Packing Irregular Shapes For Three-Dimensional Printing: A Bibliographical Study

Ajinkya Warade, Dr. Preeti Mulay, Apurva Chaudhari

Abstract: Packing optimization of printer volume can significantly contribute to greater efficiency in 3D printing in terms of time, output and cost reduction. The purpose of this bibliometric analysis is to understand current research done in this area. In this paper survey, two databases, Scopus and Web of Science (WoS), are primarily used. A third study focused on specific keywords related to packing of irregular shapes for 3D printing. Time-series analysis showed contributions in this area over the years. Also, by geographical analysis, China and the USA are two major contributors, by subject area analysis most of the research is done in Engineering and Computer Science. This methodology fuses the idea of octrees, to isolate 3D objects into a tree-like structure, checking collision within numerous items and printing space and then packing those with the assistance of simulated annealing. The effectual 3D Printing can be done by optimizing and stabilizing the packing of irregular shaped objects in printing space, hence this study.

Index Terms: Bibliometric, Efficiency, Irregular shapes, Machine learning, Optimization, Simulated annealing, 3D printing.

1.INTRODUCTION

Added substance manufacturing (AM) has an expanding scope of applicability. Compared to old style fabricating it demonstrates a few points of interest. Beforehand unimaginable shapes and structures are accessible, prompting models that can be delivered without a huge stock or generation chain. Thus, the assembling of new items is quickened, the agreeing expenses are decreased, and a wide scope of client specified items can be created. Given the 3D model of the item, it tends to be created medium-term and conveyed to the buyers. While 3D printing (3DP) is one specific AM strategy (forms that consecutively store material onto a powder bed with inkjet printer heads), these days, the two terms utilized as umbrella terms for a few advancements, which incorporate laser stereolithography (SL), particular laser sintering /softening (SLS/SLM), electron shaft dissolving (EBM), layer cover producing (LLN), and combined layer displaying (FLM). Various research papers on the efficient pressing of items for 3D printing have been distributed isolates the work into two classes: 3D packing and looking for an ideal sequence for orientation, The Packing efficiency of the 3D printer's printing volume can be optimized by this approach. More over with leading advancement in technology, Machine Learning [6],[16] techniques can be applied to make this technology more efficient and prominent. This approach incorporates the concept of octrees, to divide 3D objects into a tree like structure and then arranging or packing them with the help of simulated annealing, further ahead checking the collision within the multiple objects and the printing space.

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These steps would result in sequence of orientations of the objects in the printing space for the most efficient packing. Further this approach aims to solve the stability of the overall printing objects in the 3D printer by applying physics engine to the sequence (by keeping in consideration print material stability with respect to gravity) finally with the help of 3D printing software supports within objects and overall support for the printing material can be determined for the printing of the objects.

2. PRELIMINARY DATA COLLECTION

We have collected the data from various sources including but not exclusive Scopus, Web of Science(WoS), Google Scholar, Research Gate, IEEE and ACM. We also used our educational institutional access to these sources. Few sources required commercial resources for access which was fulfilled by the support of our affiliated educational institution. Scopus is the biggest dynamic and reference database of companion assessed examine writing in the field of science, building, innovation, medicine, material science, sociologies, expressions, and humanities. The paper takes into consideration the Scopus database and WoS (data from both sources are represented in parallel to show relative difference between both as well), with the help of significant keywords identified in section 2.1.

2.1 Significant Keywords

While doing survey, keywords play a very pivotal role in the search results. Changes in few keywords can make a substantial difference in the results. Multiple keywords were considered for searching through the databases. The keywords used are mentioned in the following table 1.

