Research Article

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A Qualitative Study of the Sustainable-Oriented Modularity Methods Based on the Bibliometric Analysis

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Abstract

Global awareness of environmental protection is growing. The modular method can meet the personalised, complex, and customised needs of sustainable products, which is critical to meet the current environmental environment protection. As a result, experts and scholars in industrial design pay more attention. This paper is a bibliometric analysis of all modularity-related articles published between 1997 and 2020 in the SCOPUS database. The following section of this paper discusses the publication trends in the sustainable-oriented modularity method. During the study period, the bibliometric analysis reveals annual scientific publications, the yearly average number of citations in magazine science, the most frequently locally cited documents published, the most relevant sources, the corresponding author's country, the country's scientific production, and the country's collaboration world chart, among other things. The paper's qualitative analysis section is divided into subject and method detail descriptions of the most frequently cited articles.

Keywords: *Modularity, sustainable product, bibliometrics, method and subject*

1. Introduction

Today, owing to advances in science and technology, sustainable design pushes out new, integrated designs of products and services and creates effective product service systems to achieve sustainable solutions (Abadi et al., 2018). However, many companies and designers pursue creating sustainable products, but at the same time, there is another hidden danger: over-design (Byggeth &

Hochschomer, 2006). Therefore, while focusing on the research and development of sustainable products, reducing or eliminating excessive design is the top priority of service design. Sustainable development has become the central idea of today's era. Economic growth, social inclusion, and environmental sustainability are typically included. However, redesigning industrial methods, services, and infrastructure is necessary for sustainable consumption and production (Sarkar & Sarkar, 2020). Industry and regulators have turned their attention from manufacturing techniques to commodities and their life series. The making, coupling, trying, distribution, procedure, service, recycling, remaking, and recycling processes are all included in the product life cycle, which spans the whole process from conception to disposal. Increasingly demanding consumers are pushing for the creation of sustainable goods. It is the goal of creating comprehensive product regulations, especially in Europe.

Product planning substantially impacts the entire product life series and consequently influences the product's sustainability (Zheng et al., 2020). Modularity attempts to analyse the product architecture into materially separating pieces, and the modular product architecture can simplify the coupling of suitable life series tactics with product design. Therefore, modular product design comes into being; its fundamental purpose is to comprehensively improve the product business strategy measures to meet people's psychological needs. The idea of modular design is to allow different modules to be combined to form a product through a defined interface.

For the systematic study of publications, bibliometric approaches have been employed to quantify systematic development in several specialties (Kalantari et al., 2017). However, several other indicators are needed to evaluate research. In numerous cases, citation analysis and peer review have ensured better judgment. Currently, a variety of technologies have greatly simplified the generation of bibliometric reports (Ellegaard & Wallin, 2015). These databases include the Web of Science Core Collection (WoS), SCOPUS and Google Scholar. However, with the addition of citation handling, Google Scholar does not charge all academic literature types, making its coverage questionable (Mongeon & Paul, 2016). The most comprehensive databases for searching the literature in different scientific fields are WoS and SCOPUS (Chadegani et al., 2013). Therefore, this study compares the coverage of “Modularity” studies in the SCOPUS and Web of Science databases and selects the greatest modularity for this study.

2. Methodology

This study uses bibliometric research methods to assess publication trends and identify insights into modularity publications. First, a title search was conducted for “Modularity.”Based on two reputable databases, SCOPUS and WoS, the idyllic data collection database was chosen, with 3158 documents on SCOPUS and the same number of copies searched on WoS (2958 records). SCOPUS claims to have more extensive journal coverage than WoS, even though WoS is one of the principal and most reputable databases for literature exploration and study (Ghanbari et al., 2019). The data is therefore collected from the SCOPUS database for the “Modularity” title search. A title search for “Modularity” in SCOPUS was for 158 documents on 5 December 2020.The total number of citations for all papers was 89386 since 1998, an average of 25.41 citations per document. As depicted in Figure 1, the volume of publications in “Modularity” has upsurged dramatically. Even though WoS is one of the principals and most reliable databases for literature exploration, study and analysis, SCOPUS looks to have a more widespread journal coverage than WoS (Ghanbari et al., 2019). The data is therefore collected from the SCOPUS database for the “Modularity” title search. A title search for “Modularity” in SCOPUS returned 3,158 documents on 5 December 2020.The total number of citations for all papers was 89386 since 1998, an average of 25.41 citations per document. As illustrated in Figure 1, the extent of publications in the "Modularity" field has grown substantially.

