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Application of nanosilica in the construction industry: A bibliometric analysis using *Methodi Ordinatio*

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Bibliographic portfolio applying *Methodi Ordinatio* and VOSviewer

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ABSTRACT

The number of publications related to the implementation of nanotechnology in the construction industry, and specifically to the application of nanosilica (SiO_2), has had a constant increase in recent years. Based on this, in the present work, an analysis was carried out using bibliometric techniques, with the aim at characterizing the development of specialized literature and identifying the largest areas of growth in the field, maintaining hydrophobic nanosilica as the research guideline. This analysis acquired information from the Scopus and Web of Science (WoS) databases to compare bibliometric indicators of the publications. It should be noted that, even though bibliometric analysis is useful to identify the study areas of greatest interest, to complement this work, the implementation of a method that helped in the research process to obtain the most important bibliography was required. This study implemented *Methodi Ordinatio*, which helped to take a new direction. Therefore, based on this method, a list of articles cataloged and ranked is obtained, which is the basis for integrating the final bibliographic portfolio.

- The study applies the *Methodi Ordinatio* to obtain a portfolio of the most relevant articles to guide the researchers' work.
- Insightful information can be obtained using VOSviewer to analyze and visualize metadata of the bibliographic portfolio.
- The study demonstrates how the alpha value in the *InOrdinatio* formula modifies the resulting portfolio.

Specifications table

Subject area:	Materials Science
More specific subject area:	Construction Industry
Name of your method:	Bibliographic portfolio applying *Methodi Ordinatio* and VOSviewer.
Name and reference of original method:	*Methodi Ordinatio*: a proposed methodology to select and rank relevant scientific papers encompassing impact factor, number of citations, and year of publication.
Resource availability:	VOSviewer https://www.vosviewer.com/

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Introduction

In recent decades, researchers have focused their interest on the study and applications of nanotechnology due to the possibilities it provides, which has allowed research and implementation in different materials, improving their characteristics, resulting in a rapid increase of its application in many important areas of technology [1], materials [2–4], chemistry [5,6], medicine [7], and construction [3], among other fields. The elaboration of these nanomaterials implies a process of design, synthesis, characterization, and application of nanoparticles, so knowledge of each stage is needed to choose the process that best suits the needs of the material [8–11]. Table 1.1 shows some of the applications of the different types of nanoparticles, among which is Titanium Dioxide (TiO_2) used in the preparation of coatings to mitigate the corrosion of structures located in aggressive environments; in the same way, polypropylene has been implemented to make super hydrophobic surface [12–14], Zinc Oxide (ZnO) has been used in the process of manufacturing membranes for water treatment and coating systems [15,16], the protective coating capacity of Cerium Oxide (CeO_2) has been studied to reduce corrosion and in coatings for aluminum alloys [2,17], Zirconium dioxide (ZrO2) has shown excellent ability to protect against corrosion [17], Calcium Carbonate ($CaCO_3$) has been investigated for its addition to epoxy resins to improve their physical characteristics [18], Silicon dioxide (SiO_2) has been implemented on hydrophobic surfaces as well as polypropylene membranes [8,19], Iron oxide (Fe_2O_3) has been studied for its addition in polydimethylsiloxane coatings [20], and finally, Aluminum Oxide (Al_2O_3) has been added coating to materials to increase their durability to weathering [21].

Within the large number of materials studied at the micro and nano scale, Silicon Dioxide (SiO_2) has attracted great attention due to its physical-mechanical properties that have been very beneficial in industrial applications, for example, its chemical inertness, morphology, availability, low cost, easy surface functionalization and well-defined particle size [10]. Due to this, it has been used as a support for catalysts [22], a separation method [23], reinforcement in plastic loads [24], industrial application of pigments and coatings [25], rubber, cement and concrete [26,27]. Table 1.2 shows the applications of SiO_2, in which the different types of applied morphologies are exposed, such as spherical, hollow spheres, colloidal, varying in the same way in particle size from 7 - 600 nm, which has had medical applications, biological, toxicological studies, improvement to the UV resistance of fabrics, and in the characterization of polymers improving their physical and chemical properties.

Silica can be extracted as a natural resource, however, this method contains impurities which are not beneficial at the time of its implementation in industrial or scientific processes, for which artificial SiO_2 is generated, which through the chemical process of synthesis, allows obtaining pure silica particles thanks to the control of morphology, size, porosity, and size distribution, through

Table 1.1
Nanomaterials and their application in industry.

Material	Application	Size	Author
$CaCO_2$	Epoxy resin nano-CaCO2 modified powder coatings	5–10 nm	Yu et al. [18]
CeO_2	Corrosion protection capability	5 nm	Kozhukharov et al. [17]
	Coatings for an aluminum alloy	5–10 nm	Schem et al. [2]
Al_2O_3	Modification of coatings	30–47 nm	Dhoke et al. [21]
Fe_2O_3	Polydimethylsiloxane coating (PDMS)	4–15 nm	Sötebier et al. [20]
ZnO	Coating system	35–40 nm	Dhoke et al. [16]
	Preparation of composite membranes for water desalination process	20–30 nm	Ardeshiri et al. [15]
TiO_2	Construction (coating for corrosion protection)	75 nm	Radhakrishnan et al. [12]
	Chemistry, polymers (superhydrophobic surfaces of polypropylene)	30 nm	Contreras et al. [14]
SiO_2	Biomimetic hydrophobic surfaces with high or low adherence	40–200 nm	Wang et al. [8]
	Superhydrophobic polypropylene membrane	26–73 nm	Shao et al. [19]

Table 1.2
Different applications of Nano-SiO_2.

