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Bond Strength of Substrate With Repair Material for Masonry Structures: Scientometric Analysis and Literature Review

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Abstract

Masonry infrastructure repair is a daunting challenge. The short intervention and limited resources have led to the loss of novel rendering and finishing materials. In the present study, the bibliometric analysis is conducted for period 2003 to 2022. Co-cited reference analysis, keywords, cluster, and temporal evolution were used for analysis using Citespace software. Additionally, summary of suitable content showed that major challenges in this field are disparities in the properties of old mortar and new materials and the lack of documents to understand nature and methodology of construction. Based on the analysis and content review, a suggestive technique is proposed inculcating four aspects: Finite element analysis, preparing numerical models, improvised techniques for bonding mechanisms and understanding mechanical attributes.

Keywords: Repair Material; Mortar; Bond Strength; Co-Citation Analysis; Characterization

1 Introduction

Historic structures are the best expression of the skill, ethos, and antiquity of their builders. For centuries, the most long-lived and impressive monuments have been evidence of true heritage spirit. With the advent of technology and deteriorating environmental conditions, it has been observed that the old infrastructure around the world has reached the stage of sheer disorder. This calls for substantial efforts from all stakeholders to render our waning infrastructure back to an operative and benign state. Therefore, the importance of the structural conservation of old constructions is to value history over progress as they signify the past of a specific region and apprise people about the construction and structural convention [1]. Keeping in view this much-needed aspect, many countries have come together to collaborate to fund the 1977 World Heritage Fund to safeguard world culture and Natural heritage that holds outstanding global worth. World Heritage Fund amounts to 5.9 billion dollars for the biennium 2022-23. The huge amount while the world face crisis due to epidemic shows the awareness and the interest of the nations to preserve their history. The culminating collaboration in USD by nations over the last 11 years is presented in Figure 1 [2]. Historic preservation is a vast domain that categorizes the major tasks as a visual inspection that reflects the building's prevailing condition, viability analysis i.e., analysis of the building based on life-safety issues, compliance with codes and anticipated longevity, context assessment, by comparison of the building with the similar building of that era, and design of rehabilitated building structure, and repair materials for historic structures [3, 4]. Though the planning of the intervention for many historical structures is significant the execution area still lacks. This is due to improper evaluation of the site; lack of resilience in our restoration materials, incapability of repairs to regulate more deterioration and an absence of lucrative placement technologies [3, 5]. This is well-curtained that the efficiency of mortar repairs depends on the quality and behaviour of the interface between the repair material and the substrate material in existing structures. Therefore, the researchers are significantly working on the reparation materials to understand their behaviours to carry out restoration and repair [4, 5].

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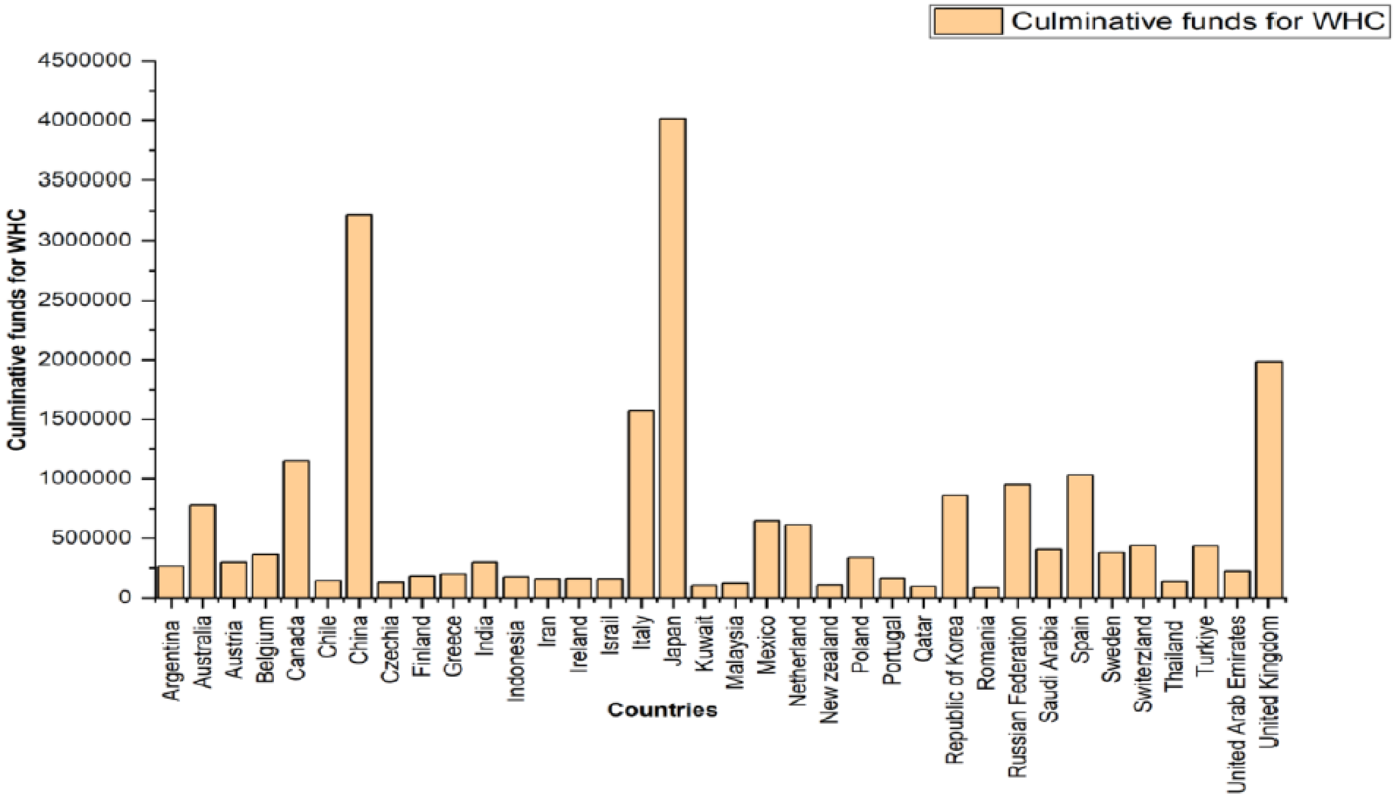


Figure 1: Culminative WHC Funds of different nations in US Dollars

Though the literature shows that the basic techniques and materials of masonry have remained untouched through the ages still there exists a dilemma in employing proper methods to repair them [6]. This concern has come to the limelight recently but still exists a few gaps that need to be addressed. There is a need to acquire a thorough comprehension of recent studies about the bond strength of substrate and repair material for ancient structures and to recognize research disparities. Therefore, the subsequent study is executed to conduct Systematic Literature Review (SLR). The SLR is an essential requirement in the present scenario as it enhances the information about the subject to be researched, and acts as the source of guidance for the selection of a suitable domain. This also helps researchers to identify problems initially and make amendments in future studies. It also provides insight into the state of knowledge about prospects to synthesize information from novel research, evaluate the degree of consensus or its dearth in the field, elaborate forthcoming opportunities, and tasks. About the information provided above, the subsequent questions are recognized in the paper.
Q1. What is the consideration for the bond between the substrate of the existing material and the repair material? What is the basis of the selection of suitable repair material?
Q2. What is the basis of research scholars' distribution working in this domain along with details of their institutes and nationalities?
Q3. What are the typical field classification and related priorities?
Q4. How to identify suitable research gaps and expected trends in the domain?