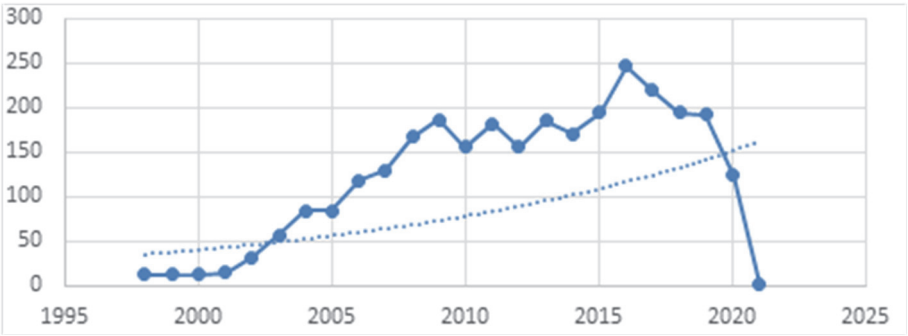

Figure 1: Published trends in the field of "Modularity" Research 1998 – 2020 (blue dotted line: predicted trend, blue line: original direction)

A subject search for "Sustainable" and "Sustainability" resulted in 160 documents in the SCOPUS database. The average number of citations per item for these 160 relevant documents is 15.90, which is lower than the number for "Modularity."This is the first relevant document, having been published in 1997. The last 160 groups of documents were analysed using the scientific mapping tool BiBliometrix-collection (http://www.bibliometrix.org/) (Aria & Cuccurullo, 2017).

Table 1 summarises the key messages from the bibliometric data collected. There are 94 articles, 52 conference papers, eight documents and three books. To map the current sub-themes in the field of modularity-based research, in particular sustainability and sustainable, we have selected the 20 most frequently cited documents from a total of 160 papers for qualitative analysis. The following sections provide quantitative and qualitative.

Table 1: Synopsis of the Essential Information of Accumulated Bibliometric Data

Description	**Results**
Documents	160
Sources (articles, conference paper, review)	152
Keywords Plus (ID)	531
Author's keywords (DE)	500
Period	1997-2020
Average citations per document	15.9
Authors	558
Authors of single-authored documents	16
Authors of multi-authored documents	542
Authors per documents	3.49
Collaboration index	3.76

Document types	**Results**
Article	94
Conference	52
Review	6

3. Quantitative Analysis

3.1 Analysis of publication years

Figure 2 illustrates the annual systematic output of publications on "Modularity", "Sustainability", and "Sustainable" for the period from 1997 to 5 December 2020. During this period, 160 scientific papers were published, including 94 articles, 52 conference papers, six review papers, three books and five other papers. There were 22 publications overall in 2018, up from 0 in 1998. There were several turning points during these peak years for publications in 2018. From 1997 to 2002, there was an almost complete absence of publications in the modularity field. From 2004 onwards, a speedy upsurge occurred in the number of publications in the field, and from 2015 to 2017, there was a decline in the number of publications. However, in 2018 more researchers were focusing on this area.

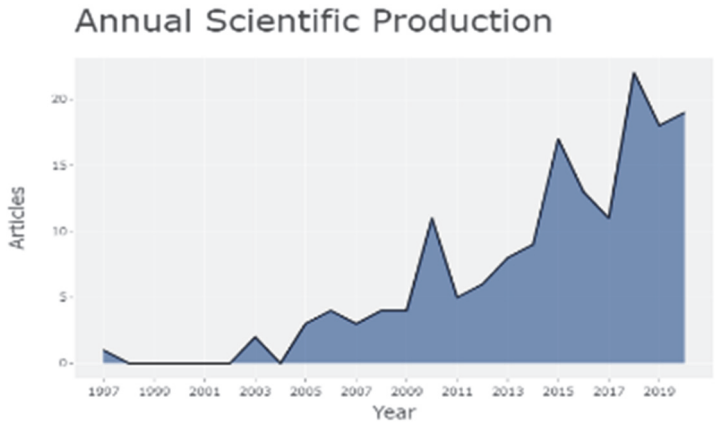

Figure 2: Annual scientific output for sustainability in modularity research, 1997 – 2020

From 1997 to 5 December 2020, the median yearly quantity of article citations is illustrated in Figure 3. According to this trend, the two articles published in 2003 had the highest average number of citations per year. While the average number of sources for papers published in 2006 was eight, the number of published articles has increased.

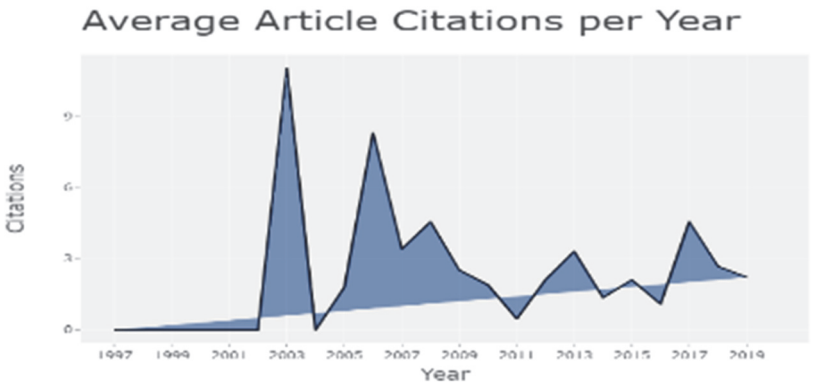

Figure 3: Average citations according to a year of articles used in modularity for sustainability research, 1997 – 2020.