Material	Application	Average size	Morphologies	Author
SiO_2	Surface characterization of polymers	20 nm	Colloidal silica	Percy et al. [23]
	Medical, biological and catalytic applications	10–20 nm	Hollow mesoporous spheres, core spheres, hollow spheres with multiple porous layers and hierarchically porous spheres	Du and He. [28]
	Conducting systematic toxicological studies to investigate structure-activity relationships	25, 70, 100, 170, y 600 nm	Mesoporous spheres	Das et al. [5]
	Improvement of ultraviolet light resistance, hydrophobicity and wrinkle properties in silk fabrics	7 nm	Mesoporous spheres	Gao et al. [29]
	Improvement of anticorrosive properties of aluminum and its alloys	70 nm	Mesoporous spheres	Qin et al. [30]
	Modeling of magnetochromatic hydrogels and improvement of optical performance	178 –185 nm	Hemispherical and oval	Zhang et al. [31]

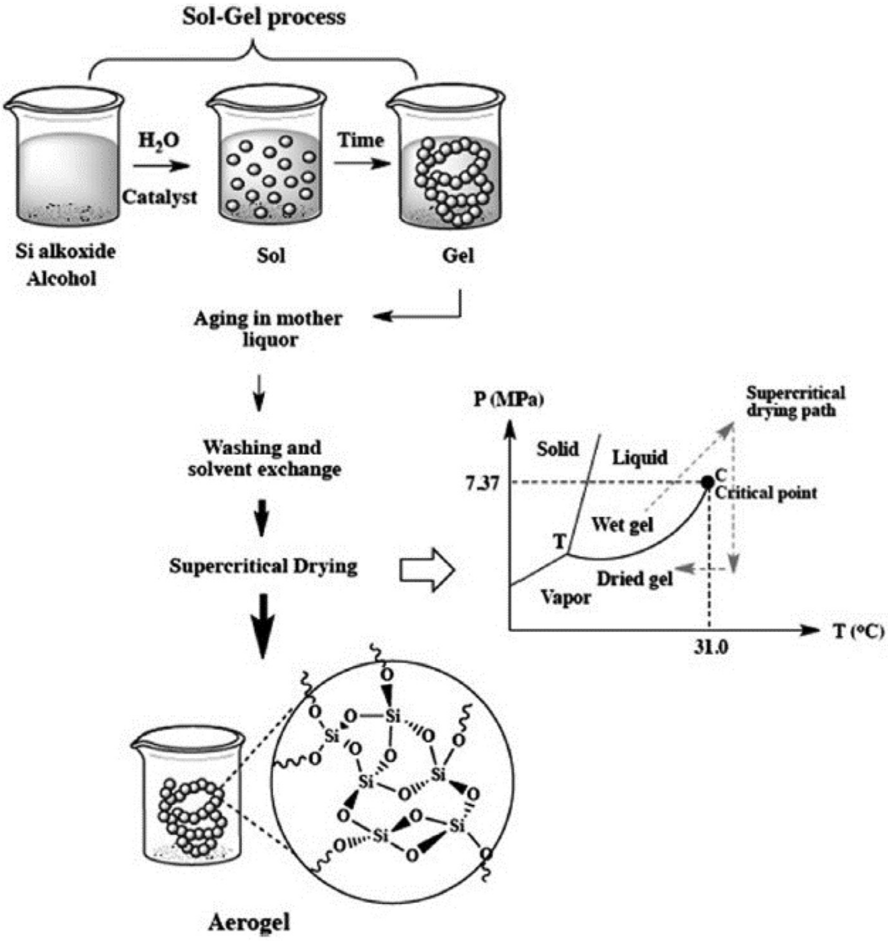

Figure 1.1. Steps of the sol-gel method for the synthesis of Silica (SiO_2) [35].

methodical control during the choice of chemical reaction parameters. In the synthesis of SiO_2 (colloidal, gels, pyrogenic and precipitated) an amorphous white powder is obtained with higher purity compared to natural silica [11,32].

Currently, the obtaining of Nano Silica (SiO_2) has been carried out through several synthesis methods such as inverse micro emulsion, by flame, interfacial emulsion polymerization process, surface living polymerization, electrostatic interaction, heterophase, and sol-gel, so a great development in the number of techniques used can be appreciated [11,26,27,33,34]. The sol-gel method is one of the most implemented due to the high yield of the product, the low temperature of the process, the simplicity of the equipment and process, safety and low cost [34]**.** The sol-gel method is based on the hydrolysis and condensation of metal alkoxides (Si $(OR)_4$), such as tetraethyl orthosilicate (TEOS), mineral acids (HCI) or bases (NH_3) that function as a catalyst (see Fig. 1.1). Silica obtained by the sol-gel method generates a hydrophilic product which, through surface modification, can provide hydrophobic properties [10]. In order to carry out this hydrophobicity process, studies have been carried out implementing ammonia and hydrochloric acid during the sol-gel process [34].

The chemistry within the complex cement hydration process has been studied for many years in an effort to understand its complexity and how it can be optimized to obtain better physical properties. The elements that are directly involved in this process are calcium silicate hydrate (CSH), which is the most critical hydration element, since it occupies the largest area and maintains the microstructure adhered. CSH makes up 50% of the volume of the cementing paste and is practically responsible for most of the physical properties. Calcium hydroxide (CH) makes up approximately 15% of the cement paste by volume from which the formation of crystals is obtained inside the cement paste that are introduced into the pores. Calcium silicate hydrate and calcium hydroxide are by-products that are generated from the chemical reaction of alite and water. Both the wing and the candle are minerals that tend to react in a similar way during the hydration process. Other elements that make up 15 to 25% are calcium aluminates and sulfoaluminate phases that incorporate the hydration products, forming tricalcium aluminate minerals and tetracalcium aluminoferrite, their contribution to physical properties compared to CSH are lower [36–38].

The cement hydration process begins once the (Aluminate C_3A) and (Silicate C_3S) come into contact with moisture, therefore, when the cement is stored for a long time, early hydration begins and its physical properties, such as compressive strength, are affected, which is a problematic situation that frequently occurs in humid regions.

