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Subgrade soil stabilization using marine debris: A literature review

Uso de los residuos marinos para estabilizaciones de suelo con fines de pavimentación: Una revisión literaria

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ABSTRACT: The use of different marine residues found in the great biodiversity of the Peruvian coast, such as crushed mollusk shells or fan shells, can be used as mechanical stabilizers for clay soils due to a change in granulometry. In this article, we reviewed 70 research studies indexed in different databases such as Scopus, Scielo, Ebsco, Proquest, Springer Link, and ScienceDirect, whose publication has not exceeded seven years, with the objective of carrying out a systematic review of the use, effect and influence of marine debris as soil stabilizers. For this purpose, the analyses of the mechanical and also physical properties of such mixtures in different marine debris were reviewed compared to the various types of stabilizers currently used. These evaluated results indicate, that the Pacific razor clam shell offers a lower bearing capacity compared to the fan shell when stabilizing clayey soil. However, the shredded output of both types of marine debris can meet the need for clay subgrade stabilization. Based on the review, it was determined that the addition of different types of shredded marine debris reduces water absorption by capillarity, increasing the resistance and bearing capacity of the soil.

RESUMEN: El uso de los diferentes residuos marinos que se encuentran en la gran biodiversidad de todo el litoral peruano como es el caso de la concha de moluscos o concha de abanico trituradas, que pueden ser utilizadas como estabilizadores mecánicos para suelos arcillosos por cambio de granulometría. En este documento se revisaron 70 investigaciones indexadas en las diferentes bases de datos tales como Scopus, Scielo, Ebsco, Proquest, Springer Link y ScienceDirect, cuyo tiempo de antigüedad no excedió los 7 años, teniendo como objetivo realizar una revisión sistemática del uso, efecto e influencia de los residuos marinos como estabilizadores de suelos. Para ello se revisaron los análisis de las propiedades mecánica y también físicas de dichas mezclas en diferentes residuos marinos en comparación con los diversos tipos de estabilizadores que forman parte de la actualidad. Estos resultados evaluados indican en este caso, que la concha pico de pato nos ofrece una menor capacidad de soporte en comparación a la concha de abanico al realizar una estabilización en un suelo arcilloso. Sin embargo, los restos triturados en ambos tipos de residuos marinos logran satisfacer la necesidad de estabilizar la subrasante arcillosa. Finalmente, según la revisión realizada se concluyó que la adición de los diferentes tipos de residuos marinos triturados, logra cumplir con la disminución de la absorción de agua por capilaridad, aumentando la resistencia y capacidad portante del suelo.

1. Introduction

There is currently a high demand for soil stabilization materials with different characteristics in the construction industry, which is one of the reasons why the world's natural resources are decreasing dangerously and drastically, thus generating a problem in our surroundings and affecting the environment.

For this reason, the construction industry is in search of new approaches, with the sole purpose of avoiding the scarcity of these resources [1]. This problem has given rise to studies and research for sustainable development.

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Among the new alternatives to mitigate environmental pollution is the disposal of waste [2], proposing the use of recyclable waste, as is the case of the use of marine waste, used as a material to achieve a stabilization that replaces traditional elements, materials or chemicals and can meet the expected result.

Soil stabilization in general is over the road progress and is a process that constitutes one of the best options from the functional, environmental and economic points of view, accepting the application of in situ soil or borrowing material as a part of the pavement structure [1].

Chemical stabilization using calcined oyster shells (COS), for example, when mixed with steel slag, achieves an effective and efficient stabilization for the improvement of a poor soil subgrade [2].

Due to the composition of these marine residues, alkaline activated, they emerge as a choice of greater durability for the chemical stabilization of the soil, positioning themselves as an idea of geotechnical processes [3].

Likewise, in the different types of soils available in our planet, we can also find soils contaminated by various elements that cause a particularly non-beneficial change for it. This is the case of elements such as Arsenic (As), Lead (Pb) or Copper (Cu) [4].

The use of calcined shells in these types of contaminated soils shows favorable results after periodic treatment of the soil, changing the properties of these contaminating materials and therefore causing an improvement, because of an evident decrease in soil leachability [4].

It is important to ensure that shell materials are free of clay, organic matter, flint or other materials that may be detrimental to the strength or performance of the subgrade [5].

