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A bibliometric performance analysis of publication productivity in the Heat Transfer and additive manufacturing

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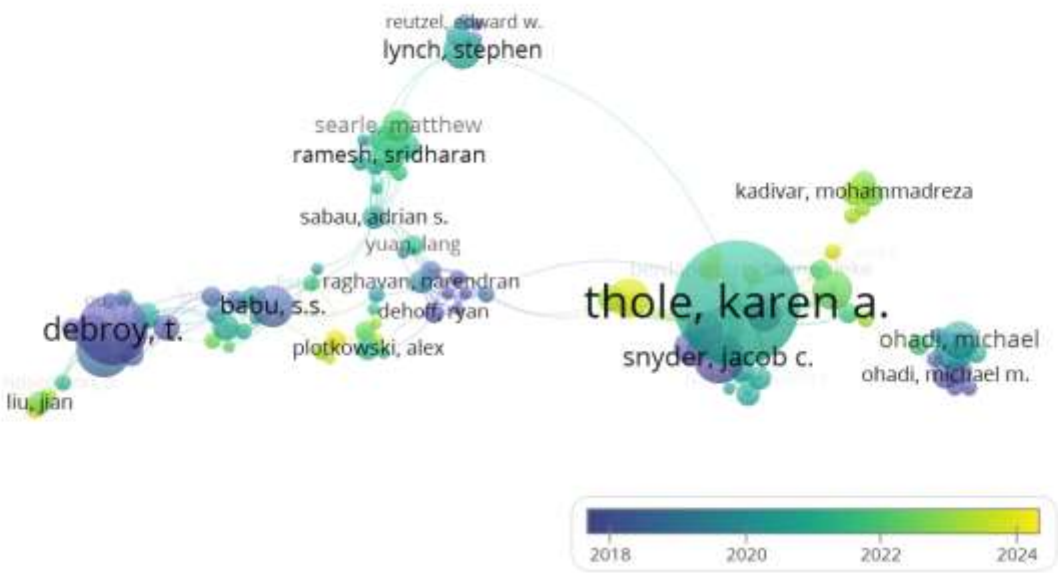

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Abstract: The paper aims to investigate research productivity in heat transfer through additive manufacturing technology (HTAM) by performing a bibliometric analysis. The search strategy was conducted using the Scopus database and its analysis tool to first identify productive HTAM authors and then examine their productivity over 10 years (2004–2014). The study examines the quantitative and qualitative publication performance of countries and authors. This study is extended to the VOS viewer to increase visibility through mapping. The results showed that Thole has the highest number of documents (almost 60 documents), and the United States of America is the largest producer of documents in this field, with the engineering sector being the most involved.

Keywords: *Heat transfer; additive manufacturing; Bibliometric analysis; VOSviewer; authors; countries,*