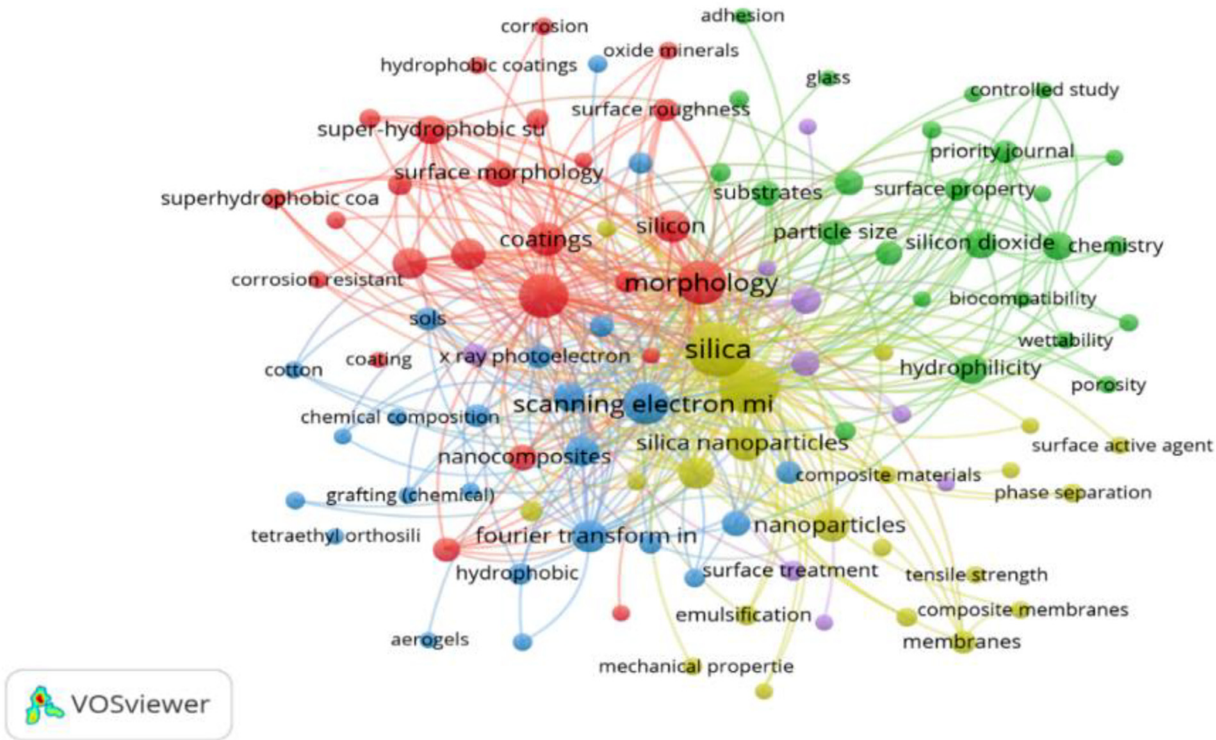

Figure 2.1. Bibliometric map created in VOSviewer based on co-occurring keywords. Source: Prepared by the authors.

The main objective of this work was to carry out a bibliometric analysis applying the *InOrdinatio* mathematical equation to highlight how the support of these tools is essential to generate an adequate portfolio of the most important articles on the study of the synthesis of hydrophobic nanosilica and its different morphologies.

Method details

A bibliometric study referring to the synthesis and characterization of nanosilica with different morphologies applying a modification to the contact angle to obtain a percentage of hydrophobicity was the first stage that was carried out to understand the behavior of the object of study through the collection of Scopus and Web of Science (WoS) data. The reason for selecting these databases is their importance for accessing a large amount of relevant literature related to the object of study. The search period used was from January 2000 to July 2022. The words used as the basis for the start of the search were ((ALL= (Sio_2)) AND ALL= (hydrophobic Sio_2)) AND ALL= (Morphologies Sio_2). A total of 359 documents were found in Scopus and 347 in Web of Science.

The study of the recurrence of keywords in the published literature can be very useful to identify the predisposition to research on certain silica topics. Using the VOSviewer tool [39,40], the co-occurrence map was prepared, which is depicted in Fig. 2.1, resulting in a total of 5 clusters, highlighting a total of 4 clusters represented in different colors with the words “Silica”, “Morphologies”, “Hydrophobicity”, “Contact Angle”, which stood out as the most recurrent within the titles and summaries of the publications made according to the largest ones. This analysis allowed the corroboration that the topic “Silica” appears in the first 20 most used keywords and, according to the network generated in the clusters, the co-occurrence and linkage among these can also be observed, this being the support of the analysis carried out in this work. As in this study, several authors, including Trianni [41], Khudzari [42], and Salvador [43], have taken the advantages of VOSviewer for bibliometric analysis.

To support the bibliographic database regarding the research of hydrophobic nanosilica with different morphologies, the *Methodi Ordinatio* (*InOrdinatio*) was implemented. Fig. 2.2 shows the phases of the method, which consists of a total of 9 phases [44–46].

Phase 1. Intention of the research: Generate an adequate portfolio of the most important articles on the study of the synthesis of hydrophobic nanosilica and its different morphologies.

Phase 2. Preliminary research with keywords: For the first search carried out within the WoS and Scopus platforms, the operations were ALL= (SiO_2) AND ALL= (hydrophobic SiO_2) AND ALL= (Morphologies SiO_2). This search helped to define a group of words to carry out the definitive search through the analysis that was carried out with the outstanding words in the articles returned, resulting in a total of 60 articles in Scopus and 41 in Web of Science.

