A Competitive Patent Analysis of Three-Dimensional Printing Technology: A Holistic Approach to Assessing Technological Competitiveness and Growth

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Abstract : Three-dimensional printing technology (3DP), recognized as one of the most rapidly developing technologies in the advanced manufacturing sector, holds extensive applications across diverse sectors in modern industry. Nevertheless, the majority of existing studies have predominantly focused on technical aspects or practical applications, with limited attention given to evaluating the current technological competitive capacity and developmental trajectory of 3DP technology from a broader perspective. Consequently, this study aims to address this gap by providing a comprehensive analysis of patent documentation in the global 3DP market, encompassing worldwide research and development endeavors. This data-driven approach allows for a robust assessment of patent activity dynamics, providing important details on the top nations and principal patent owners in the under consideration technological domain. By employing such an approach, the study unveils a holistic picture of the 3DP industry's technological competitive landscape.

Keywords: Three-Dimensional Printing, Additive Manufacturing, Advanced Manufacturing, Patent Analysis

1. INTRODUCTION

Three-dimensional printing (3DP) [1] refers to an additive manufacturing process wherein a 3D physical object is produced layer by layer, based on a computer-generated design. This innovative technique has found extensive applications in a variety of fields, including construction, prototyping, and biomedical. Charles Hull, the co-founder of 3D Systems, invented this technology in 1986[2]. Subsequent technological developments, such as DTM Co.'s commercialization of selective laser sintering (SLS) [3], Helisys' Laminated Object Manufacturing (LOM), and Stratasys' fused deposition modeling (FDM)[4], allowed the emergence of low-cost 3D printing machines[5]. Because of its low manufacturing costs and ease of use, 3DP technology has enormous application potential in a wide range of fields, touching almost every aspect of our everyday lives. Furthermore, 3DP technology provides enhancements for future technological advancements. The task of discerning the trajectory of technological development in the realm of global innovation activity, coupled with an analysis

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of the prevailing competitive landscapes within the global 3DP technology market, assumes utmost significance in this context.

Patents are the tangible results of research and development efforts that signify the latest innovative advancements and the orientation of inventive activities in modern technology. Patent information, which effectively identifies technology opportunities, contains 80% of all technology information. As a result, the current study seeks to conduct a scientometric study of the global 3DP patent literature, as well as to investigate the technological development direction of 3DP technology and to lay the groundwork for determining innovation precedence and protection strategies in the 3DP technology field. The initial effort has contributed to catching up with technological competition capability from patent information, which could serve as a reference for universities and industry in recognizing the current technological competitive environment in the 3DP technology field.

2. DATA

For the analysis of patents in the global 3DP technology domain, the IncoPat platform was employed as a patent information retrieval and analysis tool. In particular, competitor analysis was carried out using Innography. The utilization of Innography's business data facilitates the assessment of a company's market value and scale, enables a comprehensive analysis and comparison of patent holders' strengths, and provides insights into the prevailing market competition and trends [6-7]. The paper was retrieved on September 2, 2022. The incorporation of specific keywords and their corresponding International Patent Classification (IPC) categories facilitates the process of retrieving relevant documentation, and the search formula is: ((TIAB=("3D print*") OR ("additive manufacturing*") OR ("rapid prototype*") OR ("three-dimensional print*") OR ("three-dimensional print*") OR ("three-dimensional object*") OR ("three-dimensional object*") OR ("3-dimensional* print*") OR ("stereolithography") OR ("laser sintering") OR ("powder bed fusion") OR ("fused deposition model") OR ("direct metal deposition") OR ("layered object manufacturing") OR ("laminated object manufacturing") OR ("inkjet printing") OR ("contour crafting")) OR (IPC=(B33Y))). As a result, 130,597 patents were obtained after merging the application number, and 109,046 inventor patents related to 3D printing were selected for conducting further analysis.