There are 160 citations in this catalog, such as articles, reviews and conference papers. Figure 4provides the most highly local citations for 1997 – 2020. A local citations is the sum of records cited for the documents included in the collection analysis. As shown in the figure, the most-ranked extremely local citation is for content written in 2013, which is much more frequent than the second-ranked average citation frequency from 2010.

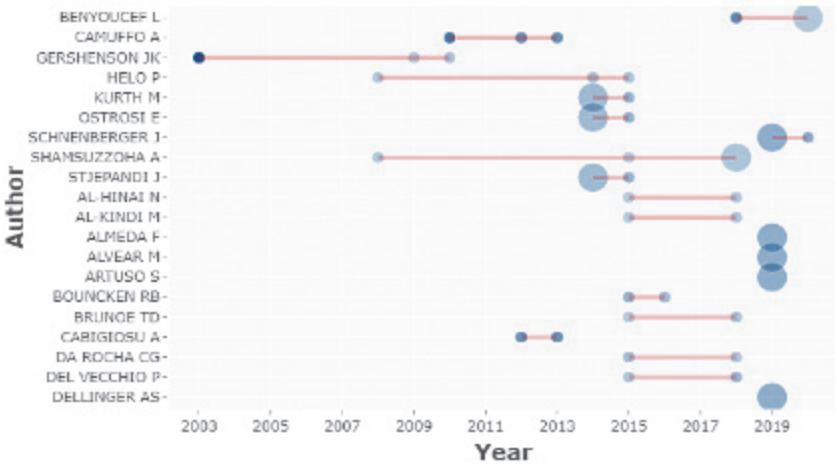

Figure 4: Top 20 locally cited publications on modularity for the sustainability research field.

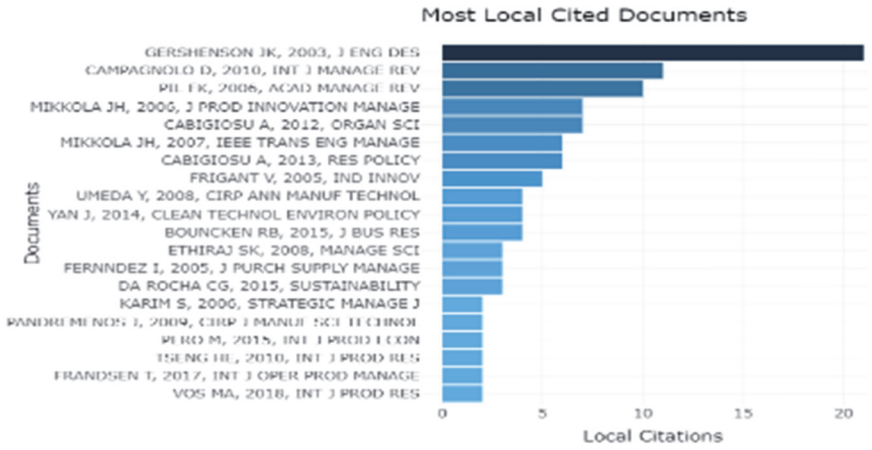

Figure 5: Top 20 most pertinent author's publications on modularity for sustainability research area from 2003 to 2020 (red stroke: the author's timeline, bubble size: the number of publications, bobble color robustness: total citations per annum

3.2 Analysis of authors

Figure 5 indicates the greatest pertinent authors' results from 2013 to 2020. The red stroke suggests the author's dockets. For example, between 2003 and 2020, Shamsuzzoha published 11 articles in the field of modularity sustainability and sustainable. Compared to other authors, Shamsuzzoha has had the most extended sustained period of article publication. The dimensions of the bubble are

proportionate to the number of yearly publications. The color intensity of the beads is correspondingly proportional to the annual total number of citations. Most literature was published in 2019 and it can be seen from the diagram, more researchers have been studying modularity recently and have developed an interest in these niches.

3.3 Analysis of sources

This book contains 140 materials from books, journals, and conference proceedings. Figure 6 illustrates the most significant pertinent sources of modularity for applications in sustainability. Each source has at least one paper included in the collection. International Journal of Production Research is the topmost critical journal in the field of modularity, with around four papers published between 1997 and 2020. IEEE Transactions on Engineering Management is the second-ranked journal, with three papers published. The top 3 journals in the diagram are essential for researchers in modularity when it comes to submitting documents.