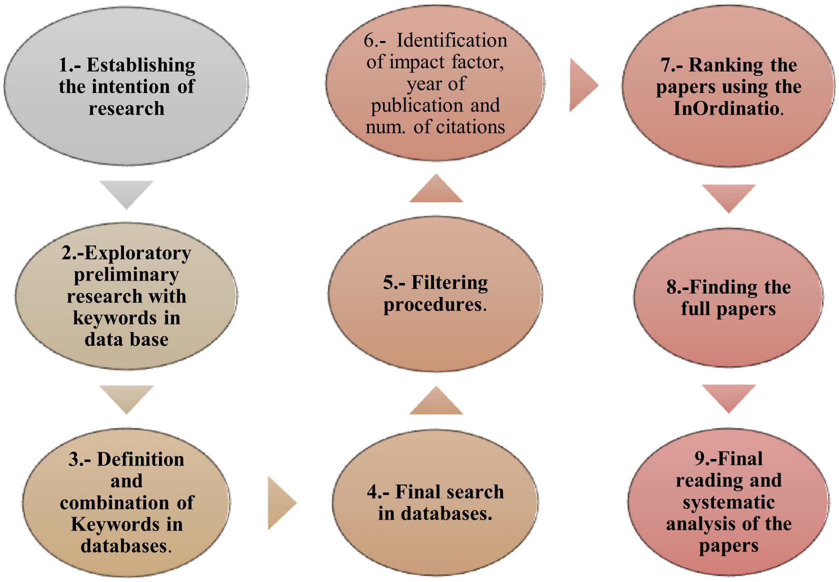

Figure 2.2. Phases of Methodi Ordinatio [44].

Phase 3. Definition and combination of keywords in the database. Based on the previously found articles, new keywords regularly implemented by the authors arose, among them are “Silica Nanoparticles”, “SiO_2 Nanoparticles”, “Surface Morphologies”, “Contact Angle”, “Hydrophobicity”, “Scanning Electron Microscopy”, “Sol-gel Method”, “Surface Chemistry”, "Particle Size". Once examined, a group of keywords was determined for the final inquiry of the Scopus and WoS databases, as shown in Fig. 2.2.

Phase 4. Final search in the databases. The investigation with the specific characters is made up of the strategic words and Boolean operators, for the mathematical and logical search in the databases. The defined keywords that were used for the search in the Scopus and WoS databases are ALL (“Silica”) AND (“hydrophobic SiO2”) AND (“Morphologies SiO2”) AND (“Surface AND Modification SiO2” OR “SiO2 Nanoparticles"). Once the search was carried out using these words, they were transferred in CSV Excel and bibText format in order to obtain the information and analyze it in the VOSviewer Software and the Mendeley bibliographic reference manager. A total of (60) articles were found in Scopus and (41) in WoS**.**

Phase 5. Filtering procedures: Within Phase 4, a total collection of articles was carried out. Subsequently, an information filtering process was performed in order to identify the most relevant articles. Fig. 2.3 shows the classification of the applied filters, which are divided into 4 stages: (I) Elimination of the repeated records, leaving a total of 88 records, (II) it was only taken into account the publications that were within the category of "Article", again leaving a total of 88, (III) the research period was established from the year 2000 to 2022. Once these 3 stages were completed, a total of 88 articles were obtained, (IV) finally, the *InOrdinatio* Index (which is explained in Section 3.2) was applied, giving a total of 36 articles which were selected to form the final group.

Phase 6. Identification of the Impact Factor (IF), the year of publication and the number of citations: Once the final articles were obtained from the databases (Scopus and WoS), an analysis was carried out of the year in which they were published and of the number of appointments. The IF of the journals that published the articles were obtained through the Scopus Source List and Journal Citation Reports websites.

Phase 7. Classification of the research paper by applying the *InOrdinatio* formula. To carry out this phase, the 6 previous phases must be completed and the *InOrdinatio* Index is applied using Eq. (1) which was applied by citation. This coefficient makes a consideration of the total citations (ΣCi), the impact factor (IF/1000), the weighting factor (6) which is set according to the criteria of the researcher and can be in the range of 1 to 10 and, in the same way, the year of the research and of the publication to catalog the articles [44–46].

$$InOrdinatio = (\mathbf{IF/1000}) + \boldsymbol{\alpha}^{*}(\mathbf{10}-(\mathbf{Research\ Year} - \mathbf{Publication\ Year})) + \left(\sum \mathbf{Ci}\right)$$

[45].

Where:

IF = Impact Factor of the journal.
α = coeficient value (1 a 10), importance of the year of the article.
ResearchYear = year in which the investigation is carried out.
PublicationYear = year the article was published.
ΣCi = total number of citations for the article.

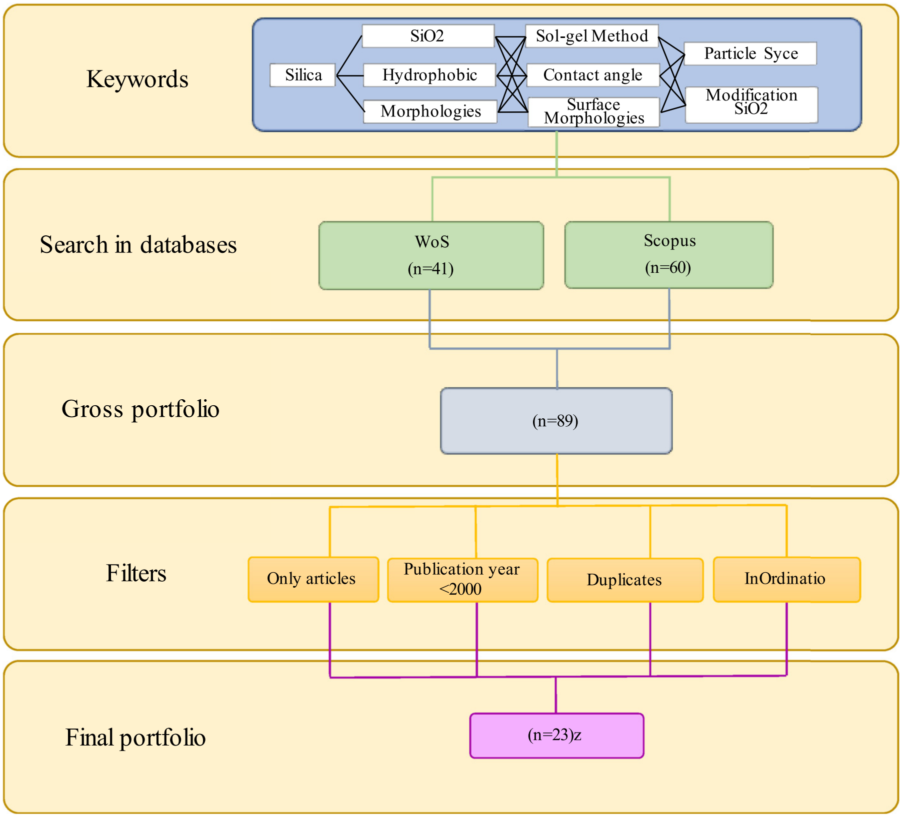

Figure 2.3. Bibliography compilation and filtering process to obtain the final portfolio [44].