Table 1 : *Keywords considered for searching through Scopus and WoS database.*

Keywords	"3D printing" OR "3D bin packing" OR "irregular shapes packing" OR "Three dimensional packing of irregular shapes" OR "Three dimensional flexible packing" OR "Simulated annealing" OR "Collision Detection"

2.2 Initial search result

In the initial search over both the databases resulted documents in multiple languages. The languages in which

documents published were mainly English, Chinese, Spanish, Russian etc. The language specific document results for Scopus and WoS are as follows:

Table 2: *No. of documents published in multiple languages in Scopus & WoS dbs*
Source: http://www.scopus.com , http://www.webofknowledge.com (accessed on 1st Dec. & 23rd Nov. 2019)

Languages	Number of Documents	
	Scopus	WoS
English	25671	12888
Chinese	1482	54
German	67	50
Russian	20	141
Spanish	43	66
Korean	34	663
Portuguese	15	10

This paper is based on the data in Scopus and Web of Science (WoS) data repository. Initial search was done with above mentioned keywords. All kinds of published and unpublished publications considered. For Scopus, the publication statistics showed that 90.9% articles, 5.9% review papers were published. Following table shows the overall statistics of the publication done overall in Scopus and WoS database.

Table 3: *The publication types from Scopus and WoS*
source: http://www.scopus.com , http://www.webofknowledge.com (accessed on 1st Dec. & 23rd Nov. 2019)

Scopus		WoS	
Document types	No. Of Documents	Document Type	No. of Documents
Article	15969	Article	12000
Review	1038	Review	1300
Editorial	39	Editorial	500
Book	34	Book	250
Conference paper	9761	Meeting	1350
Conference review	26	Abstract	800
Short Survey	35	Case report	400
Book Chapter	339	Other	1500
Note	54	Unspecified	29

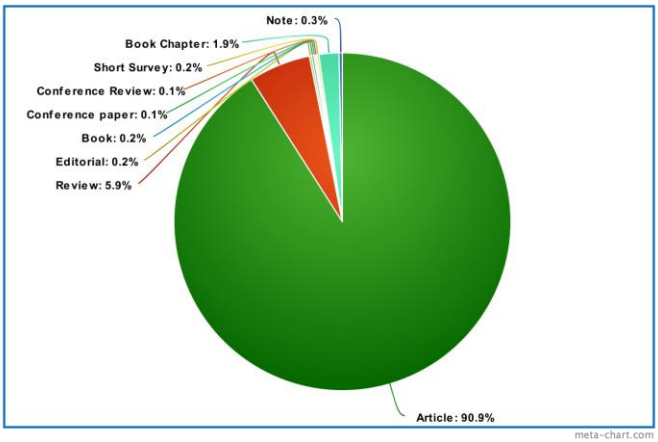

Figure 1: *Various types of Scopus publishing.*
source: http://www.scopus.com (accessed on 1st Dec. 2019)

For Web of Science (WoS) publication statistics showed that 61.5% articles were published, 7.5% other material were published. Following figure shows the overall statistics of the publication done in WoS database.

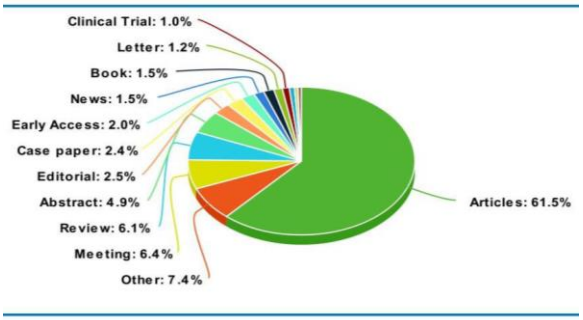

Figure 2: *The types of publications from WoS*
source: http://www.webofknowledge.com (accessed on 23rd Nov.2019)

By using Scopus for further detailed survey related specifically to “3D printing, Simulated annealing” for ranging over a period of recent seven years (i.e 2013 to 2019 till date) for type of documents published showed the results as follows:

Table 4: *The publication types in 3D printing of irregular shapes*
source: http://www.scopus.com , (accessed on 1stDec.2019)

Document type	Number of Documents
Article	75
Conference Paper	32
Review	5
Book	2
Book Chapter	1