2 Data Sources and Methodology

The systematic literature review includes a methodical and equitable search. This allows extensive and integrated assessment and analysis. The literature management is carried out using relevant bibliometric software as it permits the collection of bibliographical records and creates an outline of field knowledge. The field knowledge encompasses some scientific domains. The data is represented in form of visually enticing graphics for different knowledge spheres. Domain analysis has become a popular field that facilitates discovering large information and track development in the sphere. Citespace is a comprehensive software that enables keyword burst analysis, and timeline review providing a more complex interface [7]. Therefore, Citespace has been chosen for analysis due to its inclusiveness, consistency, and convenience of use. Following guidelines laid in PRISMA2020 [8], the data was selected from relevant sources, and it was further retrieved using screening techniques and cleaned to eliminate bias. The abstract and interactive analysis was conducted by CiteSpace. The visual representation in form of graphs in CiteSpace included nodes coloured in shades of grey to red representing evolution with time. The frequency of the label was highlighted by its size. The width of connection among nodes facilitated recognition of other parameters like network centrality, size of the cluster, silhouette, and time-dependent analysis in regards to the significance of the information. The quantitative analysis was followed by a qualitative analysis.

2.1 Data Sources

2.1.1 Description of Retrieved Keywords

The keywords “bond strength”, “repair”, “masonry”, “adhesion”, and “substrate” were used to identify the 15 most appropriate works. The thorough review of this literature aided in building a proper logic grid. Therefore, the keywords for “substrate” are “interface”, and “substrate”. Keywords for bond strength are represented as “adhesion”, “grout”, and “tensile strength of bond”.

2.1.2 Review Strategy

The first thing in this study was to identify some critical terms for bond strength investigation of substrate and repair material for masonry structures. Next, the keywords were connected using Boolean operations utilizing Web of Science (WOS) and Scopus as the literature source databases as follows: TS= ((Repair OR Adhesion OR grout) and Bond and interface and masonry not (”stone”). The search period, which covered 20 years from 2002 to 2022, was established from January 1 to December 31, 2022. This method led to the retrieval of 1430 publications from SCOPUS and 1592 papers from WOS [7]. The following actions were done to make sure the data were accurate: Choosing ”Article” as the filter for the type of literature, choosing ”English” as the language of the literature, and deciding on the scope. The construction building technology, material science multidisciplinary, civil engineering, and material science composite were selected as the focus of the literature study. The literature was manually reviewed to weed out irrelevant articles; duplicate articles were removed using CiteSpace [7]. The studies selected for each process are shown in Figure 2, and a total of 678 studies were deemed to be pertinent to the analysis.

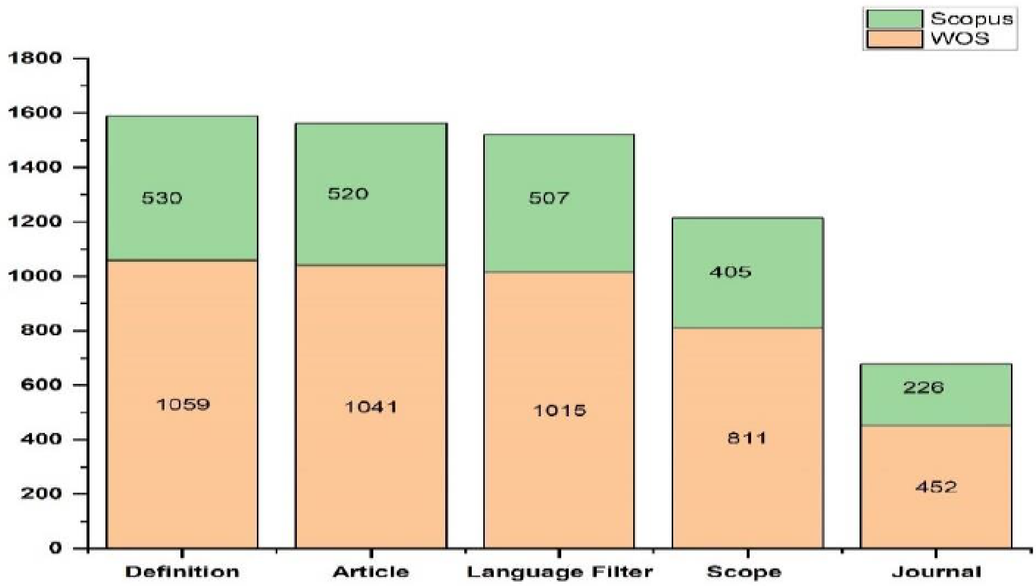


Figure 2: Data Cleaning process for articles collected from WOS and Scopus

3 Visualization Results and Analysis

3.1 Number of Published Papers

Figure 3 illustrates the statistical analysis of the literature retrieval data, which revealed that from 2003 to 2008, there were less than 20 publications. However, from 2009 to 2021, the number of articles considerably rose. The number of publications stayed around 50 over those years. Since the awareness about intervention before applying repair techniques has been enhanced over the years, an increasing number of scholars have concentrated on this topic. 2021 had a significant rise in the toll of published articles, reaching 96. From the trendline, the overall trend is in the forward direction.

3.2 Cooperative Network Analysis for Countries

Each node size represents the publications count in that country for the cooperative network among the numerous nations. According to the years 2003–2022, the node shades were coloured ranging from grey to red, with the breadth of each colour denoting the yearly number of publications. According to Figure 4, Italy had the most publications i.e., 202 followed by China, England, USA, and India. It has been observed that there is no centrality for any nation indicating independent research by different countries.

