benefits beyond the maintenance phase of the asset's life cycle.

To date, the evolution of asset management has focused on being technologically driven (Blache, 2019). Managing assets is aligned with technological change, and the approach is moving to precision maintenance, cloud-based data storage and analysis, the Internet of Things (IoT), artificial intelligence, and edge computing. Edge computing is computing that is performed close to the data source. The lower costs of sensors and processing are the most critical computing capabilities. It uses analytics for maintenance forecasts and to set out required steps, such as contacting a mobile asset for faster repair. Meanwhile, artificial intelligence enables users to gather, store, and apply information in new environments. The use of technology can help organisations achieve advantages over competitors.

It can be concluded that asset management evolved from simple maintenance, which was treated as a "necessary evil" in the 1970s, to the current position. In the new evolution, asset management activities are treated as core functions of organisational strategies and closely depend on technology. This has changed the approach and landscape, and allowed organisations to benefit.

**Gaps in the Bibliometric Analysis of Asset Management Research**

Bibliographic research generally consists of reports containing analyses from various perspectives. Several bibliometric studies related to asset management research have been conducted in the past, as shown in Table 1. These studies demonstrated a significant, accumulative increase in asset management research across the period until 2020. However, none of these studies has comprehensively covered publications related to asset management research from the beginning of the period.

*Table 1. Previous documents on bibliometric analysis of asset management research*

Author	Data source	Keyword	Year	Bibliometric indicator
Garramon e et al. (2020)	Scopus and WoS	((geographic information system* OR gis) OR (building information modelling OR building information modelling OR bim)) AND (asset* management OR am) AND (infrastructure) in the Scopus (“Article title, Abstract, Keywords” field) and in WoS (“Topic” field).	2013 to 2020,	<ul style="list-style-type: none"> <li>i. Published scientific literature</li> <li>ii. Keyword co-occurrence network</li> <li>iii. Collaboration Network, by Country</li> <li>iv. Selected articles concerning different information management approaches</li> <li>v. Classification by asset management Function</li> </ul>
Li et al. (2019)	Web of Science (WoS)	(“facilit* management”) in the Title/Abstract/Keywords	1995 to 2018	<ul style="list-style-type: none"> <li>i. Number of FM publications per year</li> <li>ii. op-10 journals with impact factor and CiteScore</li> <li>iii. Top-10 publications with the most citations</li> <li>iv. The keyword co-occurrence analysis</li> <li>v. The keyword cluster analysis</li> </ul>
Leiblein et al. (2016)	Scopus, Europe PMC, Elsevier, and Emerald .	(“Legionella” OR “Legionnaires Disease” OR “Healthcare” OR “health care” OR “Hospital” OR “Environment” OR “Facilities” OR “facility” OR “Water” OR “water system” OR “water	No time limit	<ul style="list-style-type: none"> <li>i. Rank list of the top 20 most relevant articles by the presence of the three principal keywords.</li> <li>ii. Rank list of the top 20 most relevant articles by</li> </ul>

distribution system” OR “Waterborne” OR “Nosocomial” OR “HAI” OR “hospital OR “healthcare” OR “health care-acquired infection” OR “Prevention” OR “Surveillance” OR “Risk” OR “risk assessment” OR “risk management” OR “Stakeholder”) in the titles/abstracts	the total counts of the principal keywords iii. Top 10 principal reference article
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### **Methodology**

This section details the process used in the information search procedure, as well as techniques for data analysis.

### **Data Source and Search Strategy**

Bibliometric analysis was performed using the Scopus database as of January 2021. The Boolean strings selected were “asset management” OR “maintenance management” OR “facilities management” OR “facility management”, contained in the titles of articles in Scopus search engine to search for relevant articles published on asset management. The article titles were emphasised because these are the first elements readers will observe (Jamali & Nikzad, 2011). The topics represented by the subjects of this study are important in the field of research and the study goals. No date was set limiting the start of the search, which enabled the search engine to find the earliest publications in the literature. The reviewers decided to follow the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for conducting systematic reviews of research. As shown in Figure 1, the initial search found 6,220 documents.

The documents from the year 2021(n=36) were excluded because this study aimed to analyse documents up to 2020. The subject areas included in this study consisted of Engineering, Business, Management and Accounting, Social Sciences, Economics, Econometrics Finance, and Multidisciplinary; other subject areas (n=1390) were eliminated. The study focused on document types that were journal articles and conference papers; so other documents (n=604) were excluded at this stage. After reviewing all the titles, no further filtering was done because the list contained items relevant to the topic. The final database for this study included 4,190 documents on asset management.