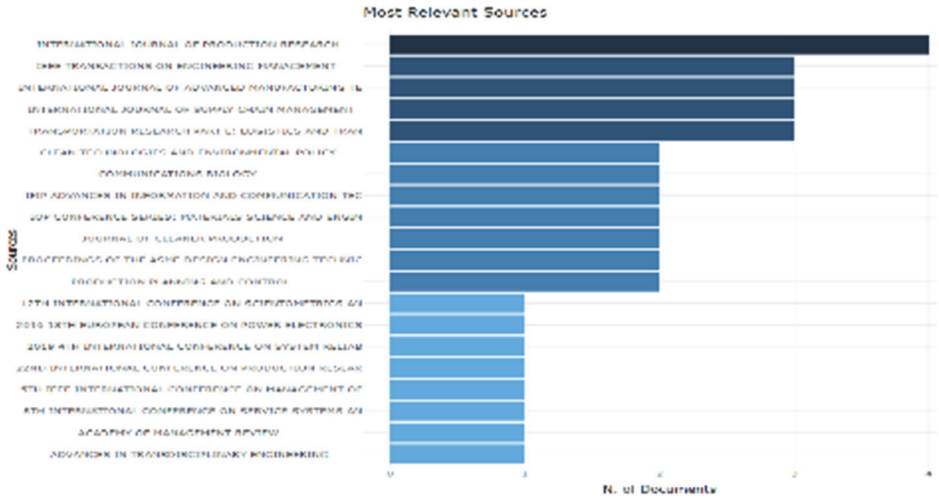

Figure 6: Top 20 pertinent sources by the number of articles and books published on modularity for sustainability study

3.4 Analysis of countries

A total of 160 papers have been published in modularity for sustainability, distributed in 46 countries. The top 20 nations' scientific production is indicated in Figure 7. The red stroke represents the publishing rate in the nation of the corresponding author who has at minimum one co-author from elsewhere. The blue stroke represents the number of articles published by writers from similar countries. Multiple-Country Publications (MCP) and One-Country Publications are their respective names (SCP). China, with 14 publications; the United States with nine publications, and Germany having six publications are regarded as the three most influential nations. So far, China has had the maximum worldwide collaboration. On the other hand, the USA has the most published by a single author.

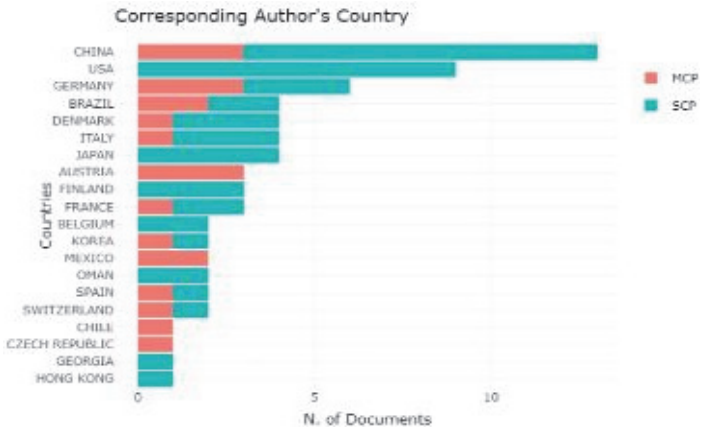

Figure 7: Top 20 corresponding author's country (red stroke: Multiple Countries Publication (MCP), Single Country Publication (SCP)).

Figure 8 comprehensively depicts the number of authors by publishing country. The number of articles co-published by the leading countries on the subject of modularity for sustainability is shown in Figure 9. The intensity of blue in both graphs is proportionate to the number of linked writers in each nation. Each shade of blue represents a spectrum of connected writers, from the darkest blue (US authors) to the lightest (Argentina, Costa Rica, and Croatia). The United States and China are the two leading research powers on modularity research for sustainability. France and Germany are the second most producing nations. In Figure 9, the thickness of the red stroke is proportionate to the number of multiparty publications in each nation. The thickest portion of the red linkages in-between nations represents the number of collaboration papers, with the United States and China having the most cooperation documents. As Figure 9 depicts, China and the USA are collaborative in systematic production. In general, the United States is the core country for all published documents, as there are several frequent connections nations between the United States and others.

