

Bioengineering Game Changing Technology: A bibliometric keyword analysis and visualisation of similarities techniques to support horizon scanning of innovative bioengineering technologies

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Conflicts of Interest

The authors declare no conflict of interest.

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Abstract

Background

Horizon scanning is a strategic method for identifying emerging healthcare technologies before they achieve widespread adoption. It plays a critical role in guiding research priorities, informing policy decisions, and enabling healthcare systems to prepare for the integration of novel treatments and technologies. Conventional keyword-based retrieval methods often fail to capture novel bioengineering applications due to the volume, complexity, and diversity of terminology. These limitations hinder the early identification of innovations that may significantly impact clinical practice.

Bioengineering encompasses a wide range of topics which presents unique challenges for horizon scanning. Bibliometric techniques, particularly network visualisation and keyword co-occurrence analysis, offer a promising alternative. These methods provide a scalable, transparent, and reproducible framework for identifying emerging technologies by analysing patterns in scientific literature.

Aim

To develop and evaluate a novel methodological approach that integrates bibliometric keyword analysis with network visualisation to support horizon scanning in bioengineering. The objective is to identify signals of technological innovation using data-driven techniques, offering a robust framework for projects with broad scope and undefined inclusion criteria. The approach is designed to complement traditional expert-led methods and enhance the detection of emerging technologies that may not yet be widely studied but hold significant potential for healthcare innovation. Unlike other bibliometric methods, this approach combines co-occurrence analysis, network visualisation, and a custom thesaurus to detect emerging trends.

Methods

A multi-step exploratory search strategy was employed using Embase (OVID), targeting free-text terms related to bioengineering. The search results were exported as RIS files, a file format which enables citation programs to exchange data, and processed using EndNote for de-duplication. VOSviewer, an open-source software tool for bibliometric mapping, was used to perform keyword co-occurrence analysis and generate visual network maps.

To improve data quality, a user-generated thesaurus was developed to refine and standardise keywords. These keywords were grouped into three thematic categories representing key areas within bioengineering: 1) tissues and medical devices, 2) therapeutics and drug delivery, and 3) genetic engineering. Co-occurrence analysis was applied to identify clusters of related terms within these categories.

Two sets of keywords were analysed: high-frequency keywords, which indicate established areas of research, and low-frequency but recent keywords, which may signal emerging innovations. Further investigation of these keywords was conducted through supplementary searches in PubMed (limited to publications since 1 January 2025) and clinicaltrials.gov (studies starting on or after 1 January 2020). Triangulation of data sources enabled a more

comprehensive assessment of the potential applications and relevance of identified technologies.

Implications

The integration of bibliometric analysis with network visualisation and a custom thesaurus enhances the transparency, reproducibility, and scalability of horizon scanning in bioengineering. This approach enables the identification of emerging technologies that may otherwise be overlooked due to their novelty or limited representation in traditional databases.

Thematic clustering provides a structured overview of the bioengineering landscape, facilitating the prioritisation of research areas and informing strategic decision-making. The findings can support funding allocation, guide research agendas, and influence policy development in healthcare innovation. Moreover, the method is particularly well-suited to complex, interdisciplinary fields where conventional search strategies may be insufficient.

Several challenges remain. Manual thesaurus creation is time-consuming, labour-intensive, and introduces subjectivity/ Therefore, incorporating large language models for synonym detection, thematic categorisation, and automated screening could mitigate these issues. Additionally, signals from patents or funding sources could enhance early signal detection.

Key points

- Novel methodology: network bibliographic analysis using VOSviewer offers a new approach to horizon scanning, especially for broad and undefined topics.
- Data-driven insights: keyword co-occurrence mapping and thematic clustering enable the identification of emerging technologies with potential healthcare impact.
- Data quality: a user-generated thesaurus standardises terms, improving data quality and enhancing map interpretability.
- Strategic relevance: findings can guide funding decisions, research priorities, and policy development in healthcare innovation.
- Future integration: combining bibliometric tools with patent and funding data could enhance early signal detection and innovation tracking.

