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Review

A Bibliometric-Statistical Review of Organic Residues as Cementitious Building Materials

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Abstract: Climate deterioration and environmental pollution has been widely studied by a wide scientific community. The effects of the ecosystem deterioration impacts directly to human activities. In this scenario, the building industry has increased the pressure on proposing new materials to replace the cementicious component and natural resources (water, sand, gravel, and limestone) on mortar and concrete to reverse this trend. To this end, organic residues can offer opportunities as an available alternative for construction applications. Therefore, this paper aims to broaden the scope of research in this field by investigating the potential use of organic residues as cementicious building material based on bibliometric-statistical analysis using scientific information. A preliminary bibliometric analysis using VOSviewer was carried out to define the keywords co-ocurrence from Scopus database. Type of organic material, constructive use, and its properties (physicochemical, mechanical, and thermal) were extracted from scientific publications. Then, a systematic analysis criteria was defined to limit the scope of the study. Finally, statistical variance analysis and multiple correlation for identifying constructive application were applied. From the co-ocurrence analysis of keywords, we determined that 54% of the selected scientific publications were closely related to the scope of this study. State-of-the-art study established that related researches grew exponentially at a rate of about 30%/year. Moreover, scientific publications reported the use of a wide variety of organic residues, such as wheat, paper, hemp, rice, wood, molluscs, olive, coconut, among others. Mainly, agricultural residues (82%) with building applications related to structural concrete, mortar, bricks, and blocks, had been evaluated. Physicochemical properties from organic residues (extractives content, lignin content, and density) were correlated to mechanical (compressive, flexural and tensile strength) and thermal properties (thermal conductivity). The identification of the physicochemical properties of the organic residues allow us to predict the mechanical and thermal behavior of the material with residues. In summary, agricultural residues are the most promising organic building material due to their abundance and lignin content, exhibiting better mechanic and thermal properties than any other organic residues.

Keywords: organic residues; cementicious material; mechanical properties; thermal properties

Citation: Yanez, S.; Márquez C.; Valenzuela B.; Villamar-Ayala, C.A. A Bibliometric-Statistical Review of Organic Residues as Cementitious Building Materials. *Buildings* **2022**, *12*, 597. https://doi.org/10.3390/buildings12050597

Academic Editors: Haoxin Li, Cong Ma and Tao Shi

Received: 1 April 2022
Accepted: 24 April 2022
Published: 5 May 2022

1. Introduction

The construction industry plays a fundamental role in the economic growth of each country, and its performance can achieve vital advances in the socio-environmental development [1]. The construction industry is expected to grow at an annual average of 3.9% until 2030, increasing the Growth Development Production (GDP) worldwide by more than one percentage point (14.7% of GDP world) [2]. However, this industry generates 19% of the total greenhouse gas emissions (CO_2-eq), and it is responsible for the consumption of 32% of the global energy related with buildings heating [3]. Therefore, there is an urgent need to refocus of research and policy efforts in light of the climate crisis [4].

In the construction industry, cementicious materials, and specially concrete, are the most used building materials [5]. Moreover, concrete is the second most produced and consumed material, only after water, reaching a global consumption of around 25 billion ton/year [6,7]. From a mechanical point of view, concrete