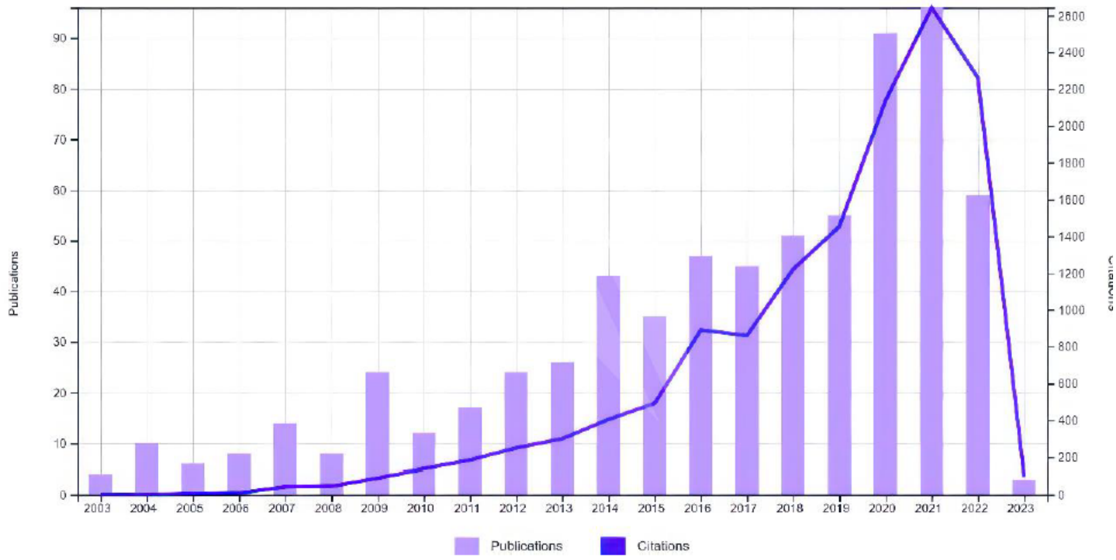
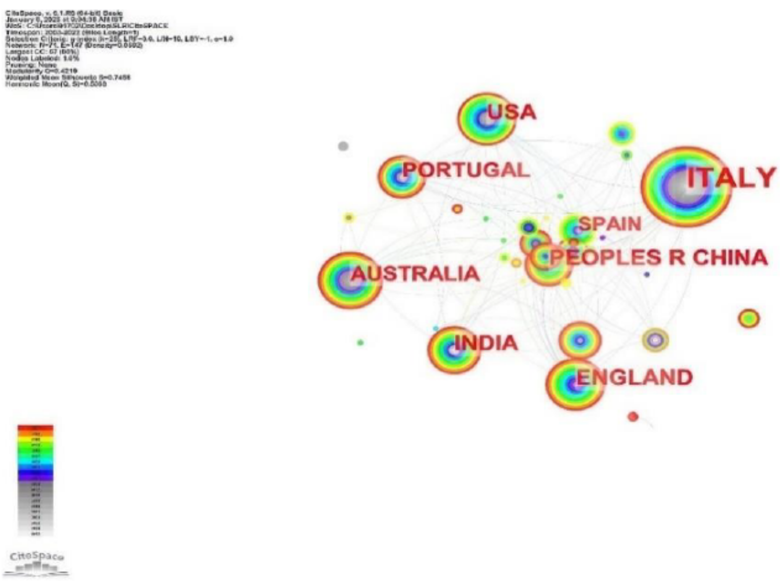


Figure 3: Number of publications and Citations based on bond strength investigation.



Countries	Number of Articles
202	Italy
53	England
53	People R China
49	USA
47	India
45	Portugal
40	Australia
31	Spain
24	Germany
22	Canada

Figure 4: The collaborative countries network

3.3 Cooperative Network Analysis for Authors and Institutions

Though, as seen in Figure 5, there were a maximum of 22 publications published simultaneously by a single author there were also a few instances of many writers working together. This demonstrated that there is not a high concentration of writers focused on this objective. Even though there was limited cooperation among institutions, the research authors were more centred and molded a core research group in their institutions, as shown by the network Figure 6 of institutional cooperation, which combined the units of authors and research institutions with the maximum publications.

3.4 Co-Citation Analysis

3.4.1 Cited Procedure

The study of the history and future directions of research on "bond strength between substrate and repair material for masonry structures" requires analyzing highly referenced literature. The period was "1 year," the node type was "Reference," and the Top 10% of each slice, up to 100, was the criteria, and Pathfinder was the network crop. The "Pathfinder" network culling technique was utilized, and the tagged terms were extracted from the pertinent citation literature using the Log-Likelihood Ratio (LLR) algorithm. According to CiteSpace's study, were referenced in three publications with the most co-citations and significantly influenced the field. Lourenco et al. suggested a constitutive model for masonry structure analysis. The discretized model is prepared to understand the slipping, cracking and crushing behaviour of the material. Valluzi et al. proposed to characterize the bonding capability of different masonry components strengthened by composites on basis of their shear action while Papanicolaou et al. developed a new material as textile-reinforced mortar to strengthen the unreinforced masonry walls.