Background

Horizon scanning is an analytical method used to describe the systematic assessment of information sources. It aims to identify unmet needs, future developments, and emerging innovations prior to their adoption onto the market.¹⁻³ Horizon scanning plays an important role in facilitating the integration of new technologies into healthcare. By identifying emerging technologies early, horizon scanning enables the exploration of opportunities, leading to the timely adoption of new technologies. As well as guiding research priorities, early identification of innovations enables health organisations to prepare for their implementation and minimises delays in patient access to innovative treatments. Horizon scanning encompasses a range of methods of searching over a wide range of sources.^{4,5} The methods are very flexible and may range from expert-based insights to data-driven or participatory methods, and may also be enabled by tools that automate some of these processes.^{1,3,6,7}

Horizon scanning usually follows a flow of actions starting with identification of weak signals, which are early, subtle indicators that may become significant trends.² This is followed by filtration, prioritisation, and finally selection and dissemination.¹ In horizon scanning, it is often challenging to start a project when the area or the problem is not well defined since the initial step for weak signal detection relies on the practitioner knowing the issue at the centre of the horizon scanning exercise. The better defined and narrow the topic, the more effectively the searches can be designed. This is of particular interest in information retrieval as methods are usually geared towards comprehensively searching around pre-determined concepts. Conceptual frameworks such as PICOS are often used to support the design of these searches. However, traditional information retrieval methods are not fully suited to broad horizon scanning projects that start with little concept definition - warranting the exploration of alternative methods.

Network bibliographic visualisation analysis is a methodological approach within the scientific discipline of scientometrics and bibliometrics, which offers a range of benefits that enhance research quality, transparency, and strategic insight. It enables the identification of emerging topics and research fronts through analytical methods such as bibliographic coupling and co-occurrence analysis by visualising the data into a map.^{8,9} These maps consist of nodes and edges: nodes represent the entities in the network, e.g. authors, institutions, or keywords, while edges represent the link between them, e.g. collaboration between authors, or shared keywords. Clusters are a group of nodes which are closely related based on the strength of their connections. Clustering allows identification of patterns or thematic groupings: for example, in a cluster a node might represent a keyword such as 'tissue engineering,' and an edge might represent its co-occurrence with 'regenerative medicine.'

A tool such as VOSviewer¹ offers an interactive interface for constructing network maps, and it can support different types of analysis and handle large datasets. VOSviewer primarily supports homogeneous networks, meaning they typically include only one type of entity and only one type of link, such as keywords.¹⁰

¹ www.vosviewer.com

Homogeneous network visualisation helps detect weak signals, emerging trends, and clusters of innovation by highlighting newer or less frequent keywords.¹¹ This is particularly useful in horizon scanning and contributes to methodological rigor, particularly when combined with other data sources.⁹

One area of research that is currently of interest in healthcare is bioengineering. Bioengineering bridges biology and engineering to develop technologies that address health-related problems. Advances in engineering and biology have enabled bioengineering to drive progress in medical technologies such as tissue regeneration, drug delivery, and implants.¹² Bioengineering's rapid growth and impact on healthcare make it a critical area for horizon scanning. The 2024 value of the global medical device market ranged from US\$542.21 billion¹³ to \$810.4 billion¹⁴, the tissue engineering market is projected to grow from \$22.13 billion in 2025 to \$43.13 billion by 2030,¹⁵ the global nanotechnology market, valued at \$8.78 billion in 2025, is predicted to reach \$115.41 billion by 2034,¹⁶ and global genetic engineering market is estimated will grow from USD 1.72 billion in 2025 to USD 2.94 billion by 2034.¹⁷ As this field continues to evolve rapidly, staying informed about promising technologies is essential for effectively applying new advancements to medical research and healthcare. A proactive approach to scanning the horizon in bioengineering ensures early identification of technologies with the greatest potential to address human healthcare challenges.

Horizon scanning is particularly valuable in the rapidly advancing field of bioengineering, since its interdisciplinary and complex nature presents significant challenges in transitioning from research to clinical practice. Incorporating a network bibliographic visualisation tool into horizon scan methodologies aims to transform complex bibliometric data into intuitive maps that highlight emerging trends, relationships, and thematic clusters within bioengineering.

Aim

The aim of this report is to describe the use of network bibliographic analyses as a novel and exploratory method to identify signals of technology innovation in a horizon scan. Our goal was to provide a robust methodological support for the identification of novel and emerging technologies in horizon scanning projects with broad scope and undefined inclusion criteria using a broad bioengineering topic as a case study. Specific data and analysis of the three main bioengineering topics 'tissues and medical devices', 'therapeutics and drug delivery systems', and 'genetically engineered organisms' have been compiled as separate reports and are available on the NIHR Innovation Observatory website.