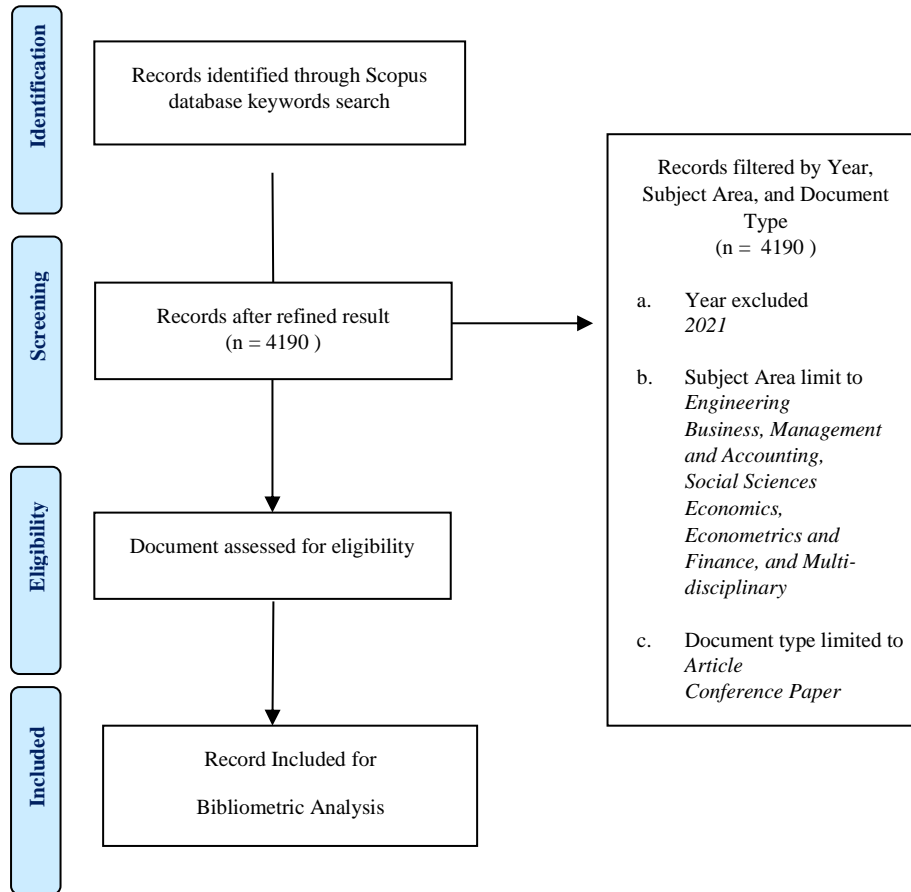


Figure 1. PRISMA flow-chart outlining search of sources for asset management research analysis

### Analysis of Retrieved Literature

The information assessed for this analysis consisted of bibliographic material that described the features of 4,190 Scopus-indexed documents. This information contained author names, titles, dates of publication, and affiliations of authors to documents, as well as extensive citation details. Descriptive statistics were used to perform trend analyses about the growth and distribution of asset management literature.

The research was conducted using various software packages, including Microsoft Excel 2021, Harzing's Publish and Perish, and VOS-viewer (version 1.6.15), to assist in producing extensive analysis, creating graphs and visualising the pattern analysis. For instance, Microsoft Excel was used to measure the frequencies and percentages of the published content and to produce the related charts and graphs. Meanwhile, Harzing's Publish and Perish was used to calculate the citation metrics, and VOS-viewer helped to construct and visualise the bibliometric networks, and synthesise the patterns of information output in the chosen format.

### Results

This section provides the results from the bibliometric analysis that were relevant to the research questions. Thus, details of the evolution and distribution of asset management research, the key



areas of asset management research, and major players and collaborations in asset management research will be discussed.

### Evolution and Distribution of Asset Management Research

The evolution of asset management research and trends in its dissemination were analysed using the data of (a) growth of publications, (b) source title, (c) document and source type, and (d) document language.

#### Analysis of Publication Growth

An estimated 4,190 Scopus-indexed publications have been released over the past 56 years, as shown in Figure 2. This reflects a steadily increasing body of knowledge relevant to asset management. Progress in asset management research was made from the 1960s to the early 1990s, but this accelerated in the early 2000s with the release of 1,154 papers. The majority of this literature was published between 2010 and 2020, which comprised 56% of the total and amounted to 2,364 publications; therefore, it can be inferred that the literature is rapidly evolving.

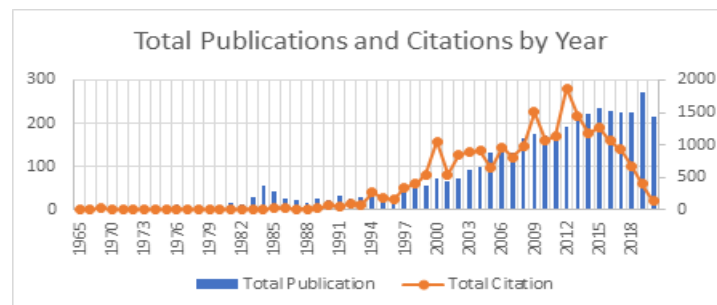


Figure 2. Growth of publications

The highest number of documents, 270, was published in 2019, while the documents published in 2011 (1,874) have been cited most often over the 56-year period. Table 2 shows the top 10 publications on asset management by year.

Table 2. Top 10 Publications by Year

No	Year	TP	CP	TC	C/P	C/CP	h	g
1	2019	270	132	400	1.48	3.03	9	11
2	2015	235	144	1272	5.41	8.83	17	30
3	2016	227	143	1062	4.68	7.43	18	25
4	2018	226	139	667	2.95	4.80	12	18
5	2017	224	146	935	4.17	6.40	15	22
6	2014	222	128	1172	5.28	9.16	17	27
7	2020	214	61	134	0.63	2.20	5	6
8	2013	210	120	1456	6.93	12.13	19	32
9	2012	193	112	1874	9.71	16.73	22	40
10	2009	175	113	1511	8.63	13.37	21	35

Notes: TP=Total Publications; CP=Cited publications; TC=Total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index.

### **Analysis of Source Titles**

The journal Facilities contributed the greatest number of publications on asset management, 231 documents. This was followed by the IET Conference Publications, which produced 122 documents, and the Transportation Research Record with 86 documents. However, the source with the highest quality and reputation and the highest Cite Score, SJR 2019 and SNIP 2019, belonged to Automation In Construction. The details of the most active source titles are shown in Table 3.