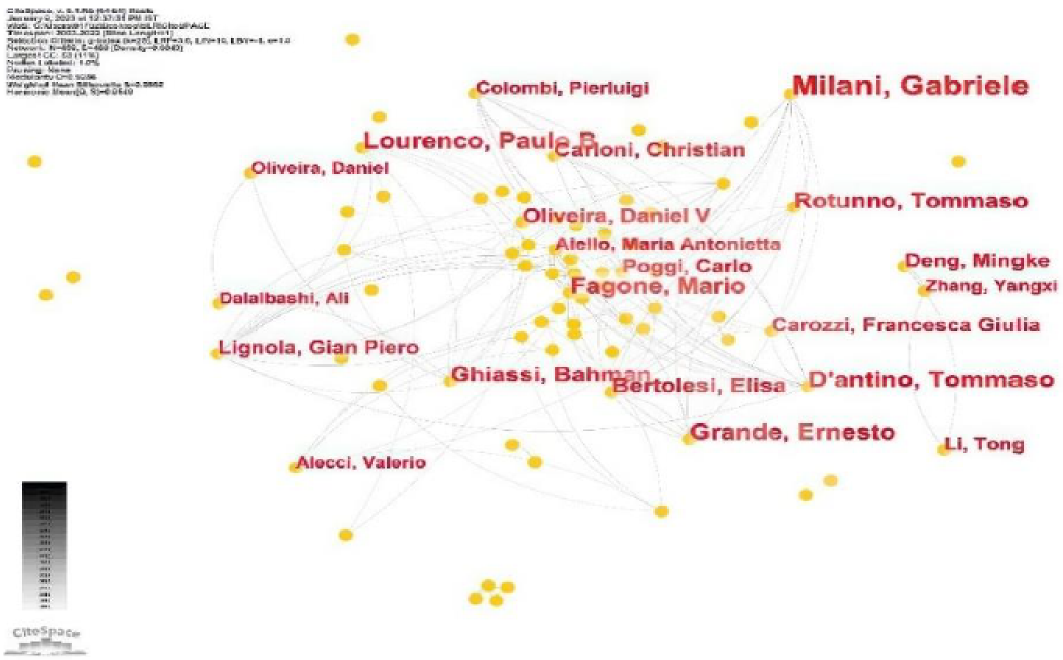


Figure 5: The collaborative authors network

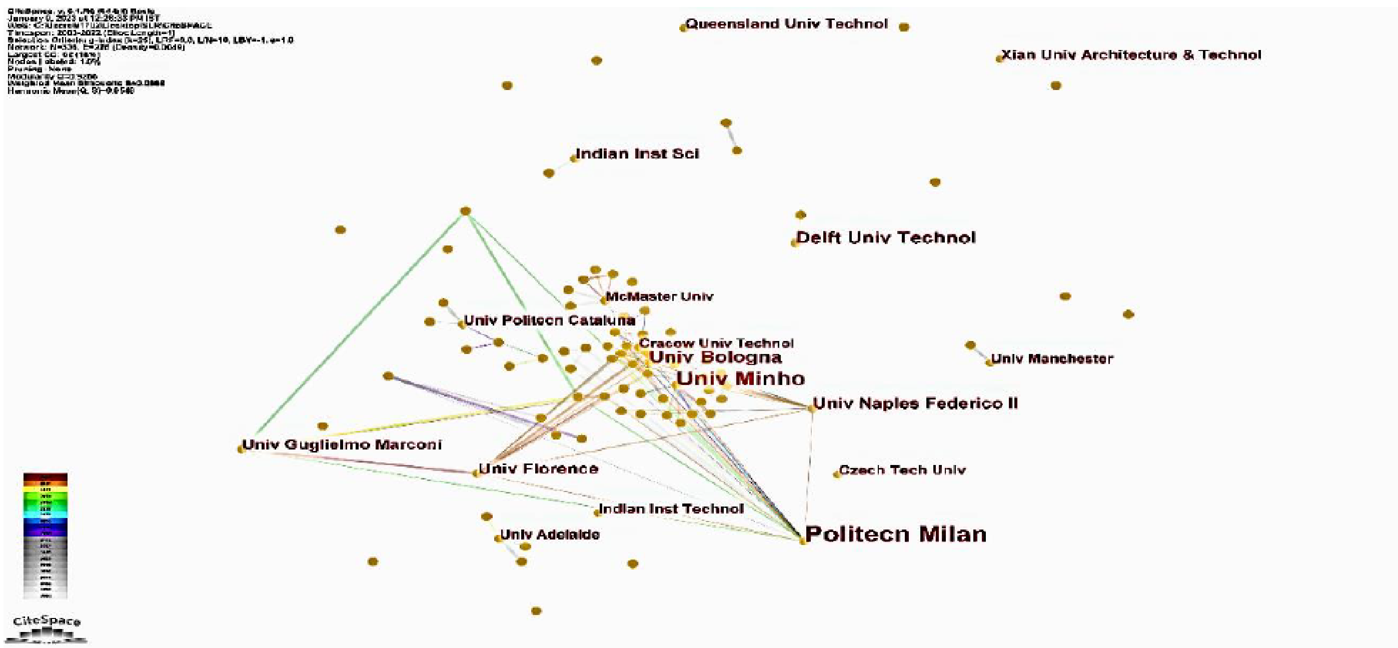


Figure 6: The collaborative institutions network working in the domain.

Table 1 highlighted the precise details of each cluster for the co-citation network. All of the clusters' silhouette scores were very near 1, indicating that there was substantial homogeneity within each cluster. In other words, the clustering results' relevance and reliability have been proven. To characterize the clusters, labels were applied using the LLR method. The biggest size of references is seen in Clusters 0 and 1. With references emerging earlier and still being continuously acknowledged in the literature, Cluster 0's average age of the literature is 2015 and Cluster 1 is 2005 indicating new material as a solution to repair on the rise.

3.5 Co-Vision Network Analysis

3.5.1 Keywords Co-Vision Network Analysis

Keywords that describe the main ideas behind current research in a discipline and indicate its fundamental substance. Given that the node type was "term," noun phrases were retrieved based on the terms in the title, abstract, authors, and publishers. The period was "1 year," and the standard was "Top 10% per slice, up to 100." Pathfinder was the web culling technique used. Figure 7 illustrates the analysis of relationship lines and keyword nodes from the database. The top 20 keywords and their occurrence in the network are detailed in Table 2.

Table 1: The co-citation Clusters summary

Cluster Label	Cluster-ID	Size	Average Year	Silhouette	Alternate Label
Tensile behaviour	0	44	2015	0.861	FRCM composite, strengthening effect
Numerical investigation	1	29	2005	0.992	Numerical investigation, brick type
HDC-masonry composite element	2	23	2014	0.997	HDC-masonry composite element, masonry cylinder
Curved masonry substrate	3	21	2015	0.905	Curved Masonry substrate, jute textile-reinforced mortar
Short PVA fibre	4	15	2017	0.906	Analytical investigation, brick masonry panel
fabric-reinforced cementitious matrix	5	14	2016	0.91	Bond behaviour, brick masonry
interlocking masonry	6	12	2014	0.978	interlocking masonry Evaluation
FRP delamination	7	9	2015	0.968	curve masonry substrate, optical sensor

Table 2: Top Keywords with their number and begin year

Keyword	Number	Begin Year	Keyword	Number	Begin Year
Behaviour	158	2010	Compressive strength	42	2003
Concrete	99	2006	Mechanical property	41	2015
Strength	78	2007	System	40	2015
Wall	78	2008	Brick masonry	37	2004
Performance	68	2010	Mortar	33	2004
Model	59	2009	Masonry wall	28	2011

In the last decade, keywords like behaviour, performance, and model have been frequently used indicating research carried out as an experimental investigation to understand the nature of materials. Concrete has been the second most used term indicating there is comparative analysis in terms of test procedures, and reference models of masonry with concrete. To test the mechanical properties and the base of different tests to determine bond strength by compressive strength justify their mentions in the literature since 2003.

To carry out the cluster analysis of the keywords in the research domain, Citespace was chosen, and the Log Likelihood Rate (LLR) algorithm was used. Based on the feature words accepted by LLR as names of the clusters, major 16 clusters were recognized. Their graph on the timeline with the generated keywords is presented in Figure 8, while Table 3 presents details of the 16 clusters corresponding to their size, label, mean year of occurrence, and a few alternate labels. The detailed information for clusters is presented below:

- Cluster #0 (frcm composite) is the cluster with the second most produced literature i.e., with 36 articles. This cluster started in 2015. The most cited terms of the cluster include frp (56), composite (51), and system (37). The most cited article is “Freeze-thaw effects on the performance of trm-strengthened masonry”. The author proposed an analytical and experimental exploration of the durability of masonry structures reinforced by TRMs [9]. Though the composite behaviour of the material showed deterioration, the freeze-thaw cycle did not affect the performance of the panels. Researchers are inculcating the use of different composites to strengthen old structures; few authors proposed the use of a fibre-reinforced matrix to enhance the mechanical properties of the structures. Most studies include testing tensile strength and conducting the shear test to understand failure behaviour [10–12].

- Cluster #1 (Rendering mortar) is the largest cluster with 40 articles. The cluster began in 2015. The cluster mainly discusses the mechanical properties and compressive strength with its mention 40 and 41 times respectively in literature as the keyword. The cluster highlights the different case studies related to enhancement made in the mortars attributing to the “Reinforcing rammed earth with plant fibres: A case study” article by Koutous A [13]. The authors investigated the performance of rammed earth with additives like cement, barley, and date palms in terms of compression and tensile characteristics. This was concluded that though natural fibres reduced stiffness they overall improved the properties of the earth[14].

- Cluster #2 (Debonding Resistance) is the third cluster with 31 articles. This cluster mainly highlighted the response of the unreinforced masonry components, primarily walls. The different failure mechanisms and fracture patterns are reported by the researchers. They determined the effect of multilayered loading on the URM wall on basis of the macro model and proposed interaction curves [15]. This cluster proposed numerical models to investigate the behaviour of the masonry subjected to yield forces [16].