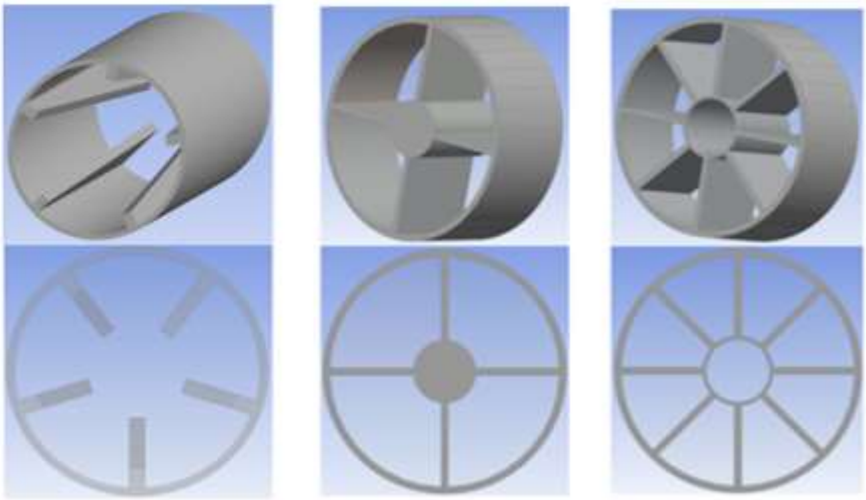
1. Introduction

Additive manufacturing, also known as layer-by-layer deposition, is a technology that has become widely utilized in various fields such as automotive, aerospace, also in the medical field, because it gives more complex parts that are mostly impossible to realize by traditional methods, with lower costs and less residue (Gibson *et al.*, 2020) (Aichouch, *et al.*, 2025). It is a technology that helps to fabricate objects layer by layer using different sources of energy depending on the material used (metal, polymer, ceramic…) (Rasiya *et al.*, 2020). Between these energetic sources, we find electron beam, laser, electric arc, ultrasonic and UV radiation (Pérez *et al.*, 2020). Different processes are used in additive manufacturing, among the most commonly used methods, especially for metal fabrication; there is Directed Energy Deposition (DED) and Powder Bed Fusion (PBF) techniques (Liu *et al.*, 2023). The first technique, which is also known by laser coating relies on the introduction of the material in the form of a metal powder into a heat source such as a laser, which melts the metal particles together as they are deposited, while the second technique is based on the fusion of the metal powder in an inert gas chamber by a high-power laser, that aims to melt the metal particles layer by layer (Álvarez-Trejo *et al.*, 2023). PBF is subdivided into several techniques, including Direct Metal Laser Sintering (DMLS), Electron Beam Melting (EBM), Selective Laser Sintering (SLS), and Selective Laser Melting (SLM) (Singh *et al.*, 2019). On the other hand, DED encompasses methods such as Electron Beam Freeform Fabrication (EBFFF), Laser Engineering Net Shaping (LENS), Laser Consolidation, Direct Light Fabrication (DLF), and Wire Arc Additive Manufacturing (WAAM) (Shah *et al.*, 2023).

Additive manufacturing has recently gained increasing interest in the energy sector, particularly in the production of energy exchangers (Mesecke *et al.*, 2025). This is especially relevant as global energy demand continues to rise, with an expected increase of 76.9% between 2021 and 2050 (Careri *et al.*, 2023). It enables the design of complex and optimized geometries, which enhances the thermal efficiency of systems (López-Barroso *et al.*, 2024). Thanks to this technology, it is possible to create intricate internal structures, such as optimized flow channels, thereby maximizing the surface area for contact between hot and cold fluids. This leads to improved thermal performance and more efficient energy management (Buckner *et al.*, 2016; Byiringiro *et al.*, 2025). Additionally, 3D printing allows for the production of lighter exchangers while reducing costs and manufacturing time (Anwajler, 2024). This method also offers advanced customization, allowing for precise adaptation to the specific needs of applications, and facilitates the use of advanced materials with better thermal and mechanical properties (Zhou *et al.*, 2024).

For instance, in concentrated solar power (CSP) systems, there are innovative receiver configurations designed to enhance heat transfer performance. However, many of these configurations feature highly complex geometries that cannot be produced using conventional manufacturing techniques. Additive manufacturing (AM) offers a solution to this limitation by enabling the fabrication of intricate shapes and internal structures that were previously unachievable. These advanced receiver designs not only improve thermal efficiency but can also contribute to lowering the capital cost of CSP plants by optimizing material usage and performance (Byiringiro, *et al*. 2023). **Photos 1** show examples of such complex geometries, which are challenging to manufacture traditionally but can be realized through additive manufacturing.

Bibliometrics is a statistical method used to quantitatively analyze research articles on a specific topic using mathematical techniques (Wang & Su, 2020) (Julius *et al.*, 2021). It also allows for the evaluation of study quality, identification of key research areas, and prediction of future research directions (Passas, 2024; Laita *et al.*, 2024). In addition, bibliometric indicators such as publication counts, citation analysis, h-index, and journal impact factor offer objective insights into the productivity and influence of authors, institutions, and countries. This helps scholars and decision-makers assess scientific performance and allocate research funding more strategically. The online database Scopus collects the majority of relevant research articles and provides integrated analysis tools to generate representative data (Arachchige *et al.*, 2021). It includes features such as citation tracking, co-authorship networks, subject classifications, and affiliation analysis, enabling users to explore collaboration trends and disciplinary impacts. Additionally, search results from Scopus can be exported to software such as VOSviewer for more in-depth analysis (Aichouch, *et al.*, 2025; Hammouti, *et al.*, 2025). VOSviewer, along with other tools like CiteSpace and Bibliometrix (based on R) (Derviş *et al.*, 2020), enables advanced visualizations and mapping of bibliographic data, including co-citation networks, keyword co-occurrence, and temporal trends. These tools support the discovery of research frontiers and the identification of thematic clusters, facilitating a better understanding of how scientific knowledge evolves over time.