*Table 3. Most Active Source Titles*

<b>Source Title</b>	<b>TP</b>	<b>TC</b>	<b>Publisher</b>	<b>Cite Score</b>	<b>SJR 2019</b>	<b>SNIP 2019</b>
Facilities	231	2972	Emerald Group Publishing Ltd.	2.1	0.399	0.933
IET Conference Publications	122	64	Institution of Engineering and Technology	N/A	N/A	N/A
Transportation Research Record	86	338	SAGE Publications Ltd	1.8	0.54	0.786
Journal Of Facilities Management	76	736	Emerald Group Publishing Ltd.	2.1	0.334	1.028
Lecture Notes In Mechanical Engineering	40	25	Springer Nature	0.5	0.165	0.275
Journal Of Quality In Maintenance Engineering	35	1232	Emerald Group Publishing Ltd.	2.0	0.417	1.28
Proceedings Annual Conference Canadian Society For Civil Engineering	35	26	Canadian Society for Civil Engineering	N/A	N/A	N/A
IET Seminar Digest	30	10	Institution of Engineering and Technology	N/A	N/A	N/A
Proceedings Of The 1st World Congress On Engineering Asset Management (WCEAM) 2006	27	73	Springer-Verlag London Ltd	N/A	N/A	N/A
Property Management	26	265	Emerald Group Publishing Ltd.	1.3	0.29	0.982
Applied Mechanics And Materials	25	18	Scitec Publications Ltd.	N/A	N/A	N/A
Procedia Engineering	25	322	Elsevier Ltd	2.7	0.316	1.333
Automation In Construction	24	854	Elsevier Ltd	9.5	1.69	2.681
Iop Conference Series Materials Science And Engineering	24	7	Institute of Physics Publishing	0.6	0.198	0.543

Advances In Intelligent Systems And Computing	23	105	Springer Nature	0.9	0.184	0.429
Built Environment Project And Asset Management	22	230	Emerald Group Publishing Ltd.	1.9	0.379	0.89
IEE Conference Publication	22	24	Institution of Engineering and Technology	N/A	0.101	N/A
VDI Berichte	22	8	Deutscher Ingenieur-Verlag	N/A	0.113	N/A
Engineering Asset Lifecycle Management Proceedings Of The 4th World Congress On Engineering Asset Management (WCEAM) 2009	20	63	N/A	N/A	N/A	N/A

Notes: TP=total number of publications; TC=total citations;

#### **Analysis of Document and Source Types**

The published documents in the data sets were also evaluated based on the "document types" and "source types". "Document types" were based on the originality of the documents, and included book series, conference proceedings, and journal articles, whereas "source types" refers to the source documents, such as books, book chapters, conference papers, and journals. This study focused on journal articles and conference papers (Sweileh et al., 2017) because these generally give a more recent perspective and have integrity because of the peer review process, in which sources are reviewed by experts in the field before publication. The total number of conference papers indexed in Scopus was 2,009 documents, or 47.95%; while the number of journal articles was 2,181 documents, or 52.15%, as shown in Table 4.

*Table 4. Document Types*

<b>Document Type</b>	<b>Total Publications (TP)</b>	<b>Percentage (%)</b>
Articles	2181	52.05%
Conference Papers	2009	47.95%
<b>Total</b>	<b>4190</b>	<b>100.00%</b>

As shown in Figure 3, the documents were categorised into six different source groups. The journals make up the largest of these, with 1,937 documents or 46.23% of the total number of documents. This group was followed by conference proceedings, book series, trade journals, books, and undefined documents.

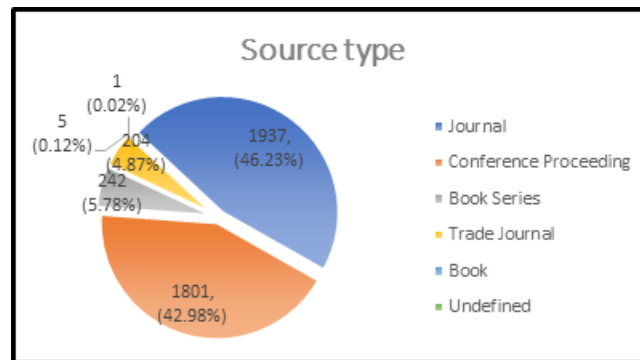


Figure 3. Total Publications per source type

### ***Analysis of the Document Language***

The languages used in the publications on asset management research are shown in Table 5. English was the most common language used in the publications obtained, comprising 92.73% of the total documents. Documents were also published in other languages, such as German, Chinese, Spanish, and French. Thirty-two publications were written in dual languages.

Table 5. List of publication languages

Language	Total Publications (TP)*	Percentage (%)
English	3915	92.73%
German	67	1.59%
Chinese	47	1.11%
Spanish	29	0.69%
French	24	0.57%
Japanese	16	0.38%
Czech	11	0.26%
Portuguese	10	0.24%
Polish	5	0.12%
Russian	5	0.12%
Serbian	5	0.12%
Ukrainian	5	0.12%
Italian	4	0.09%
Croatian	3	0.07%
Korean	3	0.07%
Dutch	1	0.02%
Lithuanian	1	0.02%
Turkish	1	0.02%
Undefined	70	1.66%
<b>Total</b>	<b>4222</b>	<b>100.00</b>

\*32 documents were prepared in dual languages

### The Key Areas of Asset Management Research

The key research areas of asset management were analysed according to two criteria: (a) main subject areas, and (b) frequency of keywords.

#### Analysis of Subject Areas

The categories of publications were summarised based on their subject area, as shown in Table 6. Since asset management involves various disciplines, mainly Engineering. This subject area represented 81% and produced the highest number of total publications. This was followed by the Business, Management and Accounting subject areas, representing 18.52% of the total publications. Additionally, the other significant subject areas in asset management research include Computer Science, Energy, and Environmental Science.

Table 6. List of Subject Areas

Subject Area	Total Publications (TP)	Percentage (%)
Engineering	3393	80.98%
Business, Management and Accounting	776	18.52%
Computer Science	585	13.96%
Energy	303	7.23%
Environmental Science	220	5.25%
Decision Sciences	203	4.84%
Economics, Econometrics and Finance	194	4.63%
Materials Science	163	3.89%
Earth and Planetary Sciences	138	3.29%
Mathematics	128	3.05%
Chemical Engineering	111	2.65%
Agricultural and Biological Sciences	40	0.95%
Chemistry	31	0.74%
Medicine	30	0.72%
Arts and Humanities	25	0.60%
Multidisciplinary	15	0.36%
Biochemistry, Genetics and Molecular Biology	14	0.33%
Health Professions	5	0.12%
Immunology and Microbiology	2	0.05%
Neuroscience	1	0.02%

\*Total publications were categorised based on the source title. In the list above, some titles are classified in several subject areas.