3. PATENT ANALYSIS OF 3DP TECHNOLOGY

3.1 Patent Publication Trend

Fig 1 reveals an overall positive trajectory in worldwide patent publications during this period. The United States and Japan were the pioneer countries to develop core 3DP technology. Since 2015, China has surpassed both countries, emerging as the primary contributor to the growth of 3DP technology patents. This trend indicates China's notable advancements and formidable competitive edge in the field of 3DP technology. However, both industrial and academic groups in China started researching 3DP technology later than other countries, resulting in a gap in the area of core 3DP technology between China and other advanced countries.

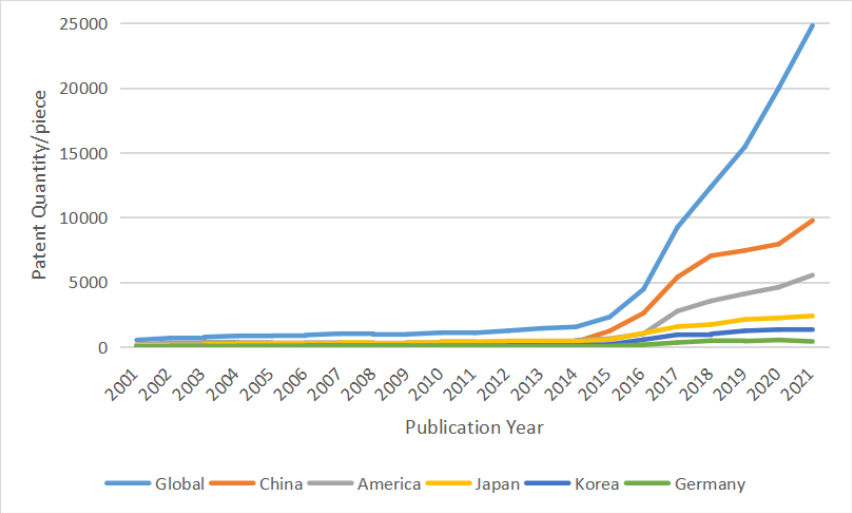

Fig 1. Patent Publication trend of 3DP technology

3.2 Regional Analysis

According to regional analysis, among all countries, China (31%), the United States (20%), and Japan (12%) emerge as the primary players in the development of 3DP (Fig 2). Notably, China leads the pack with 34,198 patents filed in this domain, followed by the United States with 21,429 patents, and Japan with 13,024 patents.

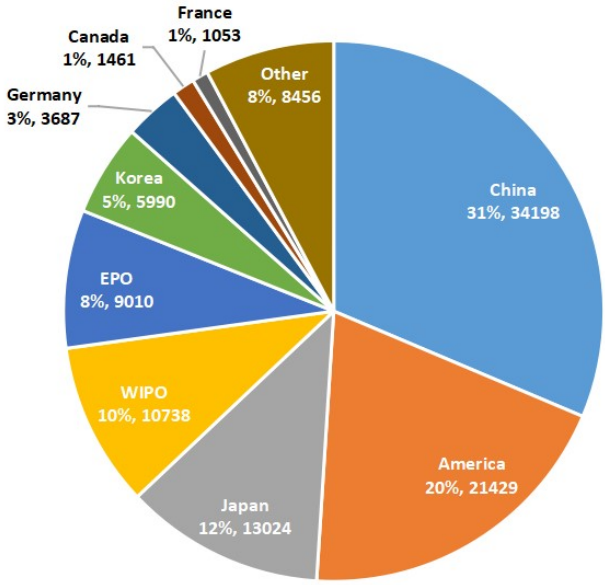

Fig 2. Patent regional analysis

The Paris Convention created the patent priority system for the Protection of Industrial Property in 1883, aiming to facilitate applicants in filing subsequent applications in other contracting states following their initial filing in domestic nation. Fig 3 illustrates the count of patent applications submitted in both domestic and foreign nations, serving as a measure of the patents' market value. Patents deemed to possess a high market value are typically those that have been filed in multiple foreign countries or regions, reflecting the patentees' endeavors and investments in safeguarding their rights on a broader geographical scale.