Different studies have led to the use of diverse types of conventional elements, [6]. Some results lead to the use of lime and cement, as well as the most commonly used additives such as Consolid444 + Solidry [6].

These elements studied as alternatives for soil stabilization show an improvement in the mechanical and expansive properties, having as characteristics the improvement in its compaction and resistance [7]. However, the mass production of these new stabilizing additives creates industrial pollution constantly growing worldwide [8].

Each of these methods evaluates surface runoff in pavements, such as rigid and flexible pavements or those made of soil-cement pavers, considering factors with displacement on the surface and taking into account their roughness, obtaining semi-permeable pavements in the dimensions to be used. [9].

2. Methodology

In this review article, the search procedures used were electronic research through the correct use of databases, including Scopus, Scielo, Ebsco, Proquest, ScienceDirect, and SpringerLink.

The following words "soil stabilization", and "mollusk shell", were used as specialized search criteria and filtering the results, considering as one of the main measures the references extracted from the selected articles to understand their use in soil stabilization.

From the electronic search results, only those referring to the corresponding topic were filtered, giving a total of 70 articles of different studies on the use of marine waste. The shells of different mollusks and their characteristics were selected; a correlation of all the results, different opinions and respective conclusions of the different authors were extracted and elaborated for the preparation of the following article.

For more details, Table 1 shows the distribution of the articles considering the database and the year of publication. Table 2 describes the search criteria, filters applied and the selection of articles used in this research, closing on June 9, 2021, which shows the high impact databases that were used to search the information for this research using the Scopus, Scielo, Ebsco, ScienceDirect, Proquest and Springer Link databases, between 2014 and 2021. ScienceDirect, Proquest and Springer Link, between the years 2014 to 2021, the following keywords were used: soil stabilization and mollusk Shell, yielding a total of 128115 manuscripts, then search filters were performed in area such as Engineering, journal of materials in engineering, advances in civil engineering and civil engineering and that are and that are documents such as scientific articles and review articles and related to soil stabilization, obtaining 4092 documents which were selected 70 documents.

3. Results and discussions

This article gathers information from different studies, comparing the results and criteria of the different authors, in order to classify those findings in 6 sections, generating an exchange of opinions on the correct use of different marine wastes in clay soils for future paving.

Table 1 Articles distributed according to database and year of publication

	Year of publication								
Database	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**Total**
Scopus	7	2	5	1	1	3	6	5	30
Scielo	2	2	4		4	2	3	3	18
Ebsco	1	1	1				2	1	6
ScienceDirect		1	1			1			3
Proquest	1	1		2	3	2	1	3	11
SpringerLink		1		1					2

Table 2 Articles distributed according to database and year of publication

Database	Year of search	Keywords	Number of documents search results	Filters applied Subject/Area	Others	New search results	Articles Selected
Scopus	2014- 2021	*Soil stabilization* *Mollusk shell*	8644 2000	Engineering	Article	1862 108	22 8
Scielo	2014- 2021	*Soil stabilization* *Mollusk shell*	100 33	Engineering	Article	43 3	15 3
Ebsco	2014- 2021	*Soil stabilization* *Mollusk shell*	3936 495	Journal of Materials in Civil engineering	Soil stabilization	25 2	6 0
Science Direct	2014- 2021	*Soil stabilization* *Mollusk shell*	66734 10573	Engineering	Review articles	476 38	2 1
Proquest	2014- 2021	*Soil stabilization* *Mollusk shell*	35600 1082	Advances in Civil engineering	-	267 2	10 1
Springer Link	2014- 2021	*Soil stabilization* *Mollusk shell*	23045 6993	Civil Engineering	Article	1259 38	1 1
		Total	128115			4092	70

Source: Own elaboration

There are numerous parameters and conditions involved in the design of the construction of new roads, such as the material and the characteristics of the soil, which are fundamental factors in the design of pavements. When the soils are clayey, which is very frequent, it is necessary to stabilize them. [10].

3.1 Contamination in clay soils

The improvement of fine soils is one of the challenges that geotechnical engineering faces today. This is because such materials have low shear strength and experience large deformations during loading processes [11], especially in dispersive clays, which in the presence of relatively pure and still water, cause erosion and other soil instability problems [12].