Photos 1: Example of complex receiver configuration (Byiringiro *et al.*, 2024)

This study aims to conduct a bibliometric analysis from 2004 to 2024 on productivity in the field of heat transfer using additively manufactured materials. It focuses on identifying the most influential authors in this field, meaning those with the highest number of published articles, the most cited affiliations, the countries involved in this type of research, as well as the targeted areas of study.

2. Methodology

The global literature on heat transfer in additive manufacturing (HTAM) published between 2004 and 2024 was retrieved from the Scopus database. The search terms used to identify relevant publications included "Heat transfer in additive manufactured objects" and "Heat transfer and additive manufacturing," with these phrases being applied as keywords in the title. The data extracted from the documents that met the criteria included publication year, authors, co-authors, affiliations, and countries, all of which were exported in CSV format. VOSviewer was employed to analyze co-authorship, affiliation, and the most productive countries. VOS ("visualization of similarities") was a concept developed less than two decades ago for analyzing and visualizing patterns within data (Eck & Waltman, 2007).

3. Results

3.1. *Scopus analysis*

The bar chart indicated in **Figure 1**, derived from a bibliometric analysis within the Scopus database focusing on heat transfer in additive manufacturing (HTAM), and effectively visualizes the leading authors in this field based on their number of publications. The most striking observation is the prominent position of Thole, K.A, who has authored a significantly higher number of documents, approaching 60, demonstrating a substantial contribution to the research literature. Following Thole, DebRoy, T, Mukherjee, T, and Singh, P. have also made noteworthy contributions, with their publication counts ranging between approximately 18 and 25. The remaining authors depicted, including Snyder, J.C, Babu, S.S, Liang, S.Y, Thompson, S.M, Leong, K.C, and Ho, J.Y, have also actively engaged in publishing within this domain, with their contributions ranging from around 12 to 16 documents each. Overall, this graphical representation highlights the key researchers who are actively shaping the body of knowledge concerning heat transfer in additive manufacturing, with Thole's leading position underscoring his significant influence and productivity in this specific area of study.

After gathering information about the most prolific authors in this field, the study of affiliations also plays a crucial role, as it highlights the institutions involved in this type of work. The bar chart illustrated in **Figure 2** indicates the most productive affiliations in HATM, based on the number of documents indexed in Scopus. Dominating the landscape is Pennsylvania State University, which exhibits a notably high output with approximately 120 publications, signifying a strong and concentrated research focus within this institution. Penn State College of Engineering, Oak Ridge National Laboratory and CNRS Centre National de la Recherche Scientifique also demonstrates a substantial contribution to the field, with an amount of published documents between 40 and 75. Furthermore, significant research organizations such as Ministry of Education of the People's Re, Nanyang Technological University, School of Mechanical and Aerospace En, Singapore Cetre for 3d Printing, Tennessee, Knoxville University and Xi'an Jiaotong University show considerable research activity, within a range of 20 to 40 publications.