#### Analysis of Top Keywords

The keyword frequency analysis is critical to finding the current topics and developments that apply to a specific field (Wang et al., 2018). In order to make the results more understandable, this study

pre-treated the original data and listed it as shown in Table 7. The top keywords appearing in the asset management research included "Asset Management", "Maintenance", "Decision-Making", "Information Management", and "Facilities Management".

*Table 7. List of Top Keywords*

<b>Author Keywords</b>	<b>Total Publications (TP)</b>	<b>Percentage (%)</b>
Asset Management	1234	29.45%
Maintenance	900	21.48%
Decision-Making	402	9.59%
Maintenance Management	381	9.09%
Information Management	353	8.42%
Facilities Management	326	7.78%
Life Cycle	280	6.68%
Management	255	6.09%
Facility Management	224	5.35%
Office Buildings	219	5.23%
Costs	180	4.30%
Investments	169	4.03%
Facilities	161	3.84%
Asset Management Systems	159	3.79%
Risk Assessment	154	3.68%
Reliability	152	3.63%
Decision Support Systems	150	3.58%
Project Management	149	3.56%
Preventive Maintenance	145	3.46%
Highway Administration	140	3.34%

A total of 16,215 keywords were found after analysing a series of data management processes. To scientifically quantify the key research hotspots in this field, Vosviewer was used to construct an analysis map of the co-occurrence of all keywords, as shown in Figure 4. The nodes drawn represent a keyword; the larger nodes indicate the occurrence of keywords at a higher frequency. Conversely, the presence of links indicates the frequency of keyword co-occurrences; a thicker link represents a higher frequency of keyword co-occurrences.

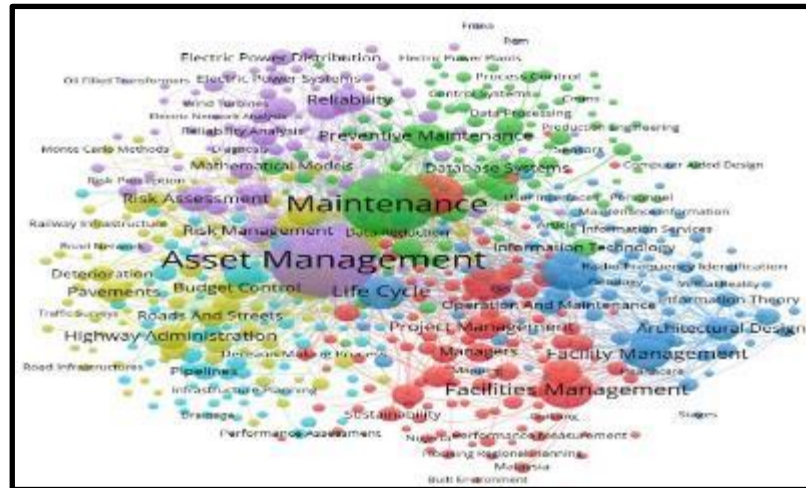


Figure 4. A visualisation map of the keyword co-occurrence network

### Major Players and Collaborations in Asset Management Research

To examine the prominent individuals in asset management research and their collaborations with various authors in different countries, analysis was conducted of several criteria including (a) authorship analysis, (b) countries contributing most to asset management research, (c) the main institutions involved in asset management research, and (d) citations analysis.

#### Analysis of Authorship

The number of authors per published document on asset management research is shown in Table 8. As previously mentioned, a total of 4,190 research papers were included in this study. Single-authored publications made up 27.52% of the total number of publications found, while 70.76% of the publications were multi-authored. Seventy-two (1.72%) publications from conference review documents did not list authors.

Table 8. Number of Author(s) per document

Author Count	Total Publications (TP)	Percentage (%)
1	1153	27.52
2	1135	27.09
3	889	21.22
4	526	12.55
5	232	5.54
6	102	2.43
7	44	1.05
8	15	0.36
9	11	0.26
10	1	0.02
11	4	0.10
12	1	0.02
14	1	0.02
16	1	0.02
18	1	0.02
21	1	0.02
23	1	0.02
0*	72	1.72
Total	4190	100.00

\*Conference review document. No author listed.

Meanwhile, Table 9 shows the most productive authors contributing to asset management research. The number of publications issued by an author can be used to gauge their productivity in a particular research area (Bottle et al., 1994). Sixteen authors published the most documents on asset management, with ten or more publications each. The top three most productive authors by publication were Pitt, M. (23 publications) from The Bartlett Faculty of the Built Environment, United Kingdom; second was Koronios, A. (18 publications), affiliated with the University of South Australia; and the third most productive author publishing on asset management was Andrews, J.D. (17 publications), from the University of Nottingham, United Kingdom. However, documents produced by Baldry, D. from the University of Salford, United Kingdom, were cited most often (22.54 citations per paper). Most authors in asset management studies came from developed countries, except Kamaruzzaman, S.N and Sapri, M., who came from Malaysia.