Overview of the three bioengineering topics

Tissues and medical devices are central to the field of bioengineering, playing a pivotal role in addressing some of the most pressing healthcare challenges. The bioengineering of tissues is a key component of regenerative medicine, a field focused on developing solutions for organ repair, regeneration, and replacement. Medical implant devices are instruments, apparatuses or machines that, unlike many therapeutics, do not depend on chemical action or being metabolised to achieve their therapeutic purpose in the body. These devices are designed to

remain in the body for extended periods, providing mechanical or functional support to damaged tissues or organs.

Bioengineered therapeutics and drug delivery systems are rapidly advancing, with innovations in gene editing, synthetic biology and surface modification enabling the engineering of proteins, cells and microbes. They overcome the drawbacks of traditional therapy, which include abrupt release, high toxicity, lack of specific targets, rapid degradation, and resistance.

Genetic engineering is a key part of bioengineering as it comprises genome editing, which can directly modify an organism's DNA through a targeted intervention in the genome. One of the most important and widely used applications is clustered regularly interspaced short palindromic repeats (CRISPR). It is used as both gene therapy (as a drug to repair a defective or mutated gene) or cell therapy (to make the body's cells attack toxic cells or regenerate beneficial cells).

Methods

Our method consisted of a multi-step approach used for the identification, filtration and prioritisation of bioengineering innovations. Figure 1 presents a visualisation of the methods used.

First, an information specialist devised a bioengineering-related search strategy in the Embase (Ovid) database. This strategy aimed to maximise sensitivity. The results from that search were downloaded into EndNote (Clarivate) for de-duplication. After duplicates were removed, a RIS (Research Information Systems) file was exported. We used VOSViewer (Leiden University), an open-source software that constructs and visualises bibliometric networks, to perform a keyword co-occurrence analysis of the RIS file containing all Embase bibliographic records.

From that analysis in VOSViewer we exported the network map files that produced a list of all the keyword terms in the network with a ranking and link strength. These terms were then used to create a thesaurus that disambiguated terms with more than one meaning or grouped equivalent terms with different spellings under one single term. Additionally, we screened all terms and grouped them thematically into three different main categories. Finally, we generated visualisations for all three different categories by loading the RIS file and the relevant thesaurus into VOSviewer. Our analysis identified high-frequency (most repeated keywords) or new terms (less repeated but more recently appearing in the published literature). This shortlist of terms ranked by their frequency and recency were then used to search for bioengineering innovations in different sources such as clinicaltrials.gov and PubMed.