In this work, for the application of the *InOrdinatio* Method, an α value of 10 was chosen, which makes it possible to determine the most important articles that were published most recently and assigns greater importance, without neglecting those articles that are older. This is in order to give greater emphasis and rank the articles with the most recent technological trends and their application, assuming that most of them were based on older articles for such applications.

Phase 8. Finding of the complete articles. Once the articles were classified through the *InOrdinatio* Method, the articles that have open access were downloaded from the WoS and Scopus platform, while the articles that were not available in open access were purchased [44–46].

Phase 9. Final reading and systematic analysis of the articles. Systematic analysis becomes a long and complex task. From the *InOrdinatio* Method, a list is generated in an orderly manner and according to the hierarchy of importance with respect to the result obtained with Eq. (1) of Phase 7, which helps to select the articles according to the researcher's judgment in order to carry out an adequate selection and final reading.

Validation through method InOrdinatio

When defining the dimension of the research on the topic of hydrophobic silica and its different morphologies, through a bibliometric analysis, a total of two queries were used to determine the final portfolio based on the InOrdinatio Method. The search string used in Scopus was TTLE-ABS-KEY-AUTH ("Silica") AND ("hydrophobic sio2") AND ("Morphologies sio2") AND ("Surface AND Modification sio2" OR "sio2 Nanoparticles")). The query made in Web of Science included the entire database, the search series being: ALL ("Silica") AND ("hydrophobic sio2") AND ("Morphologies sio2") AND ("Surface AND Modification sio2" OR "sio2 Nanoparticles")).

In total, the gross folder is made up of a total of 101 articles. Table 3.2 shows the process of discarded articles when the criteria established in the fifth phase were applied. After completing the filtering process, a total of 36 most relevant articles were determined. Table 3.3 presents the list according to the classification with an *InOrdinatio* Index = $\alpha 6$ in the final portfolio. In the same way, a comparison is presented applying an Index = $\alpha 8$ and an Index = $\alpha 10$ to be able to differentiate the ranking that is obtained from the importance of the year of publication.

Table 3.3 shows the list of articles according to the ranking obtained, with respect to the alpha value used in the *InOrdinatio* Method equation. This value is implemented according to the level of importance required by the research. According to [45], the

Table 3.2
Number of articles before and after the filtering process.

Filter	Number of selected articles	Number of discarded articles	Final selection of articles	%
WoS	41			
Scopus	60			
Total documents	101			100
Duplicates		13	88	87.12
Articles, book, conference paper		0	88	87.12
Articles published before 2000		0	88	87.12
InOrdinatio 40%		53	36	35.64
Total of discarded articles		53		52.47
Total articles in final portfolio		36		

Source: Prepared by the authors.

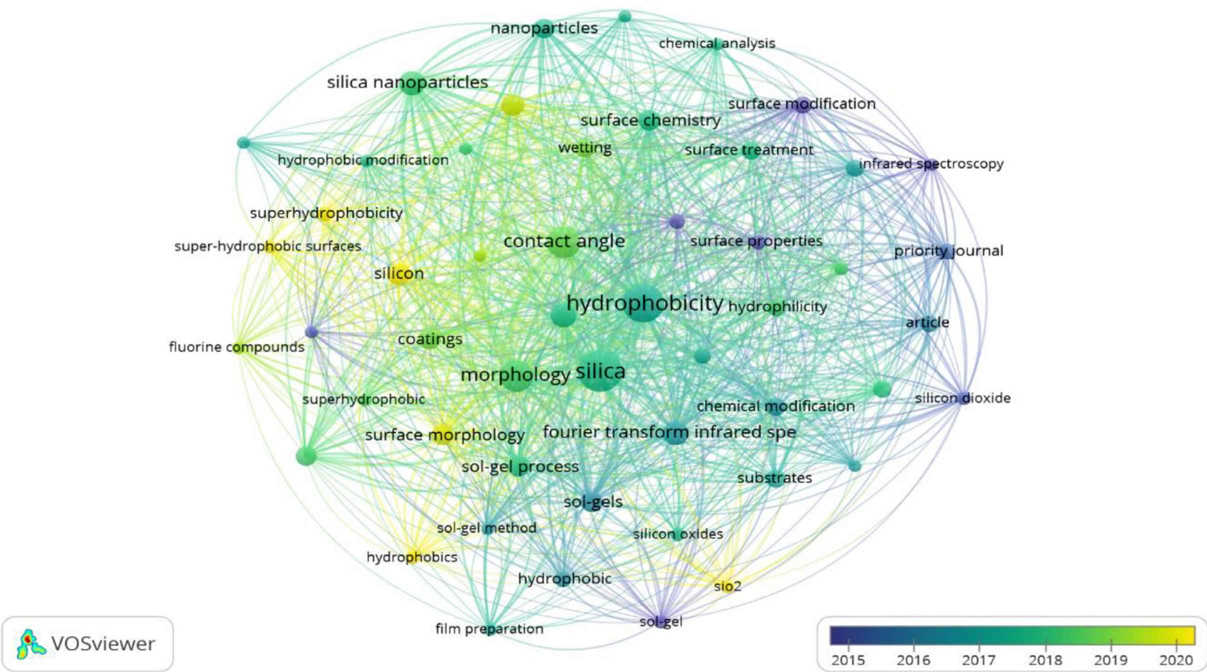

Figure 3.3. Bibliometric map of word co-occurrence on the topic of hydrophobic SiO_2. Source: Prepared by the authors.

alpha value can vary according to the researchers in a range between 1 and 10, the closer the value is to one, the less the importance the researcher attributes to the year criterion, while the closer it is to ten, the greater will be the importance of this criterion.