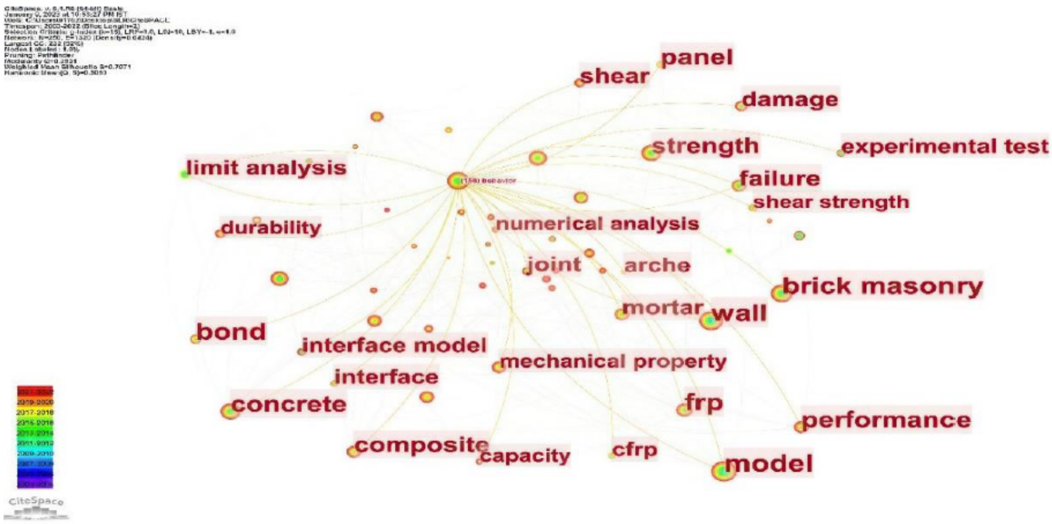


Figure 7: The Keyword Network for bond strength investigation of the substrate with repair material

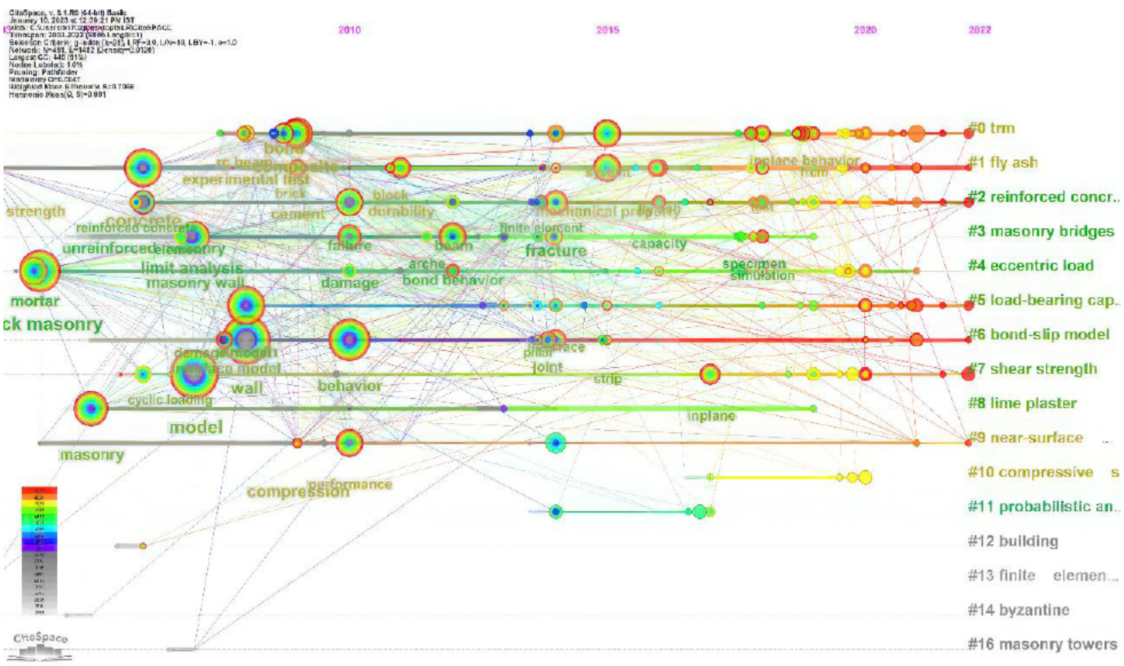


Figure 8: The cluster network of keywords addressing bond strength of materials.

- Cluster #3 (Masonry bridges) also emphasized the preparation of numerical models to examine the effect of repair materials on the components of structures. The authors applied carbon fibre-reinforced polymer reinforcement on the pillars of the masonry bridge to determine debonding mechanism in terms of ductility and friction-cohesive relationship [17].
- Cluster #4 (masonry column) included discussions about brick masonry primarily. The robustness response of the structures when subjected to different environmental impacts is highlighted. Researchers investigated the impact of efflorescence on the structure. They created artificial conditions for the development of efflorescence and subsequently proposed solutions for it [18]. They identified ettringite carbonation as the cause of efflorescence and also discussed its genetics.
- Cluster #5 (composite assemblies) was more closely related to the bond behaviour. It mainly includes "strength", "interface", and "bond strength" as the cited members of the cluster.
- Cluster #6 (a masonry structure) also constitutes articles that investigate the fracture behaviour of reinforcement to enhance the strength of the masonry structures [19]. This cluster also suggests analyzing the micromechanical behaviour of the structure as joints, cracks, and voids can complicate its study [20, 21].
- Cluster #7 (concrete masonry wall) is also composed of articles proposing the interlocking nature of materials [22, 23].

- Cluster #8 (weathering resistance), Cluster #10 (high temperature) and Cluster #14 (characterization) are related to the durability aspect of the structure. They highlight using various experimental techniques to investigate the physical, chemical, mineralogical, and thermal characteristics of the materials. As the practices to restore and repair historical structures are on the rise, many case studies are conducted to individually determine the properties of the constituent materials for various structures [24–26]. Authors used techniques like XRD, FTIR, and SEM to analyze the historical lime at Hampi, India and showed the presence of aragonite and vaterite as polymorphs of calcite in lime. Similarly, Hornikova et al. carried out a study for the physical, thermal, hygral, and mechanical properties of cementitious composites using experimental setups for elevated temperature conditions. They observed that elevated temperature compressive strength remained constant only the gas permeability enhanced for all the composites [27].

- Cluster #11 (sensitivity analysis) suggests numerical techniques to understand the effect of material parameters. Researchers prepared a micromechanical Finite element model for concrete masonry and used simulations like Monte Carlo to perform sensitivity analysis for the assessment of parameter effects [28].

- Cluster #12 (dynamic investigation) also underlined the application of numerical methods for parameter identification.

- Cluster #13 (Quality Control) suggests improvised techniques like infrared imaging for characterization. Starnes et al. proposed a study of the woven fabrics embedded in concrete to enhance their strength with the use of infrared thermography [29]. He employed both controlled-flaw experiments and FE techniques and was able to derive good agreement in the results. This gives a new dimension to the different characterization techniques for structures to understand their constituent properties [30]. The detailed information for the clusters identified in the keyword network, including their size, silhouette scores, alternate labels, and average years of occurrence, are summarized in Table 3. This table provides a comprehensive overview of the 16 major clusters recognized in the study, offering insights into the key themes and trends in the research domain.