Table 9. List of Most Productive Authors

Author Name	Affiliation	Country	TP	NCP	TC	C/P	C/CP	<i>h</i>	<i>g</i>
Pitt, M.	The Bartlett Faculty of the Built Environment	United Kingdom	23	23	475	20.65	20.65	13	21
Koronios, A.	University of South Australia	Australia	18	14	88	4.89	6.29	5	9
Andrews, J.D.	University of Nottingham	United Kingdom	17	14	221	13.00	15.79	7	14
Anon	United States Army	United States	16	0	0	0.00	0.00	0	0
Tighe, S.L.	University of Waterloo,	Canada	16	6	9	0.56	1.50	2	2
Baldry, D.	University of Salford	United Kingdom	13	10	293	22.54	29.30	8	13
Vlok, P.J.	The University of Tennessee, Knoxville	United States	13	12	40	3.08	3.33	3	5
Gao, J.	University of South Australia	Adelaide, Australia	12	10	58	4.83	5.80	4	7
Lavy, S.	Texas A&M University, College Station,	United States	12	10	231	19.25	23.10	9	12
Haider, A.	University of South Australia	Australia	11	6	39	3.55	6.50	3	6
Kamaruzzaman, S.N.	University of Malaya	Malaysia	11	10	86	7.82	8.60	5	9
McNeil, S.	University of Delaware	United States	11	8	63	5.73	7.88	5	7



Sapri, M.	Universiti Teknologi Malaysia	Malaysia	11	9	49	4.45	5.44	5	6
Schwan, M.	Siemens AG, Munich	Germany	11	7	159	14.45	22.71	4	11
Alexander, K.	Centre for Facilities Management, Manchester	United Kingdom	10	10	110	11.00	11.00	6	10
Elmualim, A.	Constructing Futures, Adelaide	Australia	10	7	198	19.80	28.29	6	10

Notes: TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index.

The network visualisation made with VOSviewer software displays the mapping of co-authorship between various authors. The mapping was constructed using the fractional counting method and data from authors with at least two documents on asset management. The strength of the relationship is indicated by the colour, size, font size, and thickness of connecting lines. Related authors are commonly listed together with the same colour used to denote them. For example, in Figure 5, the illustration demonstrates that Koronios A., Parlikad A.K., and Haider A., from the same Australian institution, worked together closely. Meanwhile, Liu Y appeared to have numerous collaborations with authors from all over the world.

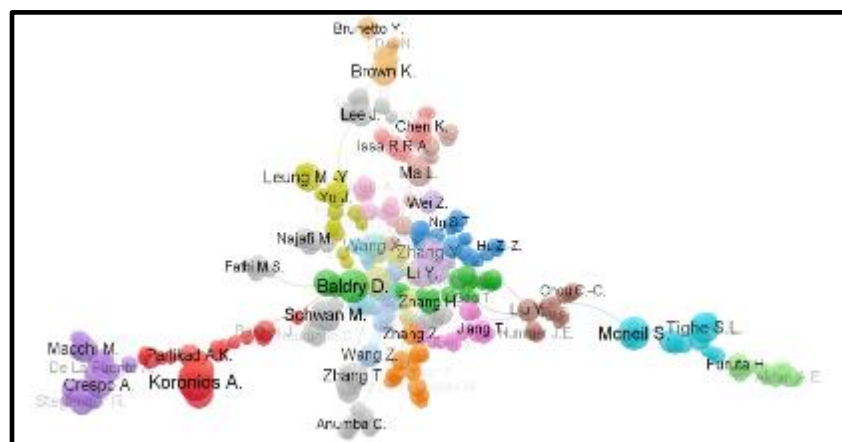


Figure 5. A visualisation map of co-authorship networks

The network visualisation map of the authors based on the countries with which they were affiliated is shown in Figure 6. In order to ensure the results were statistically relevant, only countries with at least five documents and at least five citations were included in this analysis. Using the full counting method, the maps show that United States-based authors were at the forefront of research on asset management, in terms of collaborations with authors from other countries. The former authors

closely collaborated with colleagues from the following countries: (a) Thailand, (b) Canada, (c) the Philippines, and (d) Iran. Several international collaborations were also established by authors from China, Spain, Japan, Australia, Germany and the Netherlands.

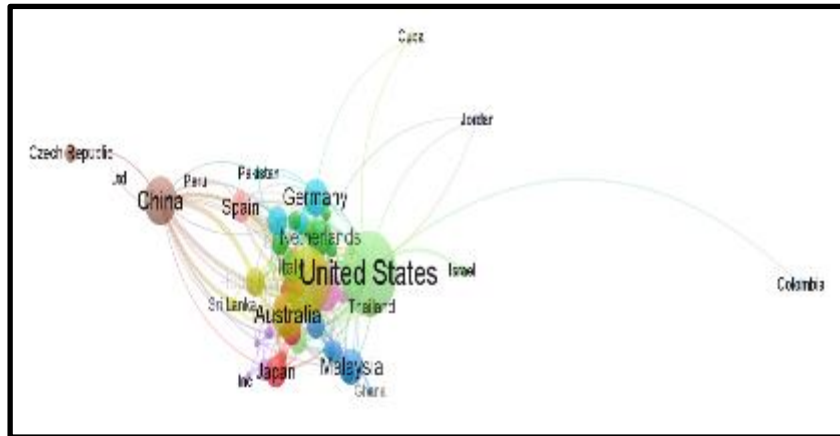


Figure 6. A visualisation map of authors based on country networks

**Analysis of the Countries Contributing most to Asset Management Research**

Table 10 lists the top 20 countries contributing to publications on asset management. The United States was the lead country in producing such publications, and contributed 808 documents. It was followed by the United Kingdom (523 publications), China (245 publications) and Australia (227 publications). Other countries contributed less than 200 publications. However, most documents published by Sweden were cited, meaning the country was listed as having a higher number (15.45) of citations per paper. It is evident that asset management plays a significant role in many geographical regions.

*Table 10. List of Top 20 Countries contributing to publications*

<b>Country</b>	<b>TP</b>	<b>NCP</b>	<b>TC</b>	<b>C/P</b>	<b>C/CP</b>	<b>h</b>	<b>g</b>
United States	808	439	4810	5.95	10.96	32	53
United Kingdom	523	364	4965	9.49	13.64	37	51
China	245	121	967	3.95	7.99	16	27
Australia	227	162	1688	7.44	10.42	21	34
Canada	193	116	2054	10.64	17.71	23	42
Germany	144	73	689	4.78	9.44	12	24
Malaysia	133	89	601	4.52	6.75	14	20
Netherlands	122	78	642	5.26	8.23	15	20
Italy	98	74	704	7.18	9.51	14	23
Japan	98	44	335	3.42	7.61	10	17
France	90	56	657	7.30	11.73	13	24
Spain	86	61	885	10.29	14.51	17	28
Hong Kong	83	62	791	9.53	12.76	17	25
India	77	49	275	3.57	5.61	10	14
South Africa	67	43	261	3.90	6.07	8	14
South Korea	65	44	538	8.28	12.23	12	22
Brazil	59	24	167	2.83	6.96	7	12
Sweden	58	44	896	15.45	20.36	11	29
Taiwan	49	25	270	5.51	10.80	11	16
Finland	48	37	314	6.54	8.49	10	16

Notes: TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index.