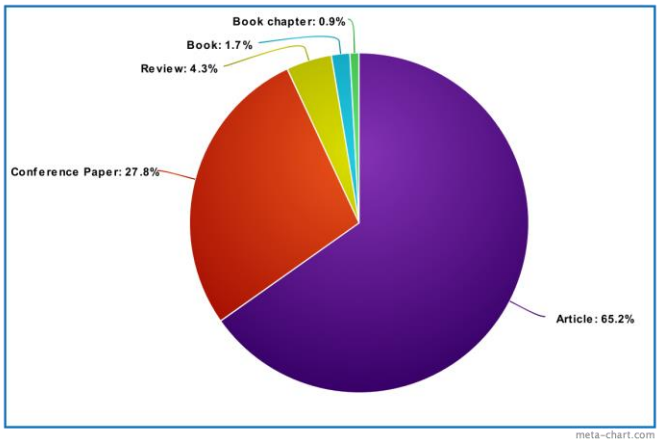

Figure 3: *Types of publications specific to 3D printing of irregular shapes in Scopus*
source: http://www.scopus.com (accessed on 1st Dec.2019)

2.3 Preliminary data highlights

All the relevant documents retrieved are in the form of articles, review papers, conference papers, reports etc. For overall Scopus and WoS publication in a year-wise manner showed following results depicting number of documents published in the specific year, the following table shows the year and number of documents published in that year.

Table 5 : *Annual Scopus and WoS publications. Source: http://www.scopus.com , http://www.webofknowledge.com (accessed on 1st Dec. & 23rd Nov. 2019)*

Year	No. of Documents	
	Scopus	WoS
2019	4667	2800
2018	4494	4000
2017	3787	2500
2016	2919	1750
2015	1970	1200
2014	1238	750
2013	836	250
2012	670	200
2011	601	180

By using Scopus for further detailed survey related specifically to keywords, “3D printing, Simulated annealing” for over a period of recent seven years (i.e 2013 to 2019 till date) showed the results for year-wise publication, are as follows :

Table 6 : *Yearly publication of papers for 3D printing, simulated annealing*
source : http://www.scopus.com (accessed on 1st Dec.2019)

Year	No. of Documents
2019	34
2018	30
2017	15
2016	14
2015	13
2014	4
2013	3

2.4 Data investigation

A bibliometric[1],[2],[3] research was conducted in the following section to determine the distinguishing features of literature, major surveys and researchers in the field of packing irregular shapes [8],[13],[18],[19],[22] for 3D printing being geographical attention of research, statistical affiliation, contributions of authors, published journals and their statistics .

3.BIBLIOMETRIC ANALYSIS

To carry out the bibliometric[1],[2],[3] analysis of packing irregular shapes for 3D printing. Two approaches were considered, those are as follows:

- Analysis of geographical region.
- Statistical representation of Affiliation, Author, Subject Area, Keywords etc.

3.1 Geographic regional analysis

According to the results obtained from Scopus and WoS , the top countries are mentioned for the geographical country wise publication of documents, the total number of documents with respect to the country is given in table 7 below,

Table 7 : *Geographic regional publications source : http://www.scopus.com , http://www.webofknowledge.com (accessed on 1st Dec. & 23rd Nov. 2019)*

County/territory	Number of Documents	
	Scopus	WoS
China	6765	1250
United States	6632	4200
United Kingdom	1803	700
Germany	1407	770
South Korea	954	800
Australia	890	710
Canada	870	600
Italy	827	630

According to the results obtained from Scopus and Web of Science(WoS), various countries are mentioned for the

geographical country wise publication of documents, it is observed that the United States and China are leading contributors.

By using Scopus for further detailed survey related specifically to keywords, “3D printing, Simulated annealing” for over a period of recent seven years (i.e 2013 to 2019 till date) showed the results for geographical country wise publication, It is observed that China has published most documents, followed by the United States and Canada as per the numbers. Overall data about country wise publications are as follows :

Table 8 : *Country wise publications specific to 3D printing of irregular shapes.*
source : http://www.scopus.com (accessed on 1st Dec.2019)

Country/Territory	Number of Documents
China	38
United States	36
Canada	8
United Kingdom	7
Germany	6
Australia	5
India	4