Figure 8: Country's systematic production world map of modularity for sustainability research area (blue color robustness: the number of authors related with each country, grey color: non-affiliated country)

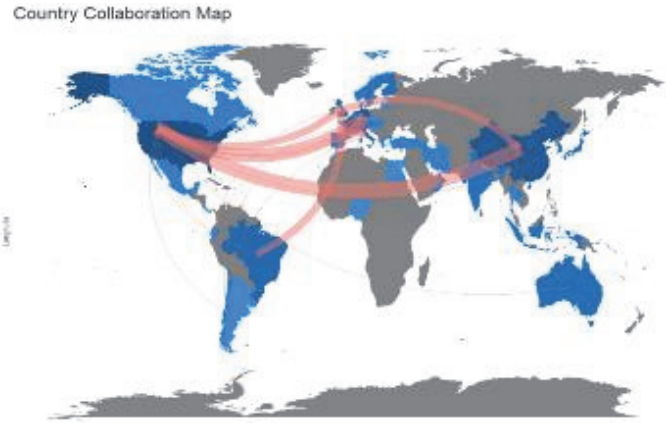

Figure 9: Country alliance world map of modularity for sustainability research field (blue color concentration: the number of authors allied with each country, grey color: non-allied country, red stroke thickness: the number of shared publications).

Figure 10: Thematic map of keywords network clusters in modularity for sustainability research area (bubble magnitude: the collections word occurrence rate)

3.5 Analysis of topics

To analyze the focal themes of the modularity publications on sustainability, keyword networks were used. The keyword networks show how different bibliographic databases interact. By clustering keyword networks, distinct subjects may be highlighted. Each keyword is exclusive to one topic. Therefore, specific episodes serve as thematic maps for each theme. Figure 10 in the thematic diagram shows the modularity research area focusing on sustainability. Each bubble shows a cluster of keyword networks. The cluster name is the word with maximum presence. Consequently, product development, cost reduction, complex networks, innovation, power electronics, conservation, morphometry, article and comparative study are the most important theme indicators.

The magnitude of the bubble is related to the occurrence of cluster words and its location relies on the criticality and density of the cluster. Criticality and concentration illustrate the thematic importance and thematic improvement of the modularity research area. Thus, the thematic theme map features topics vastly developed and secluded in the upper left, sports themes at the upper right, hooksthat are developing or fading in the lowest left, and essential and transverse themes in the lower right. Keywords such as innovation, conservation, distributed computer systems, and activation

energy, are the four cluster representatives of a few numbers of existences. They are referred to be exceedingly developed and secluded themes since they are of low significance and have undergone significant development.

Furthermore, keywords like modularity, product development, cost reduction, and environmental impact are four clusters that represent of primary and transversal themes. Product development, complex networks, environmental impact and innovation are the most common keywords, which are expected to be utilized for upcoming modularity studies.

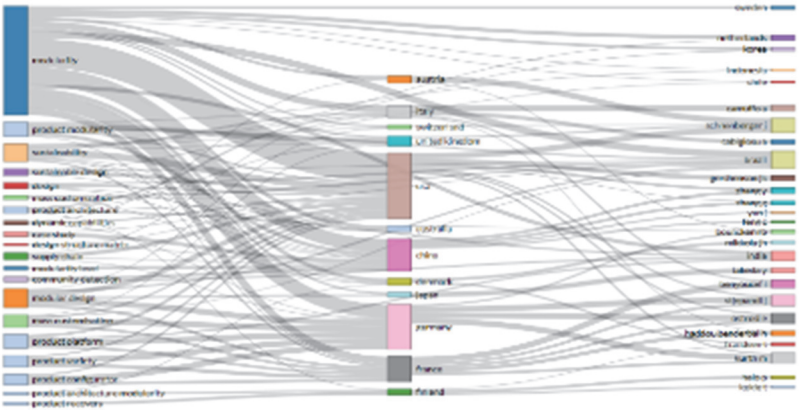

Figure 11: Three-area plot for the affiliation among topmost keywords (the left area), top authors (the right area), and top countries (the mid area) in modularity for sustainability publications

3.6 Keywords analysis

Three field diagrams have been created to provide a general perspective on using sustainability in modularity article keywords. Figure 11 and Figure 12 show a diagram of the three areas, which emphasize on the most important keywords. Figure 11 demonstrates how to choose three primary metadata areas: country as the midfield, keyword as the leftward area, and author as the right area. It demonstrates the connection between the top keywords, the topmost writers and the countries involved. As indicated in Figure 9, the authors 'preferences for keyword research areas are shown for all countries.

The most commonly used relevant keywords are product modularity, sustainable design, modular design, product platform, product variety, product configurator, supply chain and case study. In addition, the most common keywords authors use are sustainability, modularity level, community detection, design, mass customization, product recovery and dynamic capabilities. Countries such as the USA, Germany, China, France, Italy, Austria, Switzerland, United Kingdom, Denmark, Japan and Finland are the country where these keywords are most frequently used.