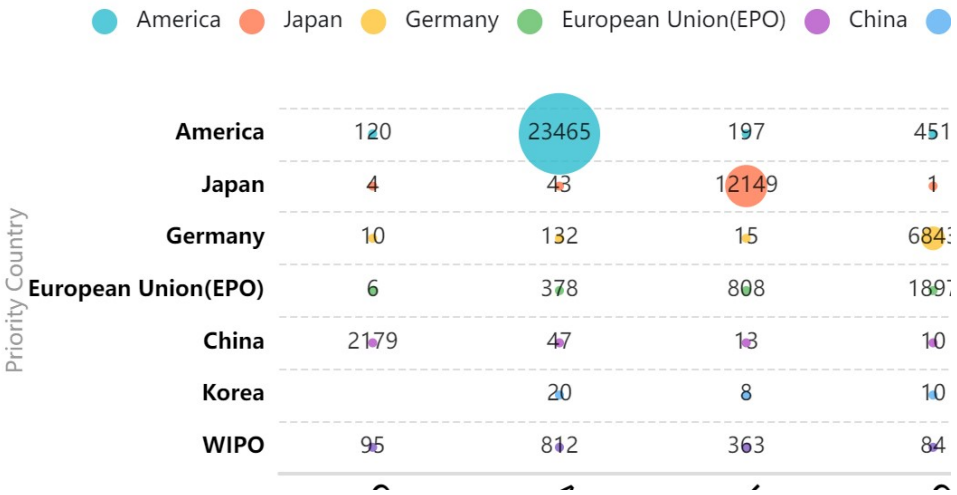

Fig 3. Patent applications submitted in both domestic and foreign nations

The United States is the leading country in terms of filling priority patent applications in foreign nations, followed by Japan and Germany, indicating the global key players. Due to its early entry into the 3DP market, the United States now has mature 3DP technology and, as a result, has the greatest rate of patent applications in other nations. Specifically, despite the fact that Germany has a much lower total amount of 3DP patents than China, the United States, and Japan, Germany places a high value on foreign patent layout. China, however, possesses the most 3DP technology patents overall and has the fewest priority patent applications in other nations. This finding suggests that China may not have adequately prioritized overseas patent protection, thus potentially increasing the risk of patent infringement when Chinese entities engage in global 3DP market competition.

3.3 Applicant Analysis

Fig. 4 displays the findings of a study conducted to determine the top ten patent holders in the domain of 3DP technology. The American company Hewlett-Packard (HP) leads the world with an impressive 4,551 published patents in the 3DP technology sector. Other prominent applicants in 3DP technology besides HP include General Electric Company (US), Canon KK (JP), Seiko Epson (JP), Electro-Optical Systems (GEM), Ricoh (JP), Stratasys (ISR), Xerox (US), Siemens (GEM), and Schutzrechtsverwaltungs. (GEM). Among the top 10 applicants worldwide, three industrial firms originate from the United States, three from Germany, three from Japan, and one from Israel. According to the data, the primary global competitors in the

3DP technology realm are the United States, Germany, and Japan, which is consistent with the analysis results of the priority patent application (Fig 3).