Clay improvement techniques are commonly used for the design and construction of roads, embankments, buildings, aqueducts and sewers; [13] always seeking to obtain an optimal soil for work and mitigate soil erosion, based mainly on the protection and maintenance of roughness and surface cover [14].

The conservation of road projects, and the attenuation of dust produced by each vehicle that travels on this road design, are of interest to the industrial sector, which are always essential in looking for the care and protection of the environment [15].

Therefore, it is necessary to carry out studies that can contribute not only to reducing the environmental impact, but also to saving natural mineral reserves [16].

The subgrade of a road, in general, is a fundamental part of it, so that if it collapses, the pavement will also collapse [17]. Similarly, when designing subgrades in soft compressible soils, it is suggested to use a construction material of high porosity and low volumetric weight to avoid excessive settlements [18].

Therefore, one of its evaluation parameters will depend on the bearing capacity or resistance to shear deformation under traffic loads [19]. For this reason, the organic content of some clay soils makes them a very problematic soil for road construction [20].

In this way, an "active zone" is considered to be an area with a high presence of expansive clay; seasonal fluctuations of humidity cause circumstances of change in volume (it is the cycle of expansion and retraction); this phenomenon is responsible for the collapse of the roads [21] saturated with water and are characterized by low bearing capacity and high compressibility [22].

For this reason, it is essential to find applications that include more recycled material, thereby reducing the amount of waste requiring efficient disposal and preserving natural resources [23].

These clayey soils are usually rigid in the dry state, but lose their stiffness when when they are saturated with water [24].

Several biological materials are suitable for this purpose due to their unique mechanical resistance properties and the unique structures they present, although they are mostly made up of minerals, which, considered in isolation, can be very fragile [25].

However, when associated with organic matrices, they form hybrid composites of a ceramic and a biopolymer with highly organized sections and different microarchitectural structures with extraordinary mechanical properties such as those found in mollusk shells [26]. Shells are remarkable structures of biological origin, with unique shapes and designs, and for some mollusks, properties such as superior fracture toughness, flexural strength and hardness [27]. Because of these characteristics, marine debris can be used as replacement aggregate materials in concrete [28], but mainly as stabilizers for different types of soils, using multiple techniques with great positive results [29].

3.2 Use of marine debris in contaminated soils

There is currently much demand for n cost-effective and environmentally friendly construction practices, using waste from different elements in order to improve some aspects of engineering, from different experimental methods to improve the properties of concrete [30], demonstrating the optimization of the production of environmentally friendly concrete [31], leading to a growing interest in the development of alternatives to the massive use of traditional cementitious in geotechnical applications [32].

In recent years, this rapid progress in stabilization and concrete technology has meant a great evolution in civil engineering [29]. It consists of the increase caused by inexorable environmental damage due to the incalculable amount of natural resources demanded, as well as the pollution produced [33].

Nowadays, contaminated soils generate irreparable damage to the environment and, above all, cause alterations in the soils in which they occur, resulting in a high level of contaminants throughout the soil molecular structure, hosting in it, different particles of external substances that do not benefit the soil [31].

The calcium-based soil stabilization technique has recently attracted the attention of researchers, as such materials can catalyze the occurrence of pozzolanic reactions due to their high SiO_2 and AL_2O_3 content [34].

Similarly, the determination of the modulus of subgrade reaction (ks) is an essential geotechnical design parameter that describes the relationship between stress and the associated settlement of soils [35], these parameters are of great importance for many practical geotechnical and civil engineering applications [36].

Due to this demand and the reduced availability of suitable materials, it has been an increase in the need to use off-spec and "scrap" materials in road construction [37].

In many cases, the use of such materials requires that they undergo some form of improvement [38]; one of the most economical solutions consists in the use of geotextile for soil stabilizations, since geotextile contributes to the enhancement of the CBR by helping its stability [39].

The properties of soils in situ, as organic matter plays a prominent role in contributing to the structural stability of the soil [32]; this allows facilitating construction processes in a certain way, so it is important to find materials that can determine the characteristics of soils in order to reduce costs, be environmentally friendly and in most cases, being able to use and optimally improve the soils that are available [33].

The development manifested is evident with the emergence of new additives and reinforcing fibers that meet the demands of today's civil engineers while making it increasingly possible to use environmentally friendly materials [40].