Figure 12 is generated by choosing three different information areas: keyword plus in the mid, journals on the left-hand, and authors on the right side. It illustrates the association between top keywords plus, authors, and journals. The keywords plus are words or phrases that often appear in headline citations and are automatically generated by a computer. Compared to Figure 11, the authors and keywords mentioned in Figure 12 are more intensive. The analysis of keywords and prominent research subjects within the field of modularity research aids readers in discovering the most recent findings. As demonstrated in Figure 12, journals associated with Integration are only published in the journal Production Planning and Control. The journal also publishes many articles on manufacture, life cycle and product modularity. Keywords such as manufacture, life cycle, product modularity, modular architectures, modular designs and product design are more likely to be published in the

Proceeding of The Asme Design Engineering Technical Conference. There is a phenomenal acceptance of product design since every prominent author has utilized it in their journals published by the vast majority of accessible publishers. The top modularity authors are engaged in sustainability research. Their papers are mainly published in the Asme Design Engineering Technical Conference, Journal of Cleaner Production and Ifip Advances in Information and Communication Technology. Author Kurth has published articles on product design in The Asme Design Engineering Technical Conference and Journal of Cleaner Production. Figure 12 is appropriate for locating the subjects and themes of studies published in leading journals to offer direction for submitting papers to specific publications.

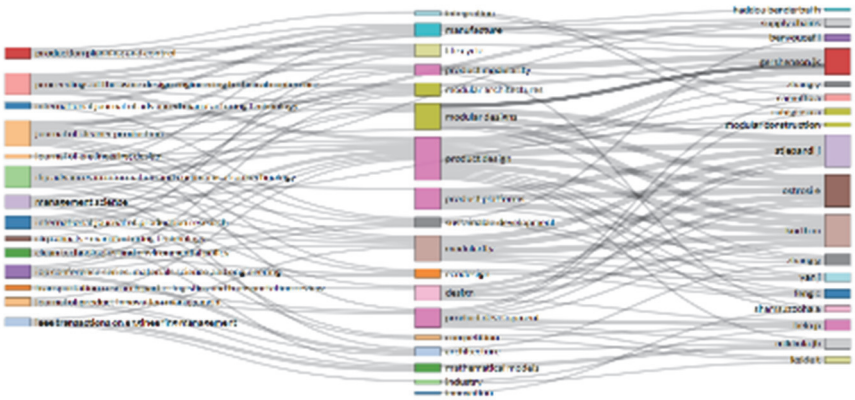

Figure 12: Three-area plot for the affiliation among top keywords plus (the mid area), topmost authors (the right-sided area), and top journals (the left-sided area) in modularity for sustainability publications.

Figure 13 illustrates the link between the publication's keywords using a conceptual strategy diagram. The dual scopes of the picture represent the average location of the articles contained in each term, and the middle of the graphic signifies the modularity center utilized in the sustainability study. In a conceptual structure, the words of each document are linked together in a system. This co-word system structure aids the reader in comprehending the topics covered by the research area and research discover the research frontiers. Separate from the network analysis, data simplification techniques permit the identification of subfields. Dimensionality reduction is achieved by applying correspondence analysis in the development of conceptual structure diagrams. As seen in Figure 13, each color indicates a recognized category cluster of words. Therefore, the keywords are separated into dual sets. The blue cluster contains three keywords: concurrent engineering, product variety, and product platforms. Almost all of the terms in this cluster are separated from one another. In contrast, the red cluster has forty keywords greater than the blue cluster. Social networking online and manufacturing, decision-making and complex networks, optimization and computer software reusability, commerce modularity and industrial management, modular construction and sustainable development, environmental performance and environmental management are all very close.

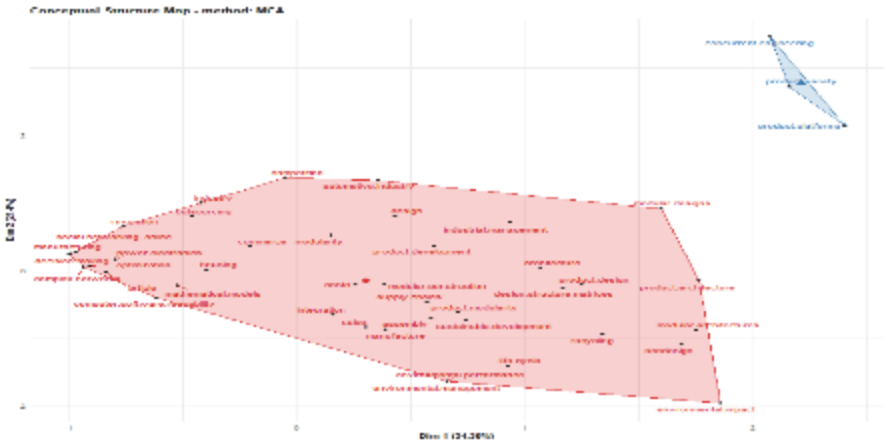

Figure 13: Conceptual structure map of keywords in modularity for sustainability publications (Dim.1 and Dim.2: the typical situation of the articles involved in each keyword)

Figure 14 shows a conceptual schematic of another keyword called Topic Dendrogram. The diagram covers similar statistics as Figure 13 but with a different interpretation. Likewise, the intangible structure tree diagram shows two sets of keywords. The detachment between words or between groups of words measures the altitude. Each tree diagram depicts a partition that is in the correct position.