For this study, a total of 36 articles were used, which represents 40% of the total articles. According to the review of the articles and the ranking of *InOrdinatio* generated, it was determined as an optimal percentage to make up the final portfolio. Each researcher has the opportunity to define the percentage or variable number of articles for the index generated by *InOrdinatio* [45]. The list of articles presented in Table 3.3 does not represent a definitive portfolio, but the main intention is to be able to provide and suggest a metric for obtaining and generating a bibliographic portfolio. The objective of generating the list of articles is to make the research process efficient during the work of systematic analysis of the literature, facilitating the work of the researcher [44].

Topics of great importance in the development of research on hydrophobic SiO_2 and its different morphologies

In this section, the bibliometric study was carried out with a total of 8 articles corresponding to the portfolio obtained prior to the application of the *InOrdinatio* Method, in which quantitative information was presented to complete the analysis on the evolution of the research area.

In the co-occurrence analysis of the keywords through the application of the VOSviewer software, the topics most frequently implemented in the investigation of hydrophobic nanoSiO_2 and its different morphologies were identified. Fig. 3.3 shows the bibliometric map of the co-occurrence words of the topics investigated during the last 20 years. The keywords "morphology", "silica", "contact angle", surface morphology", "sol gel process", "chemical modification", and "silica nanoparticles" showed the main trend in the research topic, since they represent the material to work, the physical quality obtained, the synthesis process and the surface

Table 3.3
List of articles with the *InOrdinatio* ranking that make up the final portfolio.

Author	Title	Year	*InOrdinatio* α=6	Ranking > < 40%	Index α=8	Index α=10
Ahmad et al. [47]	Functionalized PSf/SiO_2 nanocomposite membrane for oil-in-water emulsion separation	2011	179.00	1	1	1
Lu et al. [48]	Amphiphobic PVDF composite membranes for anti-fouling direct contact membrane distillation	2016	142.00	2	2	2
Xie et al. [49]	Robust and anti-corrosive PDMS/ SiO_2 superhydrophobic coatings fabricated on magnesium alloys with different-sized SiO_2 nanoparticles	2018	119.00	3	3	3
Fan et al. [50]	Bio-inspired robust superhydrophobic-superoleophilic polyphenylene sulfide membrane for efficient oil/water separation under highly acidic or alkaline conditions	2017	98.00	4	4	4
Amatatongchai et al. [7]	Highly sensitive and selective electrochemical paper-based device using a graphite screen-printed electrode modified with molecularly imprinted polymers coated Fe_3O_4@Au@ SiO_2 for serotonin determination	2019	89.00	5	5	5
Shao et al. [19]	Superhydrophobic polypropylene membrane with fabricated antifouling interface for vacuum membrane distillation treating high concentration sodium/magnesium saline water	2019	88.00	6	6	6
Zhou et al. [51]	Effects of multi-walled carbon nanotubes (MWCNTs) and integrated MWCNTs/SiO_2 nano-additives on PVDF polymeric membranes for vacuum membrane distillation	2019	84.00	7	7	7
Zhou et al. [52]	Tailoring the surface chemistry and morphology of glass fiber membranes for robust oil/water separation using poly(dimethylsiloxanes) as hydrophobic molecular binders	2018	77.00	8	8	8
Li et al. [53]	Broadband anti-reflective and water-repellent coatings on glass substrates for self-cleaning photovoltaic cells	2013	69.00	9	39	58
Jeon et al. [54]	Highly Transparent, Robust Hydrophobic, and Amphiphilic Organic-Inorganic Hybrid Coatings for Antifogging and Antibacterial Applications	2021	64.00	10	9	10
Saffar et al. [55]	Fabrication of superhydrophobic, self-cleaning and anti-icing ZnO/PTFE- SiO_2 nano-composite thin film	2021	63.00	11	10	18
Chen et al. [56]	Fabrication of repairable anti-corrosive superhydrophobic surfaces with micro-nano structures by ultrasonic cavitation	2021	62.00	12	14	19
Dolatzadeh et al. [10]	Influence of various surface treated silica nanoparticles on the electrochemical properties of SiO_2/polyurethane nanocoatings	2011	61.00	13	61	69
Jia et al. [57]	Systematic investigation on the interaction between SiO_2 nanoparticles with different surface affinity and various surfactants	2020	61.00	14	22	25
Huajaikaew et al. [58]	Comb-like poly (dodecyl methacrylate) modified SiO_2 nanoparticles as nanohybrid coatings: Electron beam grafting and tuning superhydrophobic/water-repellent surface studies	2022	60.01	15	11	9
Chen et al. [59]	Fabrication and characterization of highly hydrophobic rutile TiO_2-based coatings for self-cleaning	2019	60.00	16	29	35
Su et al. [60]	UV resistance of sol-gel hydrophobic silica antireflective coatings	2022	60.00	17	12	11
Yang et al. [61]	One-step synthesis of quaternized silica nanoparticles with bacterial adhesion and aggregation properties for effective antibacterial and antibiofilm treatments	2022	60.00	18	13	12

(*continued on next page*)

Table 3.3 (*continued*)