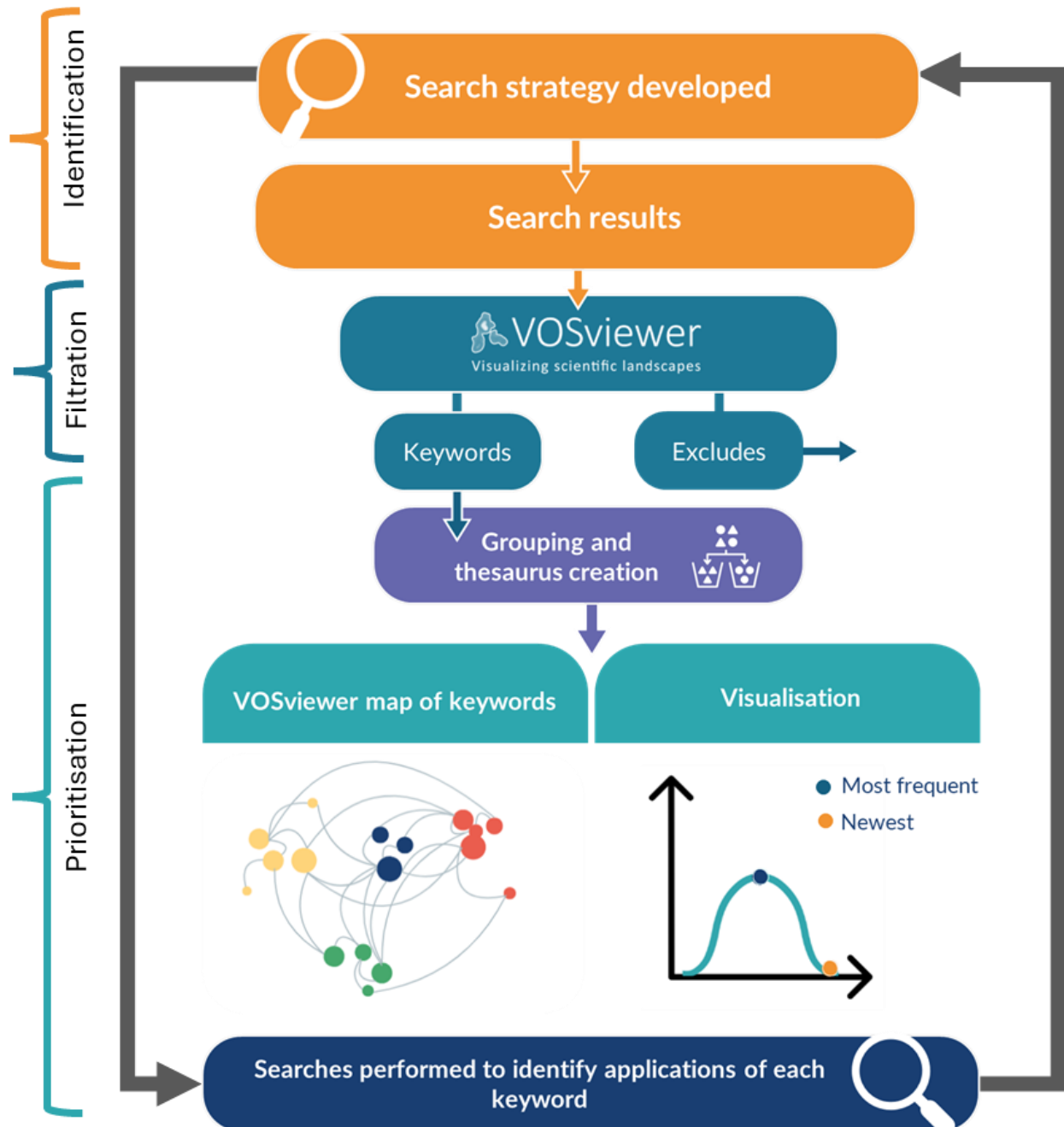


Figure 1: Visual summary of the entire process used. Image credit: Katie Twentyman.

Search strategy

A bibliographic search was developed by an information specialist in Embase (Ovid). Free-text English search strings were used, including terms for 'bioengineering', 'genetically engineered', and 'synthetic biology', developed through recent literature searches (see Appendix 1).¹⁸⁻²¹ The search was subsequently peer reviewed by another information specialist for consistency,

performance assessment, and errors following the PRESS checklist.^{22,23} Subsequent to this check some keywords were removed as they introduced noise, for example 'Tissue/organ generation', while other search terms that were deemed sufficiently precise were kept (see Appendix 1). The search was run in January 2025 and a RIS file of the search results generated. EndNote 21 was used as the repository for the bibliometric sources found.

To maximise intelligence gained from the text, the unspecified search field (.mp) was used. The unspecified search field covers multiple fields simultaneously including title, abstract, heading word, and keyword heading word. This ensures that the search is thorough and captures relevant information from various parts of the record and increases the likelihood of retrieving relevant results that would otherwise be missed if searched individually. Subject headings are standardised vocabulary that group related materials within predefined lists that describe the main topics. In information retrieval they are used to maximise the possibility of retrieving records by directing the search within databases. However, following scoping searches the decision was made to use free-text terms as the aim was to capture emerging innovations that may not yet be in controlled vocabularies, thus improving specificity.

The decision to begin the time threshold as 2020 was based on a January 2020 article by The American Society of Mechanical Engineers which highlighted bioengineering research and development trends happening this decade. The article also highlighted tissue engineering as the number one trend, the others include examples of drug delivery and generic engineering.²⁴ This society is one of the leading organisations in the world developing codes and standards. It focuses on technical, educational and research issues of the engineering and technology community and one of its divisions focuses on bioengineering.²⁵

VOSviewer

VOSviewer is a free open-source bibliometric visualisation tool which creates maps of keywords based on co-occurrence data, enabling examination of clusters of intelligence (see figure 2). These clusters represent interconnected themes or concepts within the dataset, providing insights into patterns of innovation.²⁶ For example, as shown in figure 3, in tissues and medical devices, hydrogel was identified as a cluster with co-occurrence to extracellular matrix, collagen and cell differentiation. Words and phrases that are strongly associated with only a few topics in the body of literature are identified using semantic analysis, and are included in the term map. These terms are not only domain-specific but also have a high discriminatory power, which is important to visualise the structure of the field.²⁷ The terms are located relative to each other, such that the distance between two is an approximate measure of their similarity within the set, where similarity is defined as the extent to which they refer to or link to each other. Highly related terms are then indicated as clusters.²⁸