#### ***Analysis of the Main Institutions Contributing to Asset Management Research***

Twenty-three prominent institutions produced at least 20 publications on asset management research. Out of the 4,190 documents, Delft University of Technology published 51 documents, followed by Universiti Teknologi Malaysia and the University of South Australia, which published 36 documents each. Another 20 institutions published more than 20 documents, as listed in Table 11.

Table 11. List of most influential institutions with a minimum of 20 publications

Affiliation	Country	TP	NCP	TC	C/P	C/CP	h	g
Delft University of Technology	Netherlands	52	38	280	5.38	7.37	9	13
Universiti Teknologi Malaysia	Malaysia	36	23	77	2.14	3.35	5	6
University of South Australia	Australia	36	27	233	6.47	8.63	9	14
Queensland University of Technology	Australia	33	24	243	7.36	10.13	7	15
University of Salford	United Kingdom	32	27	524	16.38	19.41	14	22
Hong Kong Polytechnic University	Hong Kong	32	27	472	14.75	17.48	11	21
Georgia Institute of Technology	United States	31	27	440	14.19	16.30	10	20
Heriot-Watt University, Edinburgh	United Kingdom	30	27	521	17.37	19.30	12	22
Virginia Polytechnic Institute and State University	United States	27	20	346	12.81	17.30	8	15
University of Waterloo	Canada	26	11	179	6.88	16.27	4	13
Norges teknisk-naturvitenskapelige universitet	Norway	25	19	362	14.48	19.05	8	19
University of Reading	United Kingdom	24	19	364	15.17	19.16	10	19
Universiteit van Pretoria	South Africa	24	12	87	3.63	7.25	5	9
University of Seville	Spain	23	18	380	16.52	21.11	8	19
University College London	United Kingdom	22	19	269	12.23	14.16	7	16
University of Malaya	Malaysia	22	19	181	8.23	9.53	6	13
University of Nottingham	United Kingdom	21	15	282	13.43	18.80	7	16
Politecnico di Milano	Italy	21	17	211	10.05	12.41	8	14
IEEE	United States	20	16	107	5.35	6.69	6	9
Universidad de Castilla-La Mancha	Spain	20	17	303	15.15	17.82	10	17
Universiti Teknologi MARA	Malaysia	20	16	93	4.65	5.81	6	8

University of Birmingham	United Kingdom	20	16	111	5.55	6.94	6	10
Concordia University	Canada	20	10	148	7.40	14.80	4	12

Notes: TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index.

### **Analysis of Citations**

Overall, asset management research citation metrics in Scopus, as indexed on January 31, 2021, are shown in Table 12. The information provided states that since 1965, 4,190 citations have been reported over 56 years (1965-2020) in asset management publications. The citation metric generated from Harzing's Publish and Perish software by importing the RIS formatted file from Scopus to the software was generated by importing the Scopus RIS formatted file into the software.

*Table 12. Citations Metrics*

<b>Metrics</b>	<b>Data</b>
Publication years	1965-2020
Citation years	56 (1965-2020)
Papers	4190
Citations	22722
Years	56
Cites per Year	405.75
Cites per Paper	5.42
Cites per Author	10735.05
Papers per Author	2222.21
Authors per Paper	2.53
h index	60
g index	87

Meanwhile, Table 13 details the top 20 most-cited articles on asset management research. The most cited article recorded in Scopus is entitled "Application areas and data requirements for BIM-enabled facilities management", written by B. Becerik-Gerber, F. Jazizadeh, N. Li, and G. Calis (2012), with an average of 45.44 citations per year.

Table 13. List of Top 20 most cited articles on Asset Management

No.	Authors	Title	Year	Cites	Cites per Year
1	B. Becerik-Gerber, F. Jazizadeh, N. Li, G. Calis	Application areas and data requirements for BIM-enabled facilities management	2012	409	45.44
2	C. De Vleeschouwer, J.-F. Delaigle, B. Macq	Circular interpretation of bijective transformations in lossless watermarking for media asset management	2003	333	18.5
3	J. Nilsson, L. Bertling	Maintenance management of wind power systems using condition monitoring systems - Life cycle cost analysis for two case studies	2007	269	19.21
4	A.N. Jahromi, R. Piercy, S. Cress, J.R.R. Service, W. Fan	An approach to power transformer asset management using health index	2009	215	17.92
5	D. Sherwin	A review of overall models for maintenance management	2000	191	9.1
6	P.D. Berger, R.N. Bolton, D. Bowman, E. Briggs, V. Kumar, A. Parasuraman, C. Terry	Marketing Actions and the Value of Customer Assets: A Framework for Customer Asset Management	2002	153	8.05
7	D.N.P. Murthy, A. Atrens, J.A. Eccleston	Strategic maintenance management	2002	138	7.26
8	A. Crespo Marquez, J.N.D. Gupta	Contemporary maintenance management: Process, framework and supporting pillars	2006	132	8.8
9	T.W. Kang, C.H. Hong	A study on software architecture for effective BIM/GIS-based facility management data integration	2015	131	21.83
10	A.E.B. Abu-Elanien, M.M.A. Salama	Asset management techniques for transformers	2010	126	11.45
11	Schneider, J., Gaul, A. J., Neumann, C., Hogräfer, J., Wellßow, W., Schwan, M., & Schnettler, A.	Asset management techniques	2006	123	8.2