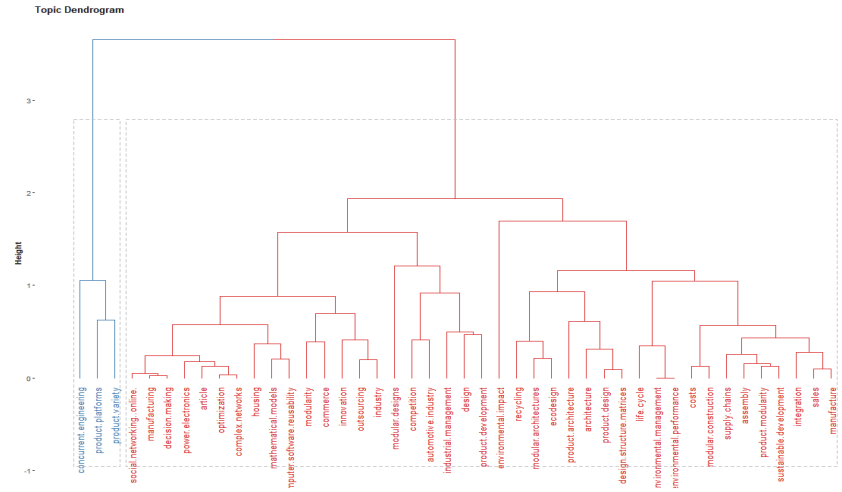

Figure 14: Conceptual structure Topic Dendrogram of keywords in modularity for sustainability publications (height: the distance among clusters of words)

Occasionally the reader demands to speedily comprehend the maximum prominent terms in the field of study. Keywords plus top, author's keywords of top, titles keywords of top and abstract words of the top are revealed in Figure 15, Figure 16, Figure 17 and Figure 18. The keywords plus accomplish the complexity of the content of the article. The author's keywords are a list of words that constitute the article from the author's perspective. A total of 1129 keywords plus 486 author keywords were utilized

to produce the outcomes of this analysis. While keywords plus and the author's keywords are equally effective in discovering knowledge in bibliometric analysis, keywords plus are more comprehensive in terms of providing the content. Figure 15 shows the keywords plus for the modularity sector from 1997 to 2020. The font size or colour of these words specifies their reputation. Figure 15 mentions keywords that occur between 4 to 58 times. Product design, product development, sustainable development etc., are the highest-ranking terms and top keywords in this research expanse.

Figure 15: Top keywords plus modularity for sustainability publications (font size: word existences).

Figure 16: Word of top author's keywords in modularity for sustainability publications (font magnitude: word existences).

Figure 16 shows the authors' keywords, from 55 to at least two existences, with product modularity, supply chain, sustainability, sustainable design and modular design etc. Figure 17 illustrates the words that appear in the title, product, integration, case, design, supply, systems, chain is the most pertinent. Figure 18 illustrates the words in the abstract, the most common being product, design, modular, study, system and process. The top summary words frequently appear in publications related to modularity. In summary, it is surprising that the words author, title or abstract keywords have a similar pattern. Thus, authors should utilize more pertinent words in their titles, abstracts or as keywords for their publications.

Figure 17: Top title words in modularity for sustainability publications (font size: word occurrences).

Figure 18: Topmost abstract words in modularity for sustainability publications (font magnitude: word occurrences)

Figure 19 shows the number of top keywords based on modularity for sustainability from 1997 to 5 December 2020. The life cycle as a research topic has been proliferating since 2014. Keywords such as life cycle, supply chains and product design have appeared more and more frequently in recent publications. Since 2015, keyword product development has much received little attention from academics. Because of the rapid increase in frequency from 1997 to 2020, will there is expected to be a great deal of work on these topics in the field of modularity research.

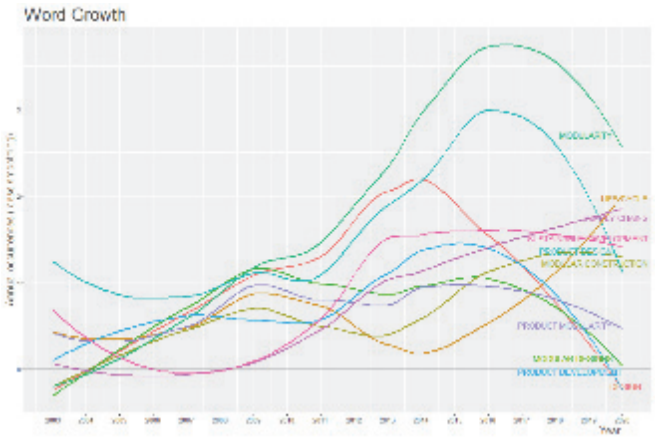

Figure 19: Annual occurrences of top keywords in modularity for the sustainability research field within the 1997 to 2020 period (method: loess smoothing)

3.7 Qualitative analysis

There are 160 papers around modularity which that related to sustainability and industrial design, published from 1997 to 2020. Among them, there are 15 publishes with high citation rates. This number states the first-class papers within our bibliographic dataset. In this section, the data is qualitatively evaluated rendering 10 highest-cited articles. The supplementary table displays the most or least studied subjects and methods in the modularity research area.