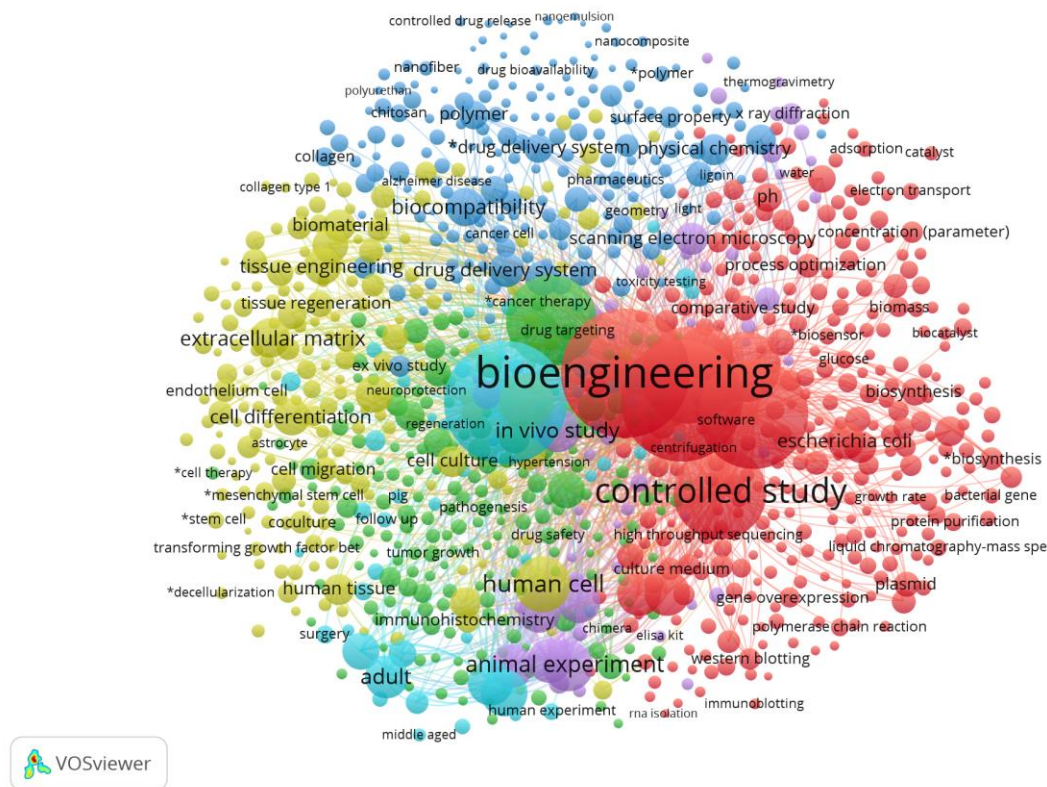


Figure 2: Example of bibliometric visualisation VOSviewer map based on co-occurrence data and full results of Embase (Ovid) search strategy.

Keywords

The RIS file generated from the bibliographic search was uploaded to VOSviewer (v 1.6.20). The type of analysis was set to co-occurrence and counting method set to full counting. Due to the size of the dataset, the threshold for the minimum number of occurrences of a keyword was set to 5 to filter out very infrequently occurring items as these were unlikely to generate keywords of interest, while the number of keywords to be selected was set to the maximum amount. For the bioengineering search (see Appendix A), VOSviewer generated a keyword list of 4266 items which was downloaded into Excel. From this dataset, a thesaurus of relevant terms and standardised keywords was generated.

Thesaurus and creation of keywords list

To produce the thesaurus list, the keyword list underwent screening and refinement to clean the data and focus the keywords. Using a user-generated thesaurus over the VOSviewer-created list enhances the quality of the dataset by removing duplicates, correcting errors and inconsistencies, and consolidating different versions of the same term (for example, due to UK/US English spelling variations) to ensure uniform treatment. This is especially valuable when dealing with large datasets to improve the readability and interpretability of the maps.