12	K.A. Kaiser, N.Z. Gebraeel	Predictive maintenance management using sensor-based degradation models	2009	122	10.17
13	X. Zhang, E. Gockenbach	Asset-management of transformers based on condition monitoring and standard diagnosis	2008	122	9.38
14	D.J.D. Vanier	Why industry needs asset management tools	2001	121	6.05
15	S. Chotipanich	Positioning facility management	2004	118	6.94
16	M. Kassem, G. Kelly, N. Dawood, M. Serginson, S. Lockley	BIM in facilities management applications: A case study of a large university complex	2015	114	19
17	A.W. Labib	World-class maintenance using a computerised maintenance management system	1998	112	4.87
18	W.T. Scherer, D.M. Glagola	Markovian models for bridge maintenance management	1994	109	4.04
19	A. Motamedi, A. Hammad, Y. Asen	Knowledge-assisted BIM-based visual analytics for failure root cause detection in facilities management	2014	108	15.43
20	Y. Wang, X. Wang, J. Wang, P. Yung, G. Jun	Engagement of facilities management in design stage through BIM: Framework and a case study	2013	106	13.25

In Figure 7, the distribution of documents with at least 20 citations is presented. It highlights various prominent authors in the field and how their ideas were interrelated. Figure 8 further details where the countries of origin are located. The United States, the United Kingdom, China, Australia, Canada, the Netherlands and Italy were perceived to be the most influential countries because asset management research authors from these countries were cited most frequently.

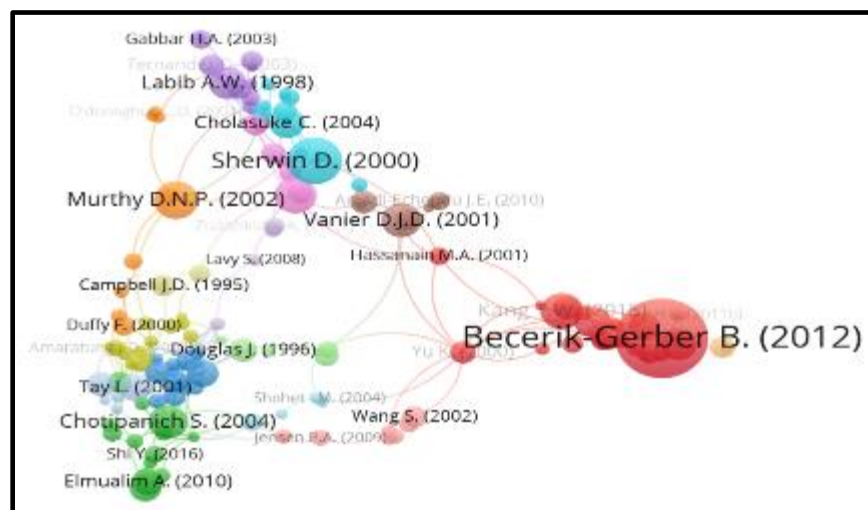


Figure 7. Network visualisation map of citations of asset management documents

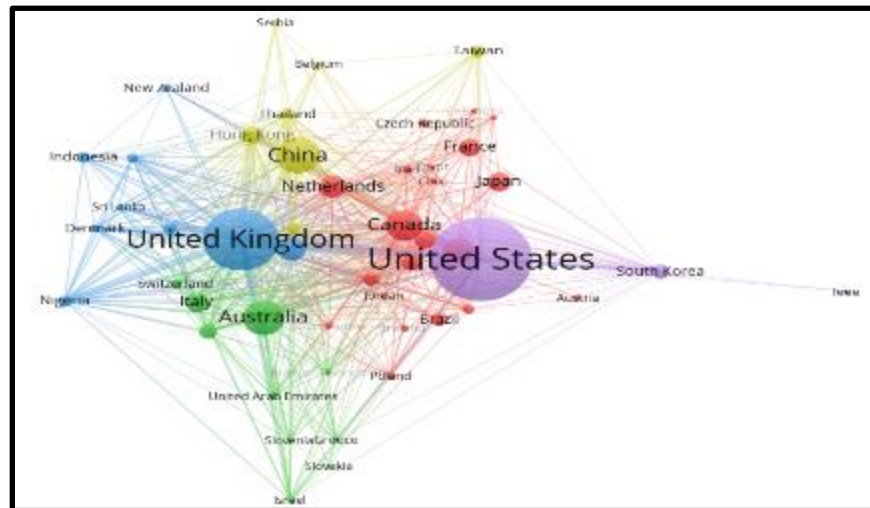


Figure 8. Network visualisation map of citations of asset management documents by country, with a minimum of ten documents per country and a minimum of ten citations per country

## Discussion

This paper aims to provide a comprehensive study of the available research information related to asset management using the bibliometric analysis technique. Bibliometric analysis is an increasingly popular technique for demonstrating trends of studies (Ahmi & Mohd Nasir, 2019). The information from the bibliometric data may be used to judge the success of a particular research domain and be beneficial for research-related agencies in regulating funding allocation policies (Gu, 2004).

This paper analysed the various publications found in the Scopus database covering asset management. This study found more than 4,190 documents from the stated database using the specified search queries. The analysis was categorised under three themes that were based on the research objectives.

## The Evolution and Distribution of Asset Management Research

Documents on asset management first appeared in early 1965, published in *Human Factors: The Journal of Human Factors and Ergonomics*. The earliest documents on asset management were written by Haglund, Richard F. from the Collins Radio Company in the United States. In 1966, another two documents on asset management were indexed in the Scopus database, also written by authors from the United States. This indicates that asset management research had already drawn interest from Western scholars in its early development stages. Analysing the documents based on publication years allowed the researchers to observe the evolution of the research topic over time (Ahmi & Mohamad, 2019).