Another great and better option is the case of subgrade stabilization using an available and unexploited residual material, such as artisanal brick ash [41], or, as another option, the use of marine residues, which emerges as one of the most sustainable alternatives in soil stabilization [3].

As in the case of clay soils, these stabilizing agents produce an ionic commutation in the active fraction of the clay particles, decreasing the electrostatic power of the particles and consequently removing their ability to absorb water [42].

During the studies of heavy material wastes, it was appreciated that marine debris can be used as soil stabilizers, using the technique in combination with lime; after being exposed to the leaching test, the results revealed the increase of PH and where it is recommended for stabilization in soils [27].

3.3 Utilization and processing of oyster shells as marine waste for soil stabilization

There are different chemical stabilizers that offer different results in pavement stabilization, such as Portland cement and styrene-butadiene emulsion [43]. However, in the case of marine debris, they are favorable in terms of cost savings compared to other methods [37].

In shallow marine Holocene, the cultivation of crops has a significant impact on nutrient and energy cycling; in other instances, increased microbial metabolism causes a decrease in dissolved oxygen concentrations [44].

As for concrete, different combustion temperatures are taken into account since they can determine the pozzolanic behavior [19]. Likewise, a study was carried out where soil contaminated with Pb and Cu was stabilized using calcined oyster shells (COS), obtaining this soil sample from a firing range [4].

In addition, analysis of the contractional behavior and flow failure in saturated granular soils is important to understand the behavior of their physical properties [45].

A study was also carried out in which a new treatment mixture was designed for the simultaneous immobilization of As, Cu and Pb in contaminated soils using natural waste materials such as waste oyster shells (WOS) and adding coal mine drainage sludge (CDMS)[4].

The methodology for this work included three phases: sample extraction, evaluation of the properties of the undisturbed samples, soil stabilization and strength analysis of the stabilized samples with selected materials [46].

The samples of the first study, found with two types of soils, were completely mixed in order to have a representative sample of Pb and Cu contaminated soils, obtained by treating waste oyster shells at high temperature by a calcination process [2].

On the other hand, in the second study, the treatments were performed using the U.S. standard sieve size No. 20 (0.85 mm) of calcined oyster shell (COS) and CDMS materials with a curing time of 1 and 28 days. Instead, the immobilization treatment was evaluated using HCl 1-N extraction fluid, while Pb and Cu immobilization treatments were evaluated using HCl 0.1 N extraction fluid based on Korean leaching standards [4].

The stabilization effectiveness of the first study was performed and evaluated in the same way, by extraction with HCl 0.1-N for Pb and Cu, showing a positive result where the leachability of Pb and Cu was significantly reduced, improving the resistance capacity of the soil to this problem [2].

The results of the treatment performed in the second study showed that immobilization of As, Cu and Pb was best achieved using a combination mixture of 10% by weight of COS and 10% by weight of CMDS. This treatment mixture was very effective and resulted in superior leachability reductions for all three target contaminants (> 93% for As and> 99% for Cu and Pb) over a 28-day curing period [4].

This research promotes the increase of slope gradients in downstream waters, either in saturated or partially saturated states with the incorporation of hydraulic conductivity curves in soils, for the engineering improvement of soils, a process suitable for its use in the different pavement capabilities [47], obtaining the possibility of having slopes in unsaturated soils and with good slope stability in dams [48].

The purpose of this research is to propose the use of pavements focused on flooding and asphalt pavement detachments, both for flexible and semi-rigid pavements; the use will consist of 70% of asphalt pavement and 30% of permeable concrete, with the purpose of extending the asphalt lifetime [49].

3.4 Use and processing of periwinkle shells as a marine residue for soil stabilization

As a result of a study conducted on soil stabilization with cement and periwinkle, both materials were analyzed in laboratories in order to evaluate the effect of ERC and PSA on the stabilization of two types of soils (A and B), to be subsequently used as a pavement layer [50].

The study of the effects of periwinkle shell ash (PSA) in a lime- stabilized soil, subjected to CBR and SCP tests, was carried out and the results were favorable since they increased considerably [51].