Inclusion criteria were specified prior to the keywords screening and refinement process. This excluded keywords, for example “activated sludge”, “yeast”, and “computer analysis”, agreed spelling convention or synonyms, and grouped similar terms, for example placing liver”, “liver cell”, “liver organoid” and “liver tissue” under the umbrella term “liver”. Criteria for the specific topics within bioengineering were also agreed: these were ‘tissues and medical devices’, ‘therapeutics and drug delivery systems’, and ‘genetically engineered organisms’. Additional topics of ‘unmet needs’ and ‘unspecified new technology’ were identified, for use on their own or in conjunction with any of the specific topics.

Creation of VOSviewer maps

Once the selection and refinement process was completed, the thesaurus files were input into VOSviewer with the bibliographic search RIS file, a file format which enables citation programs to exchange data, to produce a keyword map for analysis. The type of analysis and threshold criteria were the same as previously specified. Specific details of the numbers were noted for transparent reporting purposes. This produced a VOSviewer map using the original Embase (Ovid) search results, refined to the screened thesaurus list (see figure 3).

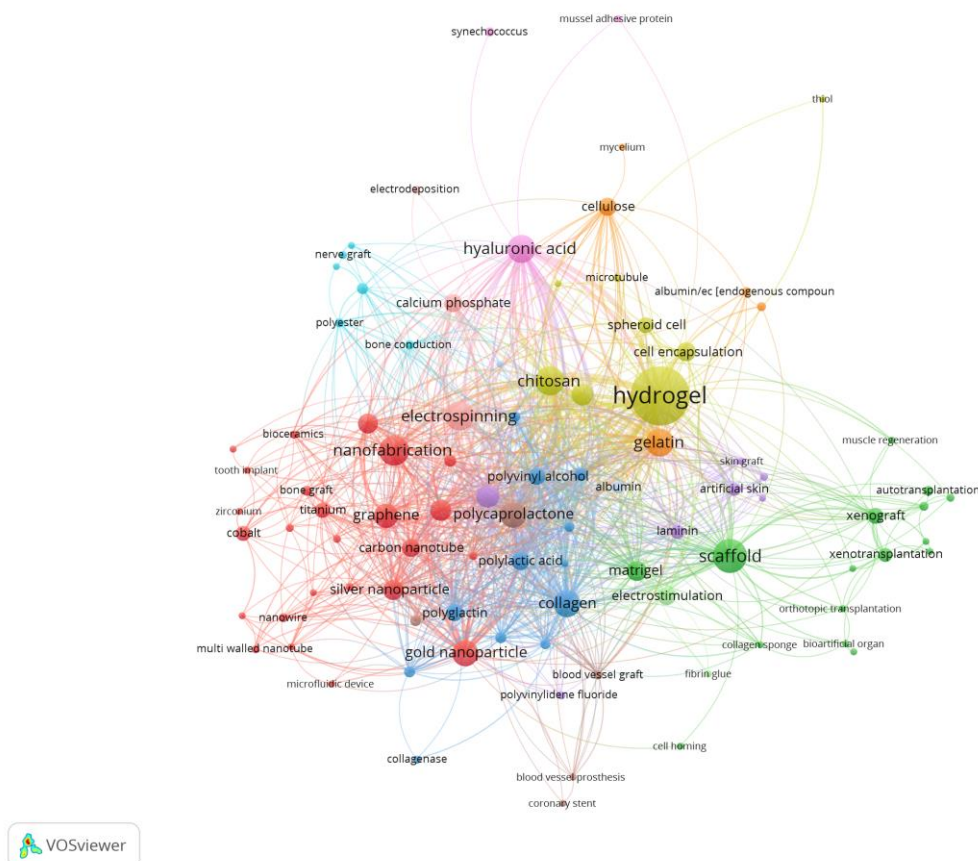


Figure 3: Example of VOSviewer map based on co-occurrence data with a custom thesaurus applied to bibliographic search RIS file.

Data analysis

The VOSviewer keyword co-occurrence map is normally used to identify research trends and thematic areas based on the keywords; however, to perform analysis at greater depth, an export of the data as a .csv file was used to perform analysis within each cluster.

The VOSviewer map file was exported as a .csv file and converted to an .xlsx file for analysis in Microsoft Excel. The overall most frequently occurring and newest keywords were analysed. The rationale for the former was that the most common keywords are those most frequently mentioned in the literature, representing a strong signal and thus high research interest (indicated with a blue dot in Figure 4). The rationale for the latter was that since focusing on the most frequently cited keywords could introduce bias towards well-established and higher-cited technologies, low frequency keywords were also investigated. The low frequency keywords appear at both ends of the curve, representing the oldest and newest technologies found. Therefore, to ensure that only newer technologies were analysed, with the potential to be game-changing, we restricted the analysis of low-occurrence keywords to this latter category, indicated by the orange dot in Figure 4.