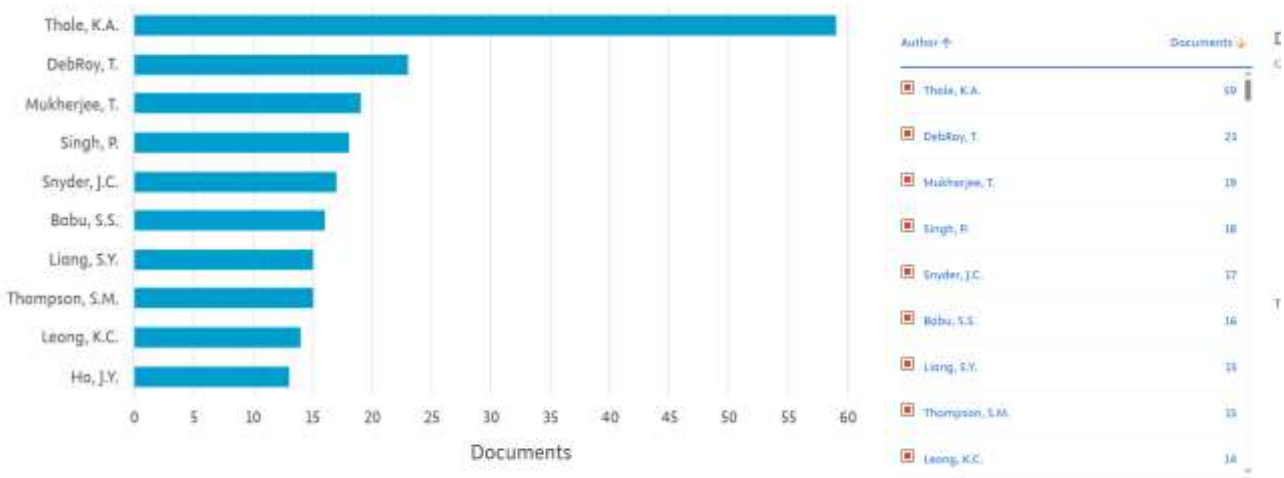


Figure 1. Author's production from 2004 to 2024

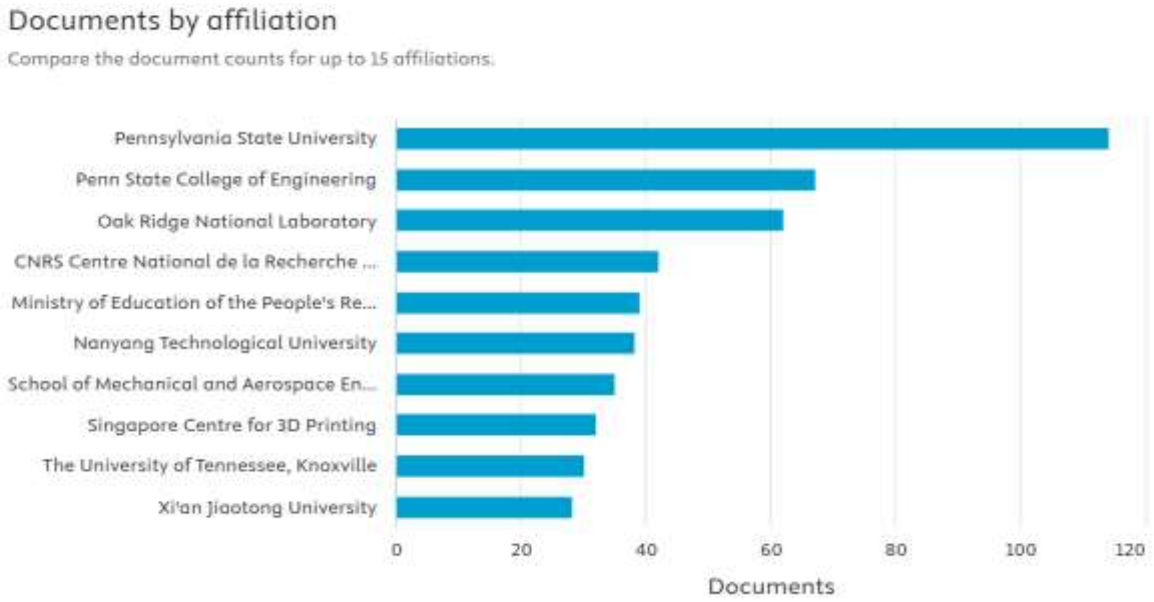


Figure 2. Author's affiliation from 2004 to 2024

Overall, this visualization highlights the key institutions, spanning both academia and dedicated research centers that are actively contributing to the scholarly literature on heat transfer in additive manufacturing, with Pennsylvania State University currently demonstrating the highest level of published output. As already known, among the most productive countries in the scientific field, the United States and China are often found. The following bar chart, as shown in **Figure 3**, effectively illustrates the leading countries in terms of research productivity within the field of HTAM, based on the volume of documents indexed in Scopus. The United States emerges as the clear frontrunner, exhibiting a significantly higher number of publications, approximately 780, underscoring its dominant position in this research area. Following the United States, China demonstrates a substantial research output with around 340 publications, highlighting its growing prominence in this domain. Among European nations, Germany and Italy show strong contributions, each with a publication count in the range of 110 to 130. Furthermore, India and the United Kingdom also demonstrate considerable research activity, with approximately 90 to 100 publications each. While France, Canada, Singapore, and the Russian Federation contribute to the global research landscape, their output is comparatively lower than the leading countries. Overall, this visualization provides a clear overview of the geographical distribution of research efforts HTAM, emphasizing the leading role of the United States and the significant contributions from China, Europe, and other actively engaged nations.