3.5.2 Analysis based on Keyword Burst

This investigation used a burst detection of keywords using an algorithm built into the software to better classify research areas in the subject, and the findings are displayed in Figure 9. There were 10 burst keywords discovered, along with their burst strength, start year, end year, and duration. The longest-lasting term was "limit analysis," which persisted for six years from 2010 to 2016. This was followed by the term "failure" and "masonry wall" which lasted three years, from 2010 to 2013 and 2011 to 2014 respectively. "Concrete and masonry structure" is the most powerful term. This shows that most of the investigation concerning masonry structures is conducted about concrete behaviour.

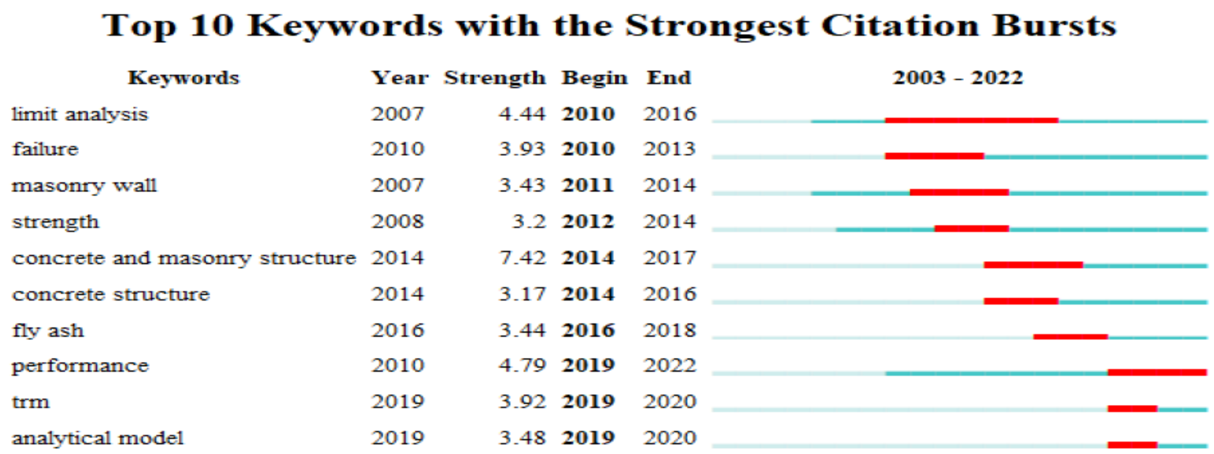


Figure 9: The Keyword with Citations Burst in the articles related to the domain

4 Systematic Review and Summary of Literature

On the basis of the bibliometric analysis presented in the "Visualization results and analysis" segment, a macro-level outline of the existing research in the field is shown, providing an inclusive understanding of the existing state of advance and future aspects of the complete field. The bibliometric analysis technique is still insufficient to provide a tangible overview of the inherent significance of the field. To address this limitation, the present study conducted a content review of the bond between the surface of historical structures with the applied repair material.

Table 3: Clusters for keyword network

Cluster-ID	Cluster Name	Size	Silhouette	Alternate Label	Average Year
1	Rendering mortar	40	0.735	Mechanical properties, gypsum efflorescence	2015
0	frcm composite	36	0.671	frcm composite, ambient vibration testing	2015
2	Debonding resistance	31	0.757	Unreinforced masonry wall, masonry component	2016
3	Masonry bridge	27	0.866	Masonry bridge, CFRP plate	2013
5	Composite assemblies	26	0.764	Mechanical properties, buckling behaviour	2016
6	Masonry structure	24	0.809	Masonry wall, bond-slip behaviour	2013
4	Masonry column	22	0.907	Masonry column, traditional masonry wall	2012
7	Concrete masonry wall	21	0.688	Masonry wall, geometric parameter	2012
9	Of-plane behaviour	13	0.825	Brick masonry, factors assessment	2014
8	Weathering resistance	11	0.925	Weathering resistance, ambient vibration testing	2013
11	Sensitivity analysis	7	0.956	Sensitivity analysis, ambient vibration testing	2016
10	High temperature	5	0.962	High temperature, masonry wall	2019
12	Dynamic investigation	2	0.997	Masonry bell tower, masonry wall	2006
13	Quality control	2	1	Preliminary thermography studies for quality control of concrete structures strengthened with fibre-reinforced polymer composites	2003
14	Characterization	2	0.997	Investigative methods for the characterization of historic mortars - part 1: mineralogical characterization	2005
16	Ambient vibration testing	2	0.993	Ambient vibration testing of historic masonry towers for structural identification and damage assessment	2007

4.1 Mortar in historical structures

One of the most prominent historical materials is masonry. It is a traditional, extensively used, enormously supple, and efficient construction material. It has considerable potential for future development owing to its sturdiness, durability, and appealing reasons. It is an assorted material with components of relatively indefinite geometry and a high mechanical inconsistency. This makes characterizing its constituent materials a subject of great interest with respect to the appropriate intervention techniques. Furthermore, the proper compatibility assessment of the materials is very essential to restore the structure as the bond between composite materials forms the weakest bond [31]. Mortars with diverse types of binders are used in the primeval period for many applications. Bricks or stones bonded with masonry mortar, wall finishing by plaster as well as render, mortar for floor finishing, infill walls comprising of rubble mortar, water conduits casing, etc. This has been observed that there exists great composition disparity in different mortars owing to their geographical location and period of procuring [32]. For about two centuries mud, gypsum, and lime have been the most used binder material, however, gradually their use was reduced with the introduction of natural cement followed by Portland cement which dominates the construction market today. The most ancient binder is mud mortar which can be identified with the use of clay in 6000 BC evident at Catal Huyuk in Turkey. A terrazzo floor at Canjenü in Eastern Turkey laid with lime mortar dates back to 5000 BC. Gypsum is the most used binder in Pharaonic Egypt, in the middle east, Germany, and Paris during the medieval period. In Europe, studies by Adams et al. showed that most Cathedrals near Paris had gypsum as a binder. Though gypsum and mortars are also prominent historical binders research shows that lime mortar supersedes them globally during the period [33]. Previously, the historic mortar characterization was done using traditional wet chemical analysis.

This method provides the result with cumbersome interpretations due to limited knowledge about the characteristics of the constituents of the mortar. However, the present mortar characterization techniques suggest optical microscopy and X-Ray diffraction methods as the initial step for qualitative determination of constituents of the mortar. These methods include analysis techniques namely SEM, FTIR, TGA, etc. [8, 34, 13] The appropriate method depends on the requirement and material availability. The selection also depends on the required intervention for the conservation of ancient structures the requirement is information about the composition of the compatible repair material, causes of degradation of old structures, and the distinction between various building phases with time [15]. The basic parameters that need to be identified for finding the most compatible repair material are the hydraulicity of the binder and the proportion and grading of the aggregate corresponding to the binder and constituents of the mortar [17]. However, in aspects of archaeology, the determining of chronology, and spatial distribution play significant roles to determine socio-economic deductions about raw material and its production. The recent development in the field of characterization involves details about the technique of procuring and processing material by burning, mixing, hydration, and carbonation and identifying mineral composition. Inclusive information about lime and old mortars has been at the interest of researchers for the last decade [4].