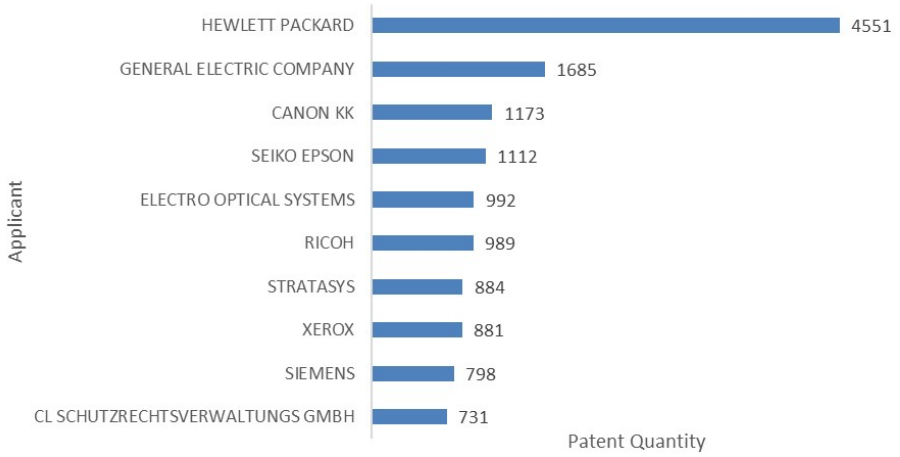

Fig 4. The patent quantity of the top 10 patentees in the field of 3DP technology

Innography is a great tool for building competing landscapes[8]. This chart integrates a vertical axis for resources and a horizontal axis for technology within the plane coordinate system, allowing for a clear display of the economic strength and technological differences among patentees. The Figure in the bubble size represents the number of patents. The technological axis encompasses crucial factors such as the percentage of patents, the classification of patents, and citations. The patentee is considered to be more technologically sophisticated the higher the abscissa value. The ordinate , on the other hand, stands for the enterprise strength index, which is related to the revenue, litigation activity, and geographical locations of the patent applicant. An applicant who has a higher ordinate value is considered to be more financially stable[9]. To facilitate a competitive study among the four most competitive nations worldwide, Fig 5 portrays the competing landscape of the top three patent holders from China, the United States, Germany, and Japan.

As depicted in Fig 5, there are a total of 10 business patentees and 2 academic patentees among the top holders. Notably, patentees from the United States, Japan, and Germany are all enterprises, such as HP Inc., Canon, and EOS. Particularlly, HP Inc. is the entity with the most patents in the field of 3DP technology. Chinese assignees are mainly from the academia in comparison to those from America, Japan, and Germany. HP Inc. and General Electric Company occupy the upper right quadrant, underscoring their dominant positions as leading American competitors in the highly competitive 3DP technology landscape. Conversely, the top 3 Chinese patentees are all concentrated in the bottom left quadrant, indicating that China lacks an edge over other countries in patent activities.

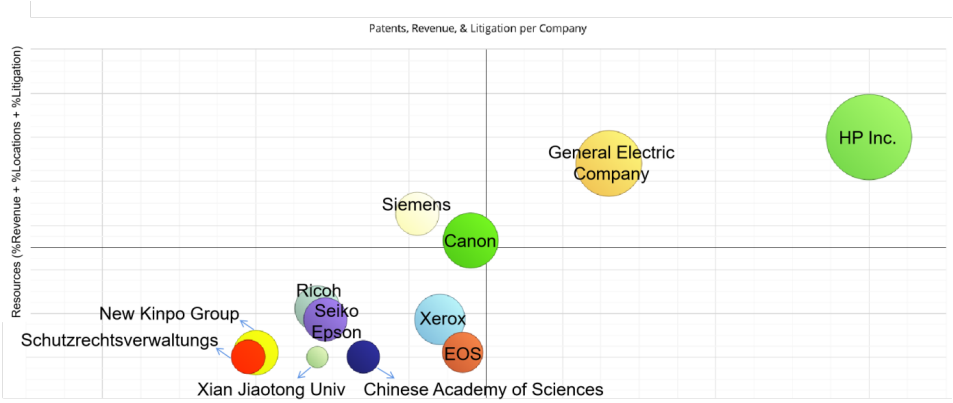

Fig 5. Competing landsacpe of the top 3 patent hoders from China, America, Japan, and Germany

3.4 Patent Value Analysis

In order to identify the 3DP technological area that requires the greatest R&D, we should pay greater attention to the examination of high value patents. Innography's novel patent evaluation indicator, termed "patent strength," encompasses more than ten critical variables, including claim and family numbers, income from patent licensing, and involvement in patent litigation, among others. Based on the patent strength scale devised by Innography, patents with a patent strength ranging from 80% to 100% are classified as core patents, those with a strength of 30% to 80% are deemed important patents, while those within the range of 10% to 30% are considered general patents within the technology domain.