The major Topics of the production from 2004 to 2024 are illustrated in the following pie chart shown in **Figure 4**, as categorized within Scopus. The most prominent observation is the overwhelming dominance of Engineering, which accounts for a substantial 37.0% of the published literature, clearly establishing it as the core discipline for this research area. Materials Science also plays a pivotal role, representing 16.6% of the publications, reflecting the critical influence of heat transfer on material properties and processing in additive manufacturing. Furthermore, Physics and Astronomy contribute significantly at 14.2%, underscoring the importance of fundamental physical principles in understanding thermal phenomena within these processes. Chemical Engineering accounts for 9.4% of the research, indicating its relevance to the chemical transformations involved in certain additive manufacturing techniques.

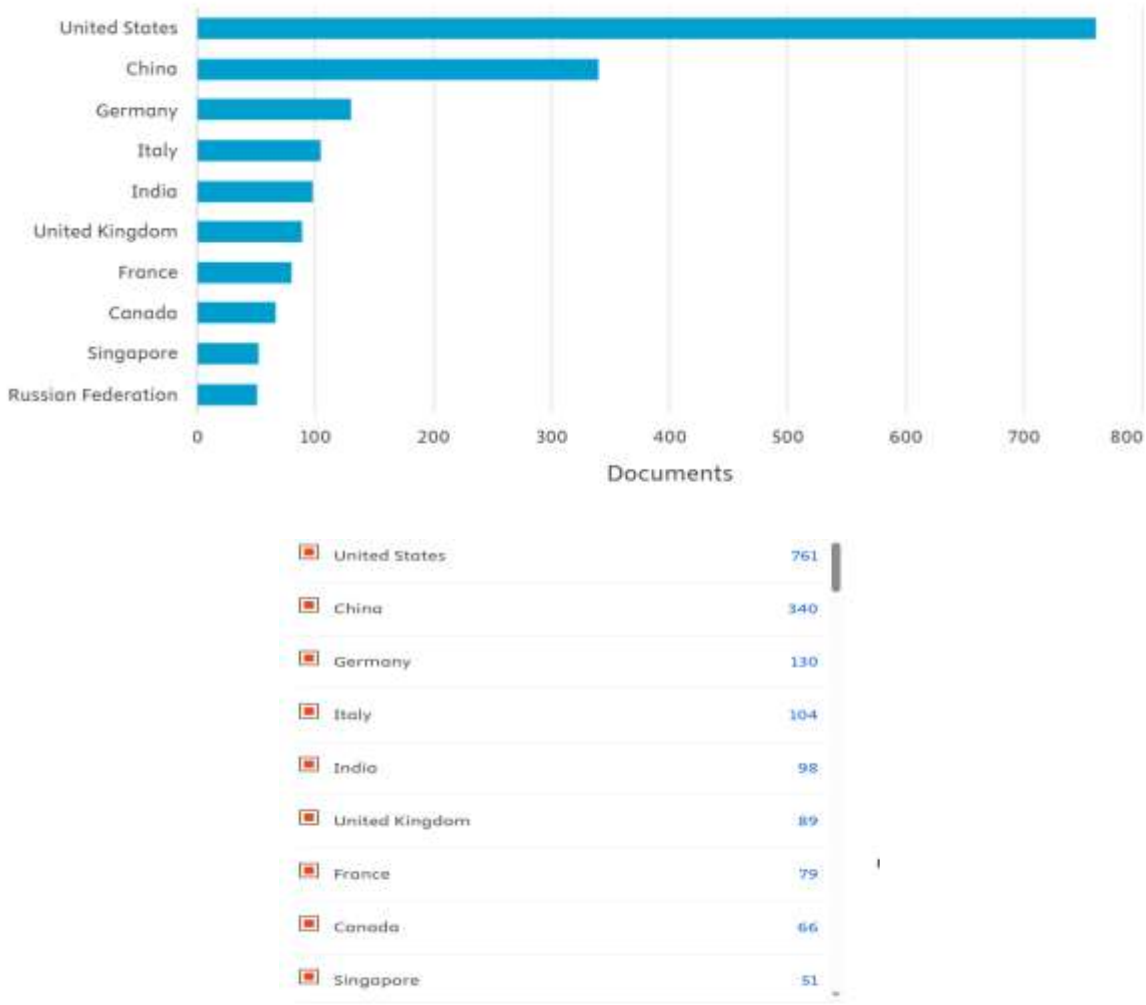


Figure 3. Production by Countries from 2004 to 2024

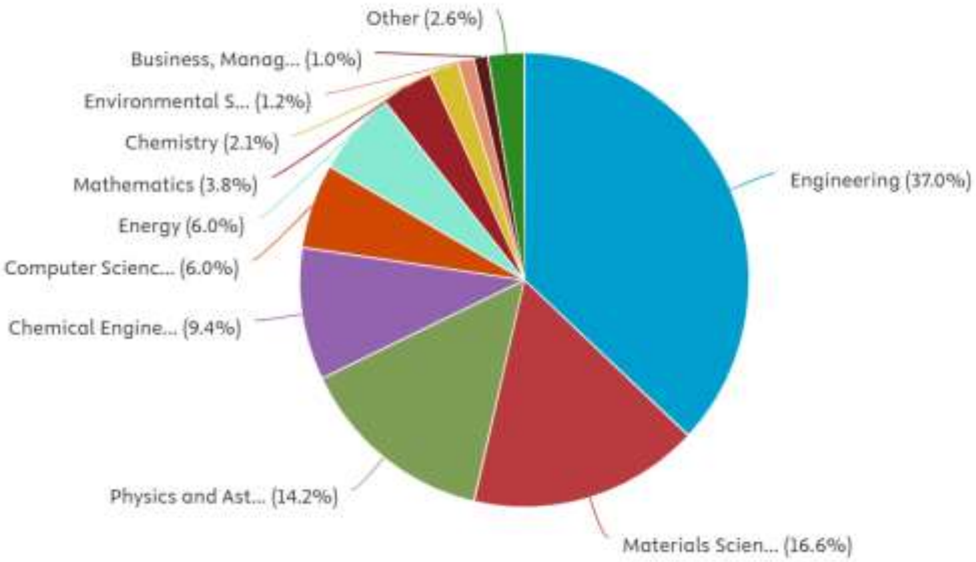


Figure 4. Major Topics of the production from 2004 to 2024

While other disciplines such as Energy and Computer Science (both at 6.0%), Mathematics (3.8%), Chemistry (2.1%), and Environmental Science (1.2%) have a smaller representation, their presence highlights the interdisciplinary nature of this field. Notably, Business, Management and Accounting have a minimal contribution (1.0%), suggesting a primary focus on the technical and scientific aspects. Overall, this visualization clearly indicates that research on HTAM is primarily rooted in Engineering, with significant overlap and contributions from Materials Science and Physics, alongside the involvement of several other relevant scientific and technical domains.

3.2. VOSviewer analysis

The following VOSviewer network visualization shown in **Figure 5** offers a compelling snapshot of the collaborative landscape among authors publishing research on HTAM. The map reveals distinct clusters of researchers, indicated by color, who frequently co-author publications, suggesting established research partnerships and communities within the field (Kachbou et al., 2025). Central and influential figures, such as Thole, Karen, A and DebRoy, T, are represented by larger nodes, signifying their substantial publication output and their pivotal roles within the collaborative network (Chakir et al., 2023). The connections between authors, depicted by lines, illustrate instances of co-authorship, with potentially stronger or more frequent collaborations indicated by thicker or more numerous links (Xie et al., 2021). Conversely, smaller or more isolated nodes represent authors with fewer publications in this specific area or those who tend to collaborate with researchers less connected to the main clusters (Saiz-alvarez, 2024). These clusters may also hint at distinct research groups or teams possibly focusing on particular aspects of HTAM. While the primary focus is author collaboration, the inclusion of affiliation information as illustrated in **Figure 6** provides some context regarding institutional links within the network. Overall, this network map effectively visualizes the interconnectedness of the research community in this domain, highlighting key collaborators and providing insights into the social structure of scientific inquiry HTAM.