3.2 Affiliation Analysis

The top contributing Universities / Organizational affiliations . The 3d printing has been a new and growing research topic among various universities such as Chinese Academy of Science, Ministry of Education China and among various others. Some of the top contributors are mentioned in the table as follows. Data retrieved from Scopus and WoS is mentioned in the following table 9,

Table 9 : *Affiliated universities*
source : http://www.scopus.com , http://www.webofknowledge.com (accessed on 1st Dec. & 23rd Nov. 2019)

Scopus		WoS	
Affiliation	No. of Documents	Affiliation	No.of Documents
Chinese Academy of Sciences	452	Chinese Academy of Sciences	285
Ministry of Education China	443	Ministry of Education China	211
Nanyang Technological University	352	Nanyang Technological University	214
Tsinghua University	328	University of California Systems	269
Zhejiang University	259	Chinese ACAD SCI	193
Georgia Institute of Technology	200	University of Texas	187

By using Scopus for further detailed survey related specifically to keywords, “3D printing, Simulated annealing” for over a period of recent seven years (i.e 2013 to 2019 till date), it is observed that multiple universities have published in this field, A list of universities and organizations with the number of contributions from each is mentioned in the table 10 as follows:

Table 10 : *Affiliated universities*
source: http://www.scopus.com (accessed on 1st Dec.2019)

Affiliation	Number of Documents
Nanjing Normal University	10
Shepherd University	6
Zhejiang University	5
Ministry of Education China	3
University of Nottingham	3

3.3 Author Analysis

From all the retrieved data from Scopus and WoS it is observed that multiple authors are contributing in this field (related to the keywords used) heavily. Following table 11 shows few of the top contributing authors with the number of documents that they have contributed so far ,

Table 11 : *Author Analysis*
source : http://www.scopus.com , http://www.webofknowledge.com (accessed on 1st Dec. & 23rd Nov. 2019)

Scopus		WoS	
Author	No.of Documents	Author	No. of Documents
Chua, C.K.	71	Zhang, Y.	88
Yeong, W.Y.	67	Li, Y.	72
Li, D.	55	Liu, Y	69
Lewis, J.A.	40	Lee, J	67
Williams, C.B.	39	Wang , Y.	62
Zhou, C.	39	Wang , J.	61
Qi, H.J.	35	Wang ,L	60
Cho, D.W.	34	Chen, Y	55

By using Scopus for further detailed survey related specifically to keywords, “3D printing, Simulated annealing” for over a period of recent seven years (i.e 2013 to 2019 till date), A list of multiple authors with the number of contributions from each is mentioned in the table 12 as follows:

Table 12 : *Author Analysis*
source : http://www.scopus.com (accessed on 1st Dec. 2019)

Author Name	Number of documents

Wang, S.	9
Zhang, Y.	8
Ji, G.	6
Yang, J.	6
Matusik, W.	5
Phillips, P.	5
Beaulieu, L.	4

3.4 Subject Area Analysis

All the documents that are published are all related to some or other subject area field. The following statistics show the overall number of documents that are published in the respective field to get a clear perspective about the area in which research contribution is done. Table 13 shows the subject area and the number of documents published in that area respectively are analysed from Scopus and WoS database.

Table 13 : *Subject Area Analysis*
Source : http://www.scopus.com , http://www.webofknowledge.com (accessed on 1st Dec. & 23rd Nov.2019)

Subject Area	Number of Documents	
	Scopus	WoS
Engineering	14867	7178
Computer Science	9350	3305
Material Science	6838	5054
Physics	3996	2929
Mathematics	3695	1449
Chemistry	1868	2261
Biochemistry	1592	1246

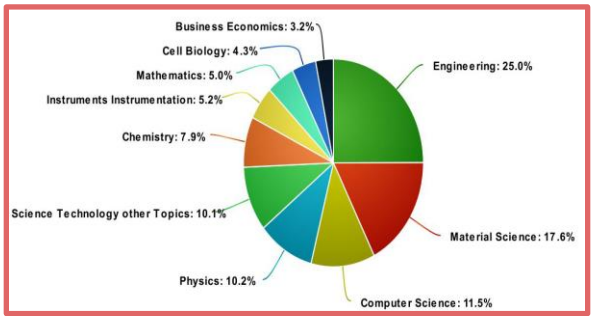

Figure 4: *Subject area analysis from WoS*
Source: http://www.webofknowledge.com (accessed on 23rd Nov.2019)