3.8 Subjects

The commonly utilized subjects in top-cited modularity papers include modularity, sustainability and industrial design (De Medeiros et al., 2014; Yan & Feng, 2014; Yan et al., 2012). The most relevant article topics followed by their sub-topics are also noted in Supplementary Table. Every top article has debated or in some way to utilized modularity methods in its case study (Bryant et al., 2004). More than half of the authors in this analysis have paid attention to product modularity and modular design as the author's papers' subjects. Although modular product design (MPD) is specific keywords and formerly was apparent in the top keywords' graph, it has occurred in nearly 25% of the highest-cited papers (Ma & Kremer, 2016).

Research subjects such as optimization modularity and component/ sub-assembly/module have already fascinated virtually half the authors of most mentioned documents. There are solely limited numbers of papers that use a modular system of question subject keywords together (Ma & Kremer, 2016a & 2016b). Ecological environment orientation has been concern by researchers (Liu et al., 2020; Qi & Wu, 2011). Environmental protection and ecological protection are considered to be important indicators of modular methods. Supplementary Table proves that virtually all top most cited focus on environment/environmental assessment. On the other hand, industrial design, such as product family design, design checklist, design structure, and product management etc. It also has a high reference cited rate. More than 80% of the papers aimed to purify modularity, and about 60% of them considered sustainability-oriented modularity, of course, approximately 50% of articles used the modularity component method (De Medeiros et al., 2014; Ma & Kremer, 2016a).

4. The Analysis of Modularity-Based Methods

The analysis of modularity-based methods is separated into dual sets, description and quantification of modularity and statistical analysis. As supplementary table shows, only a few numbers of papers have based-matrix, based-programming and based-algorithm methods. Among them, the matrix method is the most widely used and variant, for example modularity evaluation matrix, interaction matrix, driver selection matrix and prioritization matrix etc. Next to the matrix is the algorithm, for instance heuristic swapping algorithm, cluster identification algorithm and group genetic algorithm (Zheng et al., 2020). These two methods are almost used in articles with high citation rate. Meanwhile, the atomic theory has been yet to be found in the top articles (Liu et al, 2020; Mutingi et al., 2017; De Medeiros et al., 2014).

As it is illustrated in Supplementary Table, most statistical analyses were accomplished using ANOVA statistical analysis and Student's T- test. Histcite software is powerful document index software. Histcite software can be used for document analysis and directly import documents to help you quickly control the historical development of a particular industry. It is straightforward and practical. SPSS software, in the paper's simple statistical analysis method, there is the use of chart and table presentation. More than 60% of cited articles use this software for analysis (Shamsuzzoha & Helo, 2017; Ma & Kremer, 2016a).

This concluding section revised 10 modularity-based papers with the top Scopus times cited count ten full adjusted. The modular system of questions has been reported as the most famous material in modularity research. Furthermore, most of the examined references have illustrated sustainable product development and sustainable product design as their critical research gap (Huang et al., 2016; Romli et al., 2015). Finally, assessing product sustainability is an essential basis for testing whether the modular method has been optimized. Moreover, it is an important research content of many research papers with high application rates (Ma & Kremer, 2016a; Yan & Feng, 2014).

5. Conclusion

The bibliometric analysis uses mathematical and statistical methods to assess publication

scholarship. Research on the bibliometric analysis of "modular design" has not yet been fully developed. This article reports a bibliometric study of the research literature on modular methods to sustainability from 1997 to 2020, which used the Scopus data source. The outcomes confirm that modularity and modular of sustainable product-grounded discovery have been progressive in recent years. Yearly publications in modularity method research continue to grow, and peaked in 2016. Researchers from China, The USA, Germany, Baily, Denmark, Italy and Japan accounted for most of the publications. China and USA were ranked first and second in the quantity of paper outputs. Research Reported, International Journal of Production Research was identified as the most applicable journal in modularity research field. Our bibliographic set's rudiment and transverse themes are representative keywords such as sustainable design, life cycle, modular design and product platform (Ceschin & Gaziulusoy, 2016). It is foreseeable that the conclusions from this work offer a better revelation on the forthcoming research course and the sustainable-oriented modular design method has been practiced in the field of industrial design.

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