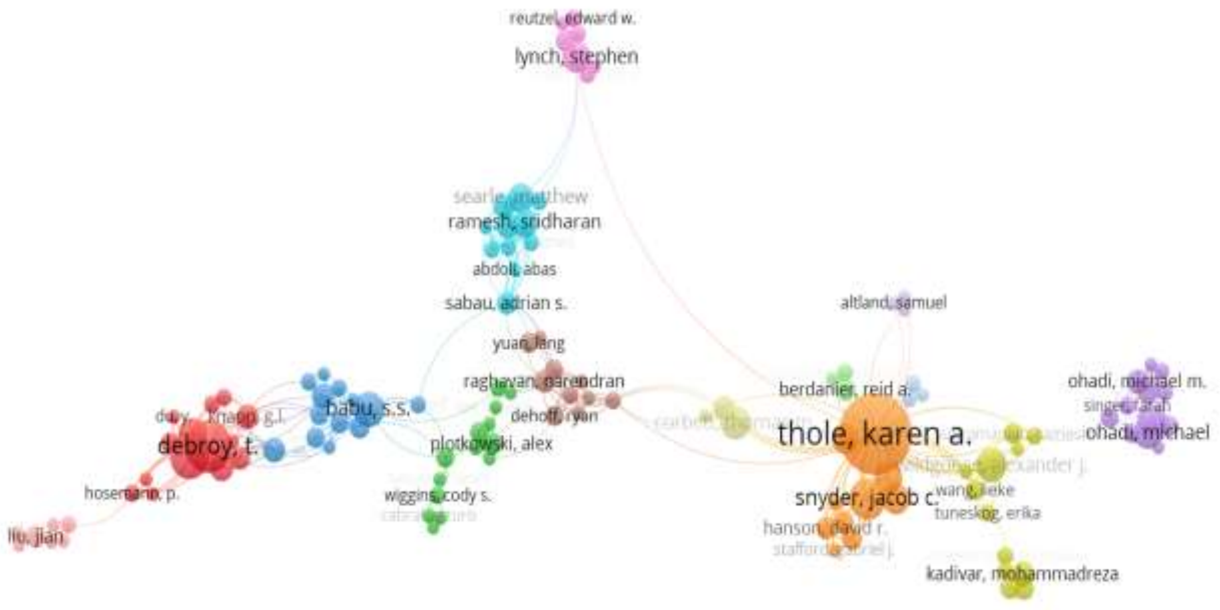


Figure 5. Network visualisation on VOS viewer of HTAM authors and collaborators

Figure 6. Network visualisation on VOS viewer of HTAM authors affiliation

The VOSviewer density map, shown in Figure 7, visually represents the key institutional affiliations that contribute to the body of literature on heat transfer in additive manufacturing. The bright yellow areas, particularly around "materials science and technology" and the "Singapore centre for 3d printing" (along with its associated "department of mechanical science"), indicate the highest concentration of publications originating from these affiliations. This signifies a strong research emphasis and significant output from these institutions or research domains in this specific field. A moderately dense green area around "oak ridge national laboratory" suggests a substantial, though comparatively less concentrated, contribution from this institution. The spatial arrangement of these labels suggests the relationships and potential collaborations between key players in the research landscape. For instance, the proximity of the Singapore Centre for 3D Printing and the Department of Mechanical Science likely reflects their close organizational ties. The overall pattern of density highlights the major institutional hubs and research areas that are most actively engaged in publishing on the topic of HTAM, with materials science and the Singapore-based center demonstrating particularly high levels of research activity.

This VOSviewer network visualization illustrates in **Figure 7** shows the collaborative relationships between the most productive countries in research on HTAM. Each node represents a country, and the size of the node typically corresponds to the number of publications originating from that country. The lines connecting the nodes indicate instances of co-authorship in publications, signifying research collaboration between those nations.