4.2 Repair material for historical structures

The major requirement for restoration work is to safeguard original renders and to fill repair the missing part of the structure with suitable mortar. The selection of the appropriate material is critical as if a material like cement is chosen, being strong and impermeable it would further accelerate the deterioration of the structure [35] [18]. The other important factor is durability as the structure is exposed to adverse weather conditions, moisture retention, and salt accumulation. Studies show that durability outweighs other parameters in the case of ancient structures. Therefore, a judicious decision needs to be made while selecting repair material [36].

Mortars are composed of binders, aggregates, and water with required additives. Therefore, varying the compositions of these parameters facilitates achieving the desired mechanical and physical properties. Binders are solely responsible for influencing the properties of fresh as well as hardened mortar [37]. The different mortars used as repair material include Non-hydraulic Lime, which improves the workability of existing mortars with hydraulic binders; Hydraulic lime, which imparts higher strength; Pozzolana lime binders, possessing properties similar to hydraulic lime and most historically used binder; calcium silicate cement, possessing shorter setting time with higher strength; and clay earth mortars, empirically suggesting longer service life. The mortar for repair action depends on the function of the mortar and inhibited masonry typology itself. As the conditions keep changing, it is possible that the intervention with a new repair mortar could be for conditions different from the situation encountered by the mortars used originally [29, 27]. The different requirements to be met for selecting repair material are discussed in detail in Table 4.

4.3 Bond of Materials with Repairs at Interface

The adhesive bond formation is the basic necessity to achieve proper intact between the substrate of the structure and the repair material. Many theories highlight the mechanism of adhesive formation [38]. The first theory is based on mechanical interlocking that occurs with the suitable adhesive material penetrating through the pores on the specimen surface [6]. The second theory takes into account the chemical bonds on the interface. The contact at phases determines bond strength [39]. The transition theory elucidates the formation of the surface at repair material and substrate contact. The adsorption theory states that the adhesive material used for repairs adheres to the wetted surface by interatomic forces [40, 41]. This theory also comprehends the notions of rheology, surface energy, electrostatic and diffusion concepts. It is very difficult to discern the most suitable theory but it can be inferred that the substrate of the structure and repair material bond is majorly dependent on the adhesive capability of the interface, interface roughness by the interlocking of aggregate and many time-varied conditions [24, 25]. Further, these characteristics depend on factors like adhesion governed by the bonding agent, compaction of the sample, roughness, age, and dampness of the repair material surface. The size, shape, and surface preparation of the aggregate influences the interlocking of the aggregate and its friction [26, 42].

There are numerous investigations conducted employing standard tests to measure bond strength [9]. The test is chosen to correspond to the state of stress and required applications like slant shear test for epoxy and latex bonding agents for compression and shear combined state. One of the most important aspects of repairing an old structure is the bond of the material with the substrate. This is because it forms mechanically the weakest linkage between the structure and binding agent [30]. It severely affects the resistance and durability of the masonry. Many studies have reported that the adhesion of the binding agent is more significant than any other mechanical property of the formulation [43]. It has also been concluded that the bond between the mortar joint and unit controls the compressive strength of the structural element rather than the compressive strength of each element individually. The cases reported separation of outer and inner walls owing to weak bond strength [31]. The most prominent seismic failures, i.e., out-of-plane failure causing wall collapse, are directly connected to bond strength. Therefore, this necessitates the need to understand the adhesive tendency of the mortars used in restoration and repair work [32]. The main objective of the mortar in repair work is to connect various components of masonry. To achieve this the tensile strength and adhesive capacity of the material should be focused on rather than other properties. This has also been concluded that the behaviour of the bond does not directly depend on the mechanical characteristics of the binding material [33].

Table 4: Aspects for Selection of Repair Material [28]

Design Aspects for Selection of Repair Material	Details
Functional Requirements	
Conservative Issues	Historical authenticity, Reversibility i.e., removal of old mortar without damage to the structure
Aesthetic Issues	Visual appearance, Match original material in color, texture, etc., Provide a surface for decoration
Structural Issues	The efficiency of flexibility and strength to bear loads
Service Life Issues	Resistance to expected environmental loads, No negative impact on the existing structure, Provide coating to protect underlying masonry
Technical Requirements	
Requirements for renders	Since renders are used in exterior applications, therefore, their service life is impacted by environmental exposure
Requirements for plasters	Plasters are used for interior applications therefore; strength plays a dominant role.
Techniques of application	Suitable consistency of the mortars, Deterrence of premature setting, Measures for elevated temperature, sturdy wind, and relative humidity, The predetermination of regime and curing period
Performance Requirements	
Common Requirements	Not to damage the existing substrate, possess higher strength, Be Flexible and strong in adhesion, low tendency to shrinkage and resistance to environmental issues
Specific Requirements for Renders	Modest water absorption and capacity of drying and possess surface strength, Resistance to soluble, releasable salts and freeze-thaw cycles
Specific Requirements for Plasters	Resistance to soluble, releasable salts and freeze-thaw cycles

The grouting material may be weak in mechanical properties but can be effective and durable. Therefore, bond strength knowledge is very essential for selecting appropriate repair solutions [44–46].The major gaps identified in the study are discussed as follows:

- **Complex Nature of Ancient Mortar:** There are significant disparities in the constituents of ancient mortar [10, 11]. Ancient masonry is intricate, mostly unreinforced or with traditional reinforcement, and often integrated into complex structures. This complexity makes it difficult to separate architectural and structural features.
- **Variations in Modern Masonry:** Modern masonry exhibits substantial disparities in materials and building technology. Traditional and local technologies vary from one country to another [47]. This diversity leads to a lack of awareness and understanding, posing barriers to the proper rehabilitation of structures.
- **Understanding Bond Parameters:** There is a lack of understanding of the significant parameters affecting the bond between mortars and units [12]. Factors such as differential volume changes between the unit and mortar, which can lead to water penetration and separation, are often overlooked. The importance of the durability of bonds is frequently neglected in practice [14]. Similarly, shrinkage, which may reduce the life expectancy of the bond, is also a neglected parameter. There is a need for more research to recognize factors influencing mortar and unit bonds, as most standards and tests are limited to the strength of the bond [48].
- **Missing Documentation:** Significant documents and drawings detailing the renderings used in old structures are often missing [16]. The inadequate intervention in ancient structures, combined with a lack of resources for modern techniques, has led to the loss of novel finishings and rendering [49]. This has created issues related to the incompatibility of old materials with new repair materials due to variations in mechanical and physical characteristics, such as strength, porosity, color, and chemical composition [22, 50].

5 Outlook

Structural strengthening for historical masonry structures using various repair composites has become a subject of interest nowadays, offering a cost-effective solution globally. The systematic Literature Review identified and examined many research barriers, which this study sought to address. Additionally, as shown in Table 4, the 14 clusters may be categorized into each phase of the conceptual model for bond strength investigation for substrate and repair material for masonry structures. This conceptual model is combined with four major research gaps identified in the literature cluster, indicating a significant demand for literature to bridge these gaps and remove obstacles. The first area of weakness is "Limited Finite Element Modeling"; there are three clusters connected to it. Proper numerical investigations aiming at assessing the debonding phenomenon of materials used as reinforcements to masonry structures are needed.