Author	Title	Year	*InOrdinatio* α=6	Ranking > < 40%	Index α=8	Index α=10
Rosales et al. [62]	Hydrophobic agents and pH modification as comparative chemical effect on the hydrophobic and photocatalytic properties in SiO_2-TiO_2 coating	2022	60.00	19	15	13
Ardani et al. [63]	Core shell Fe_3O_4@TiO_2/silica aerogel nanocomposite; synthesis and study of structural, magnetic and photocatalytic properties	2022	60.00	20	16	14
Dong et al. [64]	Low-temperature silane coupling agent modified biomimetic micro/nanoscale roughness hierarchical structure superhydrophobic polyethylene terephthalate filter media	2022	60.00	21	17	15
Forchetti Casarino et al. [65]	Synthesis and characterization of polybenzoxazine/silica-based hybrid nanostructures for flame retardancy applications	2022	60.00	22	18	16
Moaref et al. [66]	Synthesis and characterization of nearly monodisperse superparamagnetic (Fe_3O_4/Poly (methyl methacrylate))- SiO_2 nanoparticles with raspberry-like morphology	2022	60.00	23	19	17
Xin et al. [67]	Superhydrophobic Surface-Constructed Membrane Contactor with Hierarchical Lotus-Leaf-Like Interfaces for Efficient SiO_2 Capture	2021	59.00	24	20	20
Xin et al. [68]	Constructing superhydrophobic surface of PES/PES- SiO_2 mixed matrix membrane contactors for efficient SO_2 capture	2021	59.00	25	21	21
Gnedenkov et al. [69]	Wettability and electrochemical properties of the highly hydrophobic coatings on PEO-pretreated aluminum alloy	2016	59.00	26	48	53
Zhang et al. [70]	The preparation of PCL/MSO/ SiO_2 hierarchical superhydrophobic mats for oil-water separation by one-step method	2019	59.00	27	34	37
El-Fattah et al. [71]	Surface morphology and mechanical properties of polyether ether ketone (Peek) nanocomposites reinforced by nano-sized silica (SiO_2) for prosthodontics and restorative dentistry	2021	59.00	28	23	22
Protsak et al. [72]	A new route for preparation of hydrophobic silica nanoparticles using a mixture of poly(dimethylsiloxane) and diethyl carbonate	2018	59.00	29	40	42
Liu et al. [73]	Preparation of Cu@SiO_2 composite nanoparticle and its tribological properties as water-based lubricant additive	2020	59.00	30	26	31
Lyu et al. [74]	Preparation of an amphiphilic Janus SiO_2/fluorinated polyacrylate latex film and its application as a hydrophobic fabric agent	2021	58.00	31	24	23
Rukmanikrishnan et al. [75]	Rheological and anti-microbial study of silica and silver nanoparticles-reinforced k-carrageenan/hydroxyethyl cellulose composites for food packaging applications	2021	58.00	32	25	24
Petcu et al. [76]	The Influence of New Hydrophobic Silica Nanoparticles on the Surface Properties of the Films Obtained from Bilayer Hybrids	2017	57.01	33	46	49
Li et al. [63]	Preparation and characterization of SiO_2/PDMS/PVDF composite membrane for phenols recovery from coal gasification wastewater in pervaporation	2018	57.00	34	43	44
Schultes et al. [77]	Universal Nanoparticle Wetting Agent for Upscaling Perovskite Solar Cells	2019	57.00	35	37	39
Xiong et al. [78]	Fabrication of superhydrophobic and UV-resistant surface on cotton fabric via layer-by-layer assembly of silica-based UV absorber	2020	57.00	36	32	34

Source: Prepared by the authors.

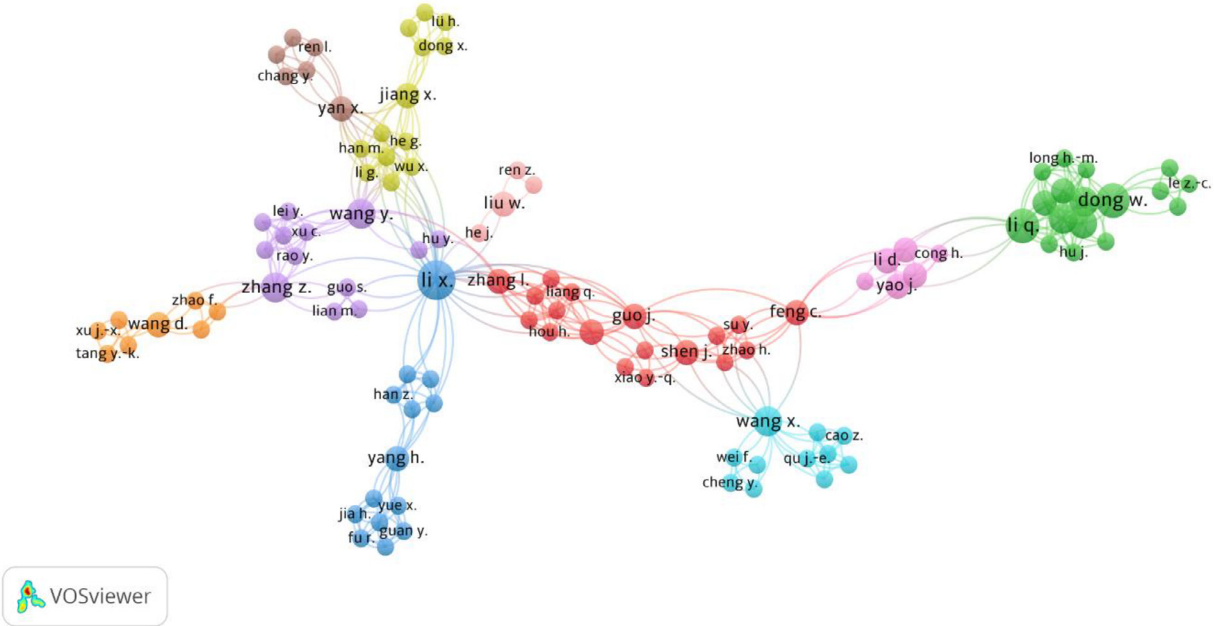

Figure 3.4. Co-author bibliometrics and word co-occurrence in hydrophobic SiO_2 published articles. Source: Prepared by the authors.