Figure 7. Density Visualization of analyses of HTAM authors affiliation

The color of the nodes and connecting lines might represent a temporal aspect, as indicated by the color scale at the bottom, potentially showing the evolution of these collaborations over time, from 2020 (dark blue) to 2023 (yellow) (Nandiyanto *et al.*, 2024; Saiz-alvarez, 2024). The United States appears as a central and significantly large node, indicating its high productivity and extensive collaboration network with numerous other countries. China also stands out as a highly productive nation with strong collaborative links. Several European countries, including Germany, Italy, and France, form a cluster with notable interconnections, suggesting active collaboration within the European research community. India, Japan, and South Korea also appear as significant players with established collaborative ties. The color variations within the nodes and links suggest that some collaborations might be more recent or have intensified in later years (leaning towards yellow). In contrast, others might have been more prominent in earlier years (leaning towards blue). The overall network structure highlights the global nature of research in this field, with the United States and China serving as major hubs that connect various research efforts across different continents. The visualization allows us to identify key international research partnerships and understand the interconnectedness of national research efforts in advancing the field of HTAM.

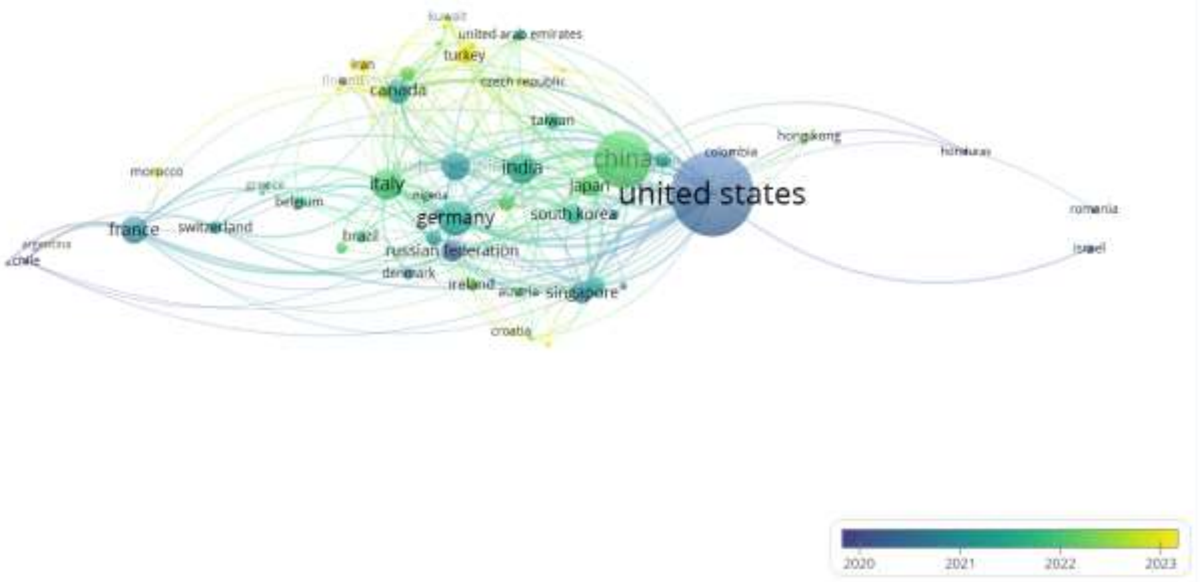


Figure 8. Network visualisation on VOS of the most produced countries of HTAM.

Figure 8 presents a VOSviewer network visualization illustrating the most prolific countries in the production of HTAM. The visualization depicts countries as nodes, with connections between them representing collaborations or research relationships. The size of each node is proportional to the overall production of HTAM from that country, while the color of the nodes indicates the average publication year, as shown in the color scale at the bottom right. The visualization displays a central, dense cluster of highly productive countries, primarily in the United States, Europe, and Asia.

Conclusion

This study examined the evolution of research on heat transfer through additive manufacturing (HTAM), a field that is the evolution of research on heat transfer through additive manufacturing (HTAM), a field gaining momentum due to its potential in fabricating complex, high-performance thermal systems. Additive manufacturing enables the design of intricate geometries for heat exchangers, significantly improving energy efficiency and customization. Through a bibliometric analysis using Scopus and VOSviewer, the study identified key contributors, revealing that the USA and engineering institutions dominate this domain. Thole emerged as the most prolific author during the 2004–2014 period. The mapping and quantitative indicators offer valuable insights for guiding future research efforts and fostering innovation in HTAM.

The co-conversion cost, high biochar yield and no electrical power requirement. The study has been able to successfully achieve the co-conversion of biomass and plastics (as typologies of MSW major components valuable products with a twin goal of waste management and product development.

Disclosure statement: *Conflict of Interest:* The authors declare that there are no conflicts of interest.
Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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