Data Retrieved from Scopus by using Specific keywords "3D printing , Simulated annealing", The Following Table 14 shows all the retrieved data:

Table 14 : *Subject area analysis*
source : http://www.scopus.com (accessed on 1st Dec.2019)

Subject Area	Number of Documents
Computer Science	59
Engineering	51
Mathematics	19
Physics and Astronomy	18
Material Science	16
Medicine	11
Biochemistry, Genetics and Molecular Biology	7
Chemical Engineering	5

3.6 Keyword Analysis

As discussed earlier keywords play a very pivotal role while surveying through any database or online repository. A single keyword can make a very substantial difference in the resulting search outcome. As seen from the tabular figure mentioned below it is clear that many documents are published related to 3D printers, followed by 3d printing, similar outcomes are observed in the WoS database (number may differ). So to look further detailed only required keywords were searched to get specific results related to packing irregular shapes[4],[8],[13],[18],[19] for 3 Dimensional Printing.

Table 15*: Keyword analysis from Scopus*
Source : http://www.scopus.com (accessed on 1st Dec.2019)

Keywords	Appearances
3D Printers	11292
Simulated Annealing	9270
3D Printing	7939
3-D Printing	7446
Optimization	7363
Algorithms	3468
Three Dimensional Printing	3265

Data Retrieved from Scopus by using Specific keywords "3D printing , Simulated annealing", The Following Table 16 shows all the data retrieved :

Table 16 : *Keyword Analysis*
source: http://www.scopus.com (accessed on 1st Dec.2019)

Keyword	Appearances
3D Printers	48
3-D Printing	26

3D Printing	24
Optimization	16
Algorithm	14
Simulated Annealing	13
Genetic Algorithms	11

4.RESEARCH IMPLICATIONS OF THIS STUDY

3D printing and 3D related research work is done all over the world, and while it is continuously growing. This research work primarily laid the firm groundwork that will prompt inventive, creative ability and enlighten the significance of 3D printing to bring in the change through more improvement in their processes. United States and China are dominating in this research field immensely and there are multiple countries like Spain, Russia, India who are growing at a quick pace in this area of 3D printing and packing.

5.CONFINES OF PRESENT STUDY

This study mainly explores two databases that are Scopus and WoS (Web of Science) by using a combination of keywords for the analysis purpose. Both databases have resulted in somewhat similar level of results but the diversity within the result matters on a huge scale. This study also include a third analysis which emphasis on specific area that is packing irregular shapes[8],[22] for three dimensional printing. Though not a lot of work is done in this field compared to overall study, researchers have a wide range of work that can be carried out to make the field of 3D printing more efficient and dynamic. Meta-Chart application was used to create graphs. This study restricts research papers in English language only.

6.CONCLUSION

This bibliometric survey on packing irregular shapes for three dimensional printing revealed that maximum publications are in the form of Articles and Conference papers, affiliated with Engineering and Computer Science. By using Scopus and WoS it is observed that the United States and China are leading contributors, followed by the United Kingdom, Germany, Spain and India. Many publishers, authors, institutes/ universities are contributing for various advancements of this field. Packing optimization of the printer volume can significantly help in more efficiency with respect to time, production and cost reduction in 3D printing. A time series analysis based on year-wise publication showed how with passing time the contribution in this field is increasing tremendously. These 3D printing and packing can help industries on an exponential level when production time, cost optimization is taken into consideration. Moreover with leading advancement in technology Machine Learning techniques can be applied to make this technology more efficient and prominent. In our approach simulated annealing is a simple machine learning model to create multiple sequences of optimal object orientation. This methodology fuses the idea of octrees, to isolate 3D objects into a tree like structure, checking collision within the numerous items and the printing space and then packing those with the assistance of simulated annealing. There was improvement in the spatial use of the printing space/volume.

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