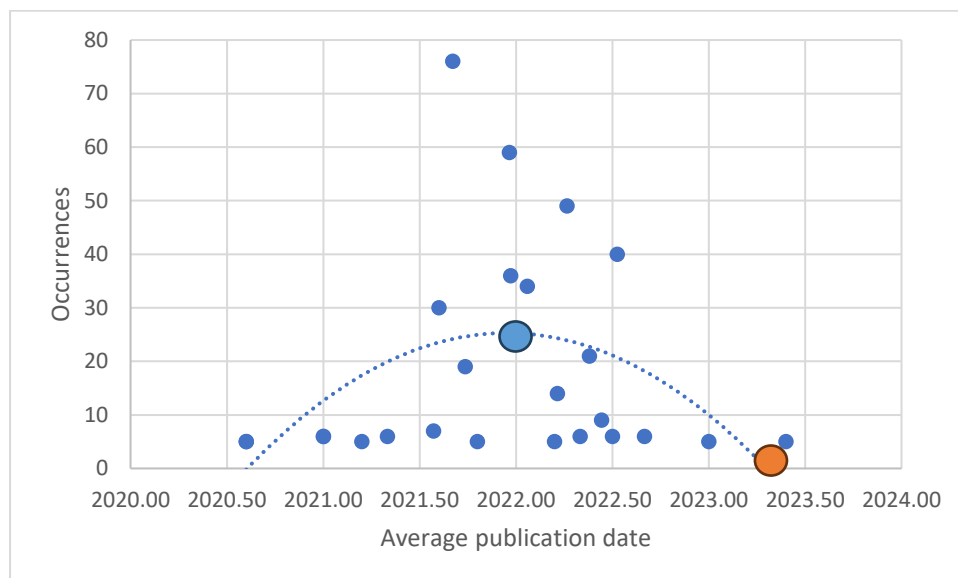


Figure 4: Example of distribution of occurrences of keywords against mean publication date.

Publication dates were extracted from VOSviewer as the mean of all dates for that keyword. To ensure validity, a sample of six keywords (the three most and three least frequent within cluster 1 from the tissues and medical devices dataset) were analysed. Their mean publication year was extracted from VOSviewer and compared to the mean publication year in the EndNote library containing all the references from the Embase (Ovid) search. Using the data in Table 1 as an example, the maximum difference between the two was 7.2 months, and a paired

two-tailed T-test revealed no significant difference ($P=0.357$). This indicates that the publication date given by VOSviewer was valid.

Keyword	Mean publication year		Difference (months)
	VOSviewer	EndNote	
Nanofabrication	2021.67	2021.67	0
Gold nanoparticle	2021.97	2021.95	0.24
Graphene	2022.27	2022.22	0.60
Microfluidic device	2023.40	2023.56	1.92
Transistor	2023.00	2022.40	7.20
Zirconium	2022.20	2022.07	0.78

Table 1: Example of mean publication years between VOSviewer and EndNote

The selected keywords (the three most frequent and the three newest) were then used as the basis for further searches in various databases and sources. Identified results were read carefully to ensure that the technology could lead to a benefit and had the potential to be game-changing.

Quality assurance

Various steps were taken to maximise the quality of the method. First, the search strategy was developed by an experienced information specialist (CE) and peer reviewed by a second (SGGM). Secondly, a pilot screen of 100 keywords was undertaken by all three reviewers (PA, RP and MF), who were blinded to the others' decisions. This was followed by peer review, which helped to guide the groupings for the technologies found. The inter-rater agreement was 93.76%. While using a simple percentage has drawbacks, the figure is well above the 80% previously stated as the minimum acceptable interrater agreement.²⁹ Finally, the methods and preliminary results were discussed and peer-reviewed by a senior member of the IO leadership team.