The second gap is the lack of required "understanding of mechanical attributes", highlighted by three clusters. Appropriate knowledge of the bond behaviour of different retrofitting solutions when applied on masonry substrates is crucial. There is a need for proper setups for bond tests, analyzing results in terms of failure modes, curves, strain profiles, and interface laws. "Developing numerical models" is essential to understand the behaviour of loads on the structure and interpret fracture and crack patterns. Four clusters majorly emphasize this aspect. Many researchers are preparing numerical models to validate their experimental investigations related to the bond strength of substrates with repair alternatives. FRP composites are becoming popular as repair composites for masonry structures. Researchers are also trying to understand the performance of these alternatives in brick masonry by employing macro modelling as a finite element technique. The fourth research gap is the demand for the expansion of characterization practices. Four clusters suggest carrying out characterization studies to guide the selection of suitable repair material corresponding to the structural requirements. This study extracted example publications from each literature cluster and compiled data to better identify specific research needs. The overview of the study is presented in Figure 10.

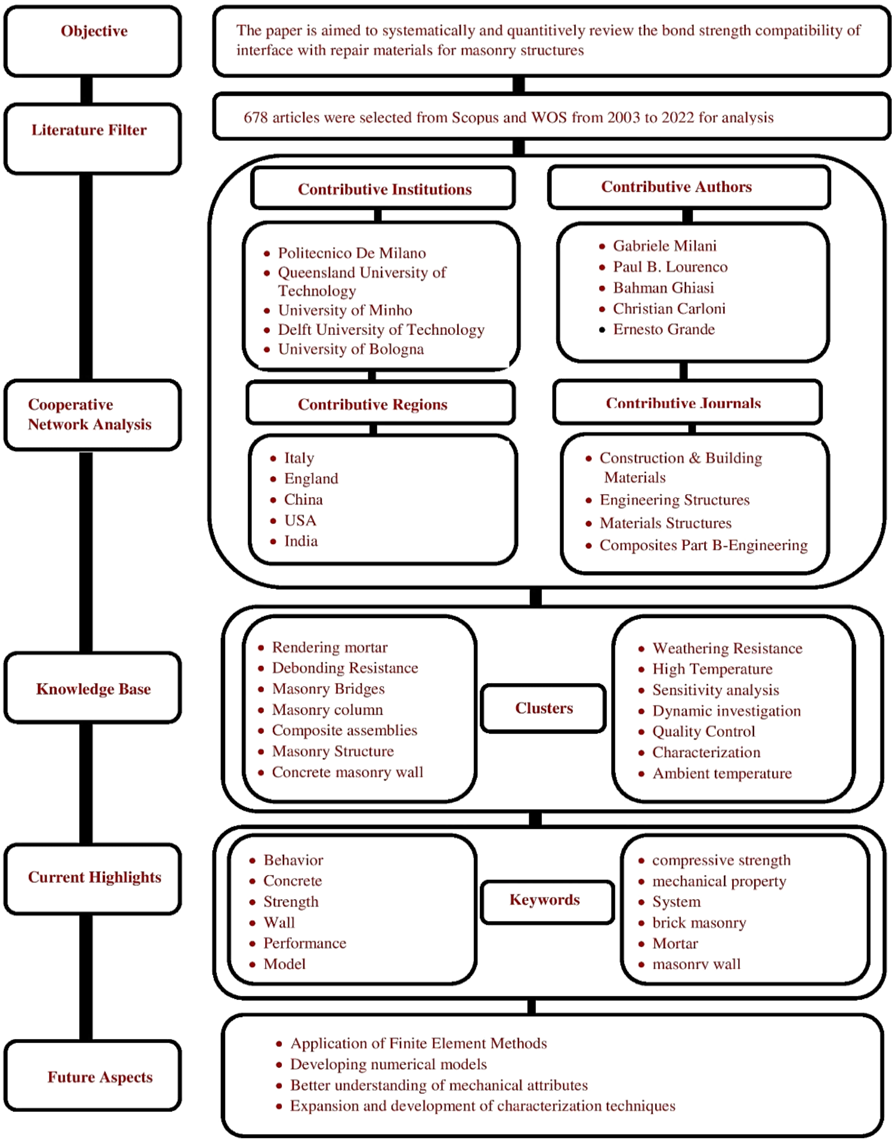


Figure 10: The overview of the systematic literature review.

6 Conclusion

In this study, 678 articles on bond strength investigation of substrate and repair material for masonry structures were analyzed and elaborated using CiteSpace. These articles included published countries, authors, authors' institutions, and papers, keywords, and clusters of keywords. CiteSpace was used to analyze and elaborate on these articles from 2003 to 2022. As a result, this study may highlight areas in need of improvement for investigating the bond strength of the original material with repair materials and offer recommendations for further investigation. It was evident from the bibliometric analysis of the articles in the literature studied that Italy had the most publications worldwide, followed by China, the US, England, and India. This reflects the growing awareness of the practices to retain old structures as epitomes of culture and heritage, with many nations contributing significantly to the domain. Additionally, researchers are exploring alternatives to old renders by characterizing them. According to the contributions and impact of the lead authors and institutions discovered in the analysis network, Gabriele Milano, from Politecnico Di Milano, is the most productive author in the area of masonry materials and its analysis. Three of the top ten publishing institutes are Politecnico Di Milano, the University of Minho, and the University of Bologna. The total collaboration network and publishing output, however, have a lot of space for growth and improvement.

In the present study, the top 10% of co-cited references were analyzed in a time slice that resulted in 527 nodes and 2712 link lines. Most of the references cited majorly proposed preparing a constitutive model to carry out structural analysis. Eight major clusters were recognized based on co-cited references, covering aspects from tensile behaviour and frcm composite to strengthening behaviour, numerical modelling, and analysis of different composite materials. Recent keywords include "limit analysis," "failure," "masonry wall," "strength," and "performance," indicating areas for ongoing academic examination. However, there is a need for further research on terms related to the bonding between different materials and the characterization of old mortars. Future research should be aligned with carrying out Finite Element Modelling for existing masonry structures to analyze and simulate their behaviour, determining the mechanical attributes of materials with various laboratory tests including SEM, XRD, FTIR, TGA, etc., preparing numerical models to predict the bonding tendency for different materials, and characterizing the constituents of the original as well as repair material. The extensive content review suggests that though masonry structures have served us for years, they are deteriorating due to weather conditions and age. The lack of proper documents from previous eras leaves us deprived of original drawings and the proper composition of constituent materials. Therefore, many studies are being carried out to implement modern techniques and devices to monitor the health of structures and detail their composition. The disparity in properties between present and ancient materials affects the practice of repair and rehabilitation. Thus, numerous investigations suggest preparing composite materials that enhance structural properties without compromising aesthetics.

Declaration of Competing Interests

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

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Author Contribution

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