Slow growth occurred, with an average of six articles per year in the 18 years since asset management was introduced. The trend increased steadily between 1983 and 1999, with an average of 33 documents produced annually. A significant change took place in 2000, with an average of 113 documents being published from 2000 to 2020, perhaps because organisations started to treat asset management as a strategic and integrated process to gain the greatest lifetime effectiveness, utilisation and returns (Pais et al., 2020). Relevant documents appeared most frequently in titles



related to facilities management, engineering, transportation and maintenance management; they were primarily located in the United States. Additionally, most documents related to asset management research were written in English, because English is a global language and has a major influence on policies and practices (Nunan, 2020).

### **The Key Areas of Asset Management Research**

The analysis of topic areas, keywords, and titles suggested that asset management research is strongly related to the fields of engineering, business, management and accounting, and computer science, as asset management pertains to various scopes and disciplines within an organisation (Amadi-Echendu et al., 2010).

A crucial element of a paper's content is its keywords, which include various information such as objectives, techniques, and ideologies (Tian et al., 2018). The most frequently used keywords in asset management research clustered into two main subject areas, "asset management" and "maintenance". Analysis of these studies concluded that most asset management studies focus on maintenance, decision-making, information management, facilities management, life-cycle, and office building. This is probably because the Asset Management role is located at the tactical and operational levels that involve the management of data, facilities and projects (Garramone et al., 2020). Therefore, future asset management studies must extend beyond these areas into other disciplines and interdisciplinary approaches. Important research, for instance, on the issue of asset management practice (Ismail et al., 2019) and good governance (Kaganova & Amoils, 2020) can help improve the importance of asset management become more widely recognised.

### **Major Players and Collaborations in Asset Management Research**

Analysis conducted on the countries, organisations, researchers and citations indicates that collaboration on asset management research appears to be extensive worldwide. Most research is highly reliant on collaborations among researchers (Su et al., 2015); scientific collaboration involves interactions between researchers, organisations, and countries. The United States was the pioneer in publishing articles on asset management, and this country remains the leading publisher in research on asset management, contributing 19.28% of the total global publications. This is possibly because the United States was one of the countries that adopted the formal management of physical assets (Naief, 2018), so financial support was received to conduct research there.

Asset management research was also largely collaborative, thus presenting a significant opportunity for asset management studies. Co-authorship can be interpreted as indicating that collaboration was underway, and demonstrated that writers who contributed to the project were working together (Adams, 2013). The results of this study show a wide range of cooperation among academics, institutions and countries in asset management research. According to Zhu et al (2018), most collaborations occur within a single institution, while a small percentage occur between countries.

Global collaboration networks enable developing countries to participate in the knowledge development process, which has historically been dominated by developed nations (Palacios-Callender & Roberts, 2018). Overall cooperation in asset management research was lacking in both Europe and Asia, possibly because different frameworks were being used for asset management. These applied different approaches based on geographical, economic, structural and cultural factors,

and the methods of asset management employed. Analysis of the most frequently referenced sources suggested that various countries were cited many times, but the United States, the United Kingdom, Canada and Australia were cited the most. The numerous citations of documents from various countries indicated that authors recognised the scientific communities in other countries, which might lead to the creation of scientific paradigms (Pan et al., 2012).

Collaboration is essential in helping asset management adapt to international frameworks and standards (Naief, 2017, 2018), and allowing the strategic design, management, and implementation of asset management strategies to contribute to overall strategic planning. The ability to exchange knowledge, and combine and strengthen expertise, is augmented by collaboration. It also allows countries to increase the sharing of information from outside an organisation, and they may then benefit from external experience. Additionally, relationships between leading universities and prominent scholars raise a university's academic credibility and broaden a publication's coverage. Knowledge transfer and reinforcement are closely related to the spread of knowledge, which is crucial for effective asset management implementation. However, the degree to which cooperation in asset management research occurs between universities in less-developed countries is uncertain. Working together with other countries, universities, and authors also correlates with the transfer of information and technology, which is essential in the discovery of new knowledge.

### **Conclusion**

Bibliometric analysis was employed to perform a systematic review of publications concerning asset management research that ranged from 1965 to 2020. Analysis of the evolution of asset management research through the key topics, fields, and collaborations, with information about publication volumes, publication sources, languages, subjects, keywords, titles, countries, main institutions, authors and citations, indicates that asset management research has been extensively developed. According to the results, early research on asset management was conducted by scholars from the West and has consistently expanded and been disseminated around other parts of the world since then. Most asset management research has concentrated on the fields of engineering, business, management and accounting, and computer science, and their related topics. As a consequence, this has limited the generation of different ideas. There has been a growing degree of collaboration on asset management research between researchers or universities from a small number of countries, suggesting that there are fewer viewpoints from different cultural and institutional backgrounds.

The evolution of asset management reflects a rising emphasis on frameworks and asset management practice worldwide. The collaborations and communications on asset management impact knowledge and, practically speaking, implementation, but have focused on particular countries. Cases of such collaboration and communication are particularly limited between Europe and Asia.

This study was based only on the Scopus database and the keywords used in document titles. Other databases such as Google Scholar or WOS, or documents that might have discussed asset management but excluded this term from the title, are beyond the scope of this paper. Extending the search range by including abstracts and keywords would probably increase the amount of relevant information and frequencies. Furthermore, it is likely that authors or institutions registered the same name or different spellings were used in the Scopus database, leading to inaccurate author affiliations or productivity information.

Despite these limitations, this study makes an important contribution to the understanding of asset management research and publication patterns. Each analysis in this study suggests the growth of this field, which could increase the current level of knowledge. This study is an extension of the results contained in the previous literature and employs bibliometric techniques. Several exciting findings demonstrate the rapidly increasing importance of asset management and its dissemination, as well as the need for more research involving collaboration between different countries and domains. Future studies, it is suggested, should explore and bridge any potential gaps that may arise in the context of asset management development, and focus on different practices in asset management across various countries.

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