Strengths and limitations

A key strength of this methodology lies in its innovative integration of bibliometric keyword analysis with network visualisation using VOSviewer. This method is particularly effective for horizon scanning in broad and undefined areas such as bioengineering. By focusing on both high-frequency and recent low-frequency keywords, the method enables identification of emerging technologies that may be overlooked by traditional search strategies. Triangulating findings with supplementary searches in PubMed and clinicaltrials.gov add depth and validity to the analysis. Quality assurance measures, including peer-reviewed search strategies and high inter-rater agreement, further strengthen the methodology. However, the manual creation of

the thesaurus, while necessary, is time-consuming, labour-intensive and may introduce subjectivity. This process would benefit from incorporating large language model tools which can support the creation of a user-generated thesaurus through synonym detection and grouping, thematic categorisation and automated screening. Additionally, incorporating data from other sources such as patent or funding, could enhance early signal detection.

Compared to other advanced tools, such as Gephi,³⁰ or R Package CRAN Task View: Network Analysis,³¹ VOSviewer lacks some advanced statistical and analytical functions, and only allows relatively basic text mining capabilities.³² It also is unable to produce other visualisations such as tree maps. However, these functions, although useful for some analyses, were not relevant to the current study and the advantages of a simple and intuitive tool such as VOSviewer outweigh these limitations.

VOSviewer is frequently cited within academic literature, indicating its widespread use and recognition.³³ It is a freely available software and designed to be intuitive and accessible, allowing for easy navigation and visualisation of bibliometric networks. VOSviewer supports a broad range of sources including PubMed, Lens, and OpenAlex; is capable of processing large bibliometric datasets efficiently; supports advanced clustering which helps to identify thematic groupings within the data, which is particularly useful for mapping the intellectual structure of research fields; and visualisations can be shared.^{32,34} Additionally, the facility to apply a user-generated thesaurus means extraneous data can be removed, and duplicate or synonymous information can be regulated.

Implications and Recommendations

The integration of VOSviewer with a user-generated thesaurus and bibliometric analysis offers a transparent, reproducible, and scalable method for identifying emerging technologies in bioengineering. This approach addressed a key methodological gap in the discovery of unknowns by visualising related terms and their frequency. Through this process, we were able to identify new records that would have remained undetected using traditional keyword-based searches, which rely on the explicit inclusion of predetermined terms in the query. The analysis of low-frequency, recent keywords highlights potential emerging technologies that may not yet be widely studied but could have significant future impact, while the thematic clustering of keywords provides a structured overview of the bioengineering landscape. These findings can inform funding priorities and early-stage research investments, as well as supporting policymakers and researchers in identifying gaps in innovation within bioengineering.

Low-frequency, recent keywords identified in the analysis should be prioritised for deeper investigation through expert consultation, grey literature review, and clinical trial databases. Future work could enhance this approach by integrating other data sources such as patent data and funding databases to triangulate findings and improve early signal detection.

This successful application of VOSviewer demonstrates that bibliometric tools can be incorporated into horizon scan methods to enhance the detection of emerging trends. To maintain relevance and accuracy, the user-generated thesaurus and keyword lists should be periodically reviewed and updated to reflect changing terminology and research focus areas.

Appendix A

Search Strategy

Database(s): Embase 1974 to 2025 January 10

#	Searches	Results
1	bioengineering/	2282
2	(bioengineered adj8 (tissue* or cell* or therap* or organ* or device* or deliver*)).mp.	2655
3	(bio-engineered adj6 (tissue* or cell* or therap* or organ* or device* or deliver*)).mp.	116
4	((protein or microbiome or nanoparticle*) adj2 engineer*).mp.	27325
5	(organ adj4 chip).mp.	3470
6	(engineering adj2 (cell* or tissue*)).mp.	107320
7	("genetically engineered" adj6 (tissue* or cell* or therap* or organ* or device* or deliver*)).mp.	6574
8	(Gene* adj2 (engineering or modification or testing or edit*)).mp.	223579
9	((Genomic or gene) adj2 sequencing).mp.	43761
10	(synthetic biology adj6 diagnostic*).mp.	69
11	(synthetic biology adj4 therap*).mp.	183
12	(synthetic biology adj8 vaccin*).mp.	108
13	("personalised medicine" or "biological vehicles" or "mini bioreactor").mp.	3664
14	(machine learning and biotechnology).mp.	671
15	("virus vector*" or "viral vector*" or "vector capsids" or "protective protein shells").mp.	47869
16	("nanobot*" or "nanorobot*" or "nanomedicine" or "microbubbles").mp.	41872
17	or/1-16	507161
18	1 and 17	22842
19	limit 18 to (english language and yr="2020 -Current")	4439

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