When evaluating the PSA study, microstructural analysis with SEM was used, identifying the morphological changes and the properties of the stabilized soil. The improvement in the resistance of both soils was obtained through the formation of new compounds generated by the mixture of the mentioned materials [50].

The samples for this study were taken from natural soils with the objective of identifying and classifying, and then being mixed with lime with percentages of (2% to 10%). They were subjected to CBR and SCP tests demonstrating that the use of this mixture works positively for soil stabilization [51].

This study shows us the impact that temperature and fluvial precipitation can have on soil organic matter (SOM), as well as the great transformation and increase of soil organic carbon, which is a significant contribution to the improvement of soils in different places with high phreatic zone [52], due to the fact that water influences the behavior of pavement structures, decreasing and affecting the resistance of its materials, and even inducing pressures to the point of destroying the wearing course [53].

The study of quaternary ammonium salts as preservatives for soil stabilization in road subgrade shows that in different types of soils such as A-6 or A-7 (according to AASTHO), it has been considered an effective stabilization since the resistance in loam soils increased to 100%, with a good correlation between CBR [54].

A study of soil classification systems such as AASHTO and SUCS was carried out, knowing that both are based on the analysis of quaternary ammonium salts and are indispensable in the characterization of soils [55].

During tillage studies that generate changes in soil properties, particles, structure and content, considering as an objective the evaluation of the Atterberg limits the DTP and OM content for soils under traditional tillage (TL), obtaining good results of such test and recommending a better quality and disposition of the OM, with respect to the matrices of soil minerals [56].

3.5 Use and processing of oyster shells in other types of soils, with different characteristics

Lateritic Soils

This type of soil is mainly characterized by containing a component called "laterite", which is a highly degraded material and is abundant in secondary oxides of iron, aluminum or both [51].

These soils are formed in warm and humid tropical regions with an average annual rainfall of 1200 mm and a daily temperature above 25 ° C [51].

A study was carried out to verify the effect of oyster shell ash (OSA) on the geotechnical properties of lateritic soil. As part of the procedure, lateritic soil treated with up to 15% OSA was used in the laboratory [57].

The laboratory result shows an evident decrease in the maximum dry density (MDD) and an increase in the optimum moisture content (OMC). The same was true for the compressive strength values [57].

The runoff coefficient (C), defined as the ratio between runoff and precipitated volumes, is used to evaluate the efficiency of the pavement (capacity to reduce peak flow and promote infiltration) [58].

This study and several other studies carried out with marine residues show that OSA can be used in a very beneficial way in the improvement of warm and lateritic soils [50].

Similarly, the stabilization of OSA with a mixture of lime or cement in deficient lateritic soils is recommended for use in road construction. [57], taking into account the endometrial tests of clay samples in both high and medium compacted activity at different densities and humidities, with the objective to optimize wall thickness and cost [59].

It is equally important to perform the correct triaxial tests that allow drawing resistance lines to evaluate the action of the stabilizer [60].

Contaminated soils in aquatic environments

On the planet, there are different types of pollution in different natural environments; one of them is heavy metal pollution, which has always been a serious environmental problem worldwide [61].

On the other hand, the world's growing population, especially in developing nations, has led to increased demand for roads and housing [62].

In recent years, globally around the world, a generation and accumulation of bio-waste has been created, which has also resulted in a series of environmental contamination of equal magnitude [63]. This soil and leachate commonly show permissible metal contents in accordance with permitted environmental standards [64].

Likewise, hydrocarbon contamination also causes serious environmental damage and problems to human health; therefore, as a solution, several techniques have been presented to friendly help the environment [65].

Their characteristics. This is one of the techniques used for soil improvement, using chemical substances that modify its characteristics [66], improving its behavior and bearing capacity (CBR or MR) [67].

However, these traditional methods and the incalculable demographic increase, as well as the impacts that are produced in the environment, become contaminations in the long term, which are not directly visualized at a determined time, generating a new environmental problem if the necessary care is not taken [61].

In this study, waste oyster shell was applied as a kind of biogenic carbonate material for the removal of Pb in an aquatic environment and, in addition, as a remediation agent for the stabilization of metals in contaminated river sediment [61].

After a treatment was performed in a leaching procedure, the Pb concentration was reduced from 810.7 to 108.6 μg/L. Therefore, this demonstrates the potential of using oyster shell waste as an adsorbent and amendment agent for stabilization in contaminated aquatic systems [61].