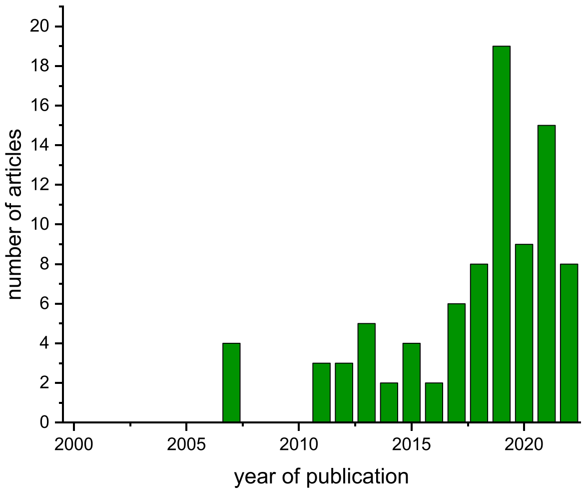

Figure 3.5. Number of publications on hydrophobic SiO_2 per year. Source: Prepared by the authors.

modification of the nanomaterial. Within the clusters analyzed in the bibliometric map, different sizes can be observed for the spheres, the largest ones being the words with a greater co-occurrence, of which, an increase can be identified from 2017 to 2021 on the study of morphology and hydrophobicity for specific application in the industry.

A total of 1081 index keywords were analyzed, of which 51 (4.71%) reached a co-occurrence of five or more times, 15 (1.39%) were used 4 times, 39 (3.60%) with a co-occurrence of 3 times and 976 (90.30%) were used one or two times. During the 22-year study period, from 2000 to 2022, a total of 329 authors have contributed to the publication of articles on hydrophobic silica and its different morphologies. Fig. 3.4 presents an interrelationship map where each of the circles represents an author and the color represents a work group. The analysis revealed 9 authors (2.73%) who contribute with at least 3 publications. Also, 10 clusters were identified, of which the one with the largest number of collaborators is made up of 18, which is equivalent to 5.47%. According to this behavior, a lack in the interrelation between each of the groups that is developing research on SiO_2 can be observed.

The author with the most citations and the highest production number is Li X., with 5 published articles and 138 citations. A total of 88 articles were published in a period of 22 years. Fig. 3.5 shows the number of publications carried out on SiO_2 from the year 2000–2022. The first four publications carried out correspond to the year 2007, while from the year 2011 a more contrasting

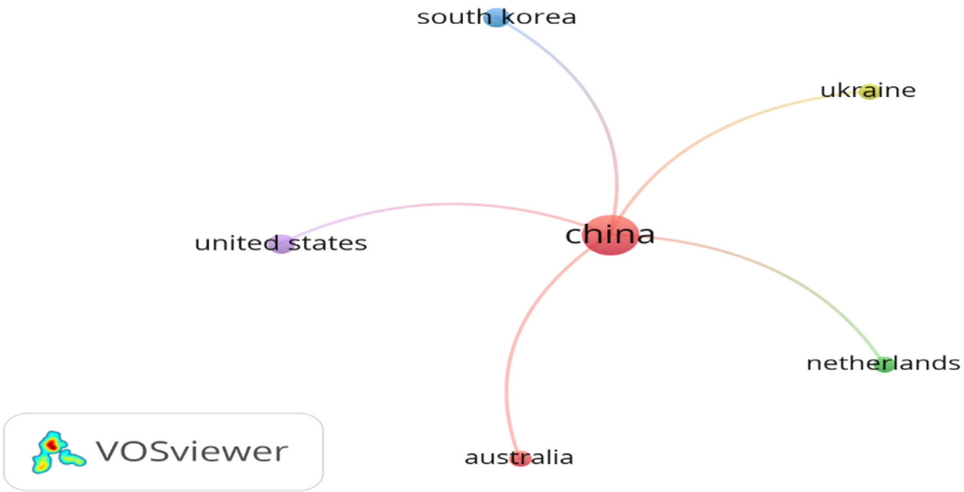

Figure 3.6. Bibliometric analysis including the countries with published articles on hydrophobic SiO_2. Source: Prepared by the authors.

ascending publication rate begins thanks to the great contribution that in the industry has SiO_2 by modifying its surface roughness obtaining hydrophobic properties, presenting an annual publication average of 6 to 7 documents.

China is one of the largest industrial producers, so its interest in the production and research of SiO_2 is reflected, being the number 1 country in publications with 40 documents and 467 citations. In Fig. 3.6, the collaboration network of co-authors is presented with China being the leader, in collaboration with Ukraine, South Korea, Australia, the United States and the Netherlands, these being the countries that lead the research on SiO_2 achieving a great impact in the industry worldwide.

Conclusions

According to the bibliometric analysis carried out, based on the most important published articles, it was possible to determine that, with regard to the form of SiO_2 synthesis, surface modifications can be obtained that generate greater surface tension, generating a greater contact angle between water and the contact surface, producing the hydrophobicity of the material.

Cement is a material that, being highly hygroscopic, quickly absorbs moisture from the environment, causing it to set since Aluminate (C_3A) and Silicate (C_3S) come into contact with water, so according to the analyzes carried out with the addition of SiO_2, a cement powder resistant to contact with humidity could be generated for longer periods of time.

On the other hand, it has been possible to synthesize silica with different surfaces, which has made it possible to obtain contact angles of up to 152°, obtaining super hydrophobic surfaces that have achieved up to 70 min before the drop of water deposited on the surface loses its circular shape.

According to the selected articles, it is possible to obtain uniform particles with berry, core shell, and raspberry morphology and with average sizes between 5 and 297 nm, regarding the diameters, resulting in a material with hydrophobic characteristics.

For future work, it is recommended to open a greater range of keywords as well as a greater amount of database including open access and develop a comparison using tools and methods different from those applied in this work.

Ethics statements

The Authors followed MethodsX ethical guidelines, this work does not involve human subjects, animal experiments or data collected from social media.

CRediT author statement

Hernández-Contreras M.: Conceptualization, Methodology, Writing-Original draft preparation. **Cruz J.C.:** Validation, Supervision, Writing. **Pamplona Solis B.:** Visualization, Investigation. **Gurrola M. P.:** Validation, Supervision, Writing. **Vega-Azamar R.E.:** Writing- Reviewing and Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the research reported in this work.

Data availability

No data was used for the research described in the article.

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