After a simple (EPO) family reduction, 3,108 patent families were retrieved using the criterion of patent strength between 80% and 100%. Fig 6 shows the top 20 patentees in terms of the total amount of core patents held. With 148 core patents, Stratasys Ltd.(Israel) surpasses other assignees, followed by HP Inc. (144, the United State), General Electric Company (117, the United State), 3D Systems Corporation (101, the United State), EOS GmbH Electro Optical Systems (71, Germany), the Boeing Company (64, the United State), Raytheon Technologies Corporation (62, the United State), Carbon Inc. (57, the United State), Align Technology Inc. (37, the United State) and Xerox Corporation (35, the United State). Furthermore, based on the top 20 patentees' licensing revenue, it is observed that 8 patent holders from the United State account for 19.85% of all key patents.

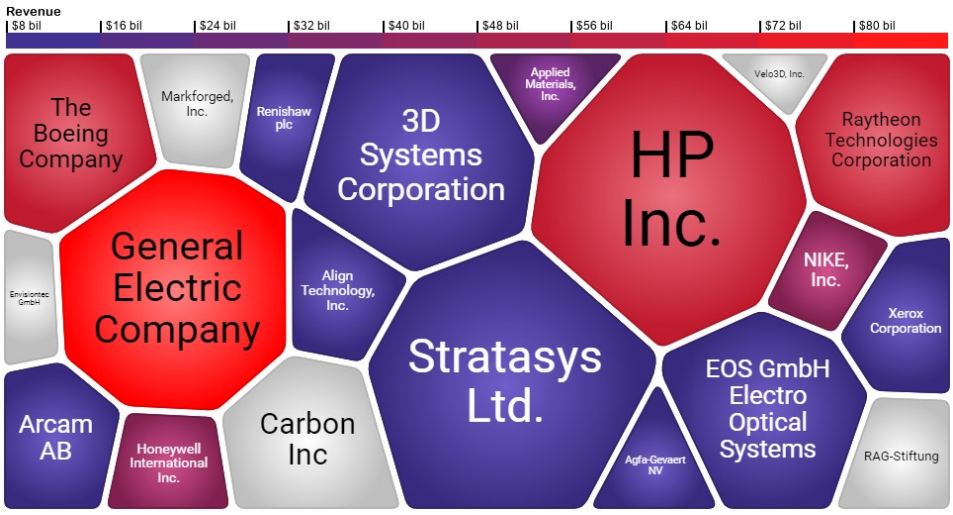

Fig 6. Heat map showing the top 20 assignees by the quantity of core patents held

4 CONCLUSION

According to the scientometric analysis and discussions presented above, the following findings can be obtained:

(1) Over the past ten years, the number of patents has increased, indicating an increased attention on the development of 3DP technology in both academia and industry.

(2) 3DP technology-related patents are receiving more and more attention from both the academic and industry community.

(3) China leads the world in terms of the total number of patents with 34,198 filings for 3DP technology.

(4) However, assessments of patent quality reveal that China still lags far behind the major competitors in the world in the field of 3DP technology.

(5) In order to offer more insightful information for identifying research hotspots and technological opportunities, further technology analysis is suggested via text clustering analysis of the core patents which are held by the main competition players around the world.

The study has contributed to analyzing the 3DP marketplace using patent information, recognizing the present global competitive landscape in the 3DP technology sector. However, the evidence is only based on patent data that was examined as a type of technology output, without taking the impact of the input variables into account. Input variables, such as business strategies and government policy, can be critical in motivating patenting activity and promoting technological development, illuminating the origins of the global competitive landscape. Futher research investigating in such issues is required in the future.

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