3.6 Use of marine debris in other cases

The changes made by man in terms of land use cause variations in the properties of soils [68].

For this reason, there are different types of solutions for this type of contamination that occur daily, one of which is chemical stabilization [65], one of the techniques used to improve soils, using chemical substances that modify.

This contaminated soil with toxic metals is a serious environmental problem worldwide, which is why low-cost absorbent materials have attracted the attention of researchers as binders for the stabilization/solidification technique [8].

If the material under study does not meet the requirements of road construction, remote quarry location and climatic conditions, it is necessary that the material installed shortly be replaced given the loss of bearing capacity [69].

A study was conducted evaluating the performance of oyster shell powder (OS), zeolite (Z) and red mud (RM) in the stabilization of heavy metals in three types of heavy metal contaminated soils [8].

The results showed that the OS component (oyster shell powder) bound approximately 82% of Pb and 78% of Cu in the real case scenario. On the other hand, the Z component was very effective in stabilizing Pb in highly contaminated artificial soils (> 50% Pb) at lower doses than OS. The RM component, on the other hand, was not effective in stabilizing metals in soils obtained from contaminated sites [8].

The outcomes of this study suggest that OS is the best low-cost adsorbent material to stabilize soils contaminated with toxic metals considered in the study [8].

Improving the properties of weak soils in terms of strength, durability and cost is the key from an engineering point of view [70].

4. Conclusion

Through the present literature review of the central topic, a clear and convincing understanding of the use of marine debris has been achieved, placing emphasis on its correct use in clay soil stabilization for paving purposes; Accordingly, based on the results and opinions of the different authors and their researches found on the topic, the following conclusions have been reached:

- The use of marine debris as the only stabilizer in clay soils achieves the main purpose, an increase in the bearing capacity of the treated soil; however, the result is not as effective compared to a mixture of these same recycled marine debris with other components that reinforce the result, such as steel slag or coal mine drainage sludge.
- The result of the first study, which was conducted under the treatment of discarded oyster shells, showed a positive result by clearly reducing the leachability of the soil and increasing the resistance capacity of the treated soil.
- Study number two, on the other hand, shows a result of mixing calcined oyster shell residues with CDMS material, obtaining a very effective treatment, decreasing leachability in a superior way compared to the use of only oyster shell as a stabilization material.
- The use of periwinkle shells in soil stabilization is adequate depending on the use given when mixed with other agents such as lime, thus improving the resistance of the treated soil through the formation of new compounds generated by the mixture of both stabilizing agents.
- The use of waste or marine debris as stabilizers, due to the properties they present, can be feasibly used in different types of environments, and is very effective in warm places with daily temperatures above 25° C.

- The effect of oyster shell ash in these hot climates, which have lateritic soils, can be used in a very beneficial way when it is accompanied by a mixture of lime or cement that improves the strength of the soil and consequently improves its use in road construction.
- Contaminated soils in aquatic environments can be treated by a leaching procedure by applying waste oyster shells as a type of biogenic carbonate material for removal and, in addition, as a remediation agent for the stabilization of metals in the contaminated river sediment.
- The studies show as a result that within the marine waste, oyster and periwinkle shells are the best low- cost adsorbent materials to stabilize soils contaminated with toxic metals considered in the study, taking into account the benefits that these materials produce in the soil to be treated.
- Marine residues can become excellent stabilizers, having in mind the treatment and the process treated together with the soil, becoming an economically beneficial product with positive results in different environments, but with greater effectiveness in very warm soils.

5. Declaration of competing interest

We declare that we have no significant competing interests, including financial or non-financial, professional, or personal interests interfering with the full and objective presentation of the work described in this manuscript.

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8. Author contributions

In the present work, the author J. Aguilar, contributed with the original idea, responsible for the development and contributing with the writing of the article contributing 50%. The authors, I. Díaz and J. Malpartida, developed the introduction, information gathering and coordination of all activities by 50%. Finally, S. Muñoz was the one who directed and gave the necessary guidelines to efficiently prepare this article.

9. Data availabity statement

For this research, data were collected electronically through the different databases, taking into account a time of no more than 7 years, with the closing date of the search being June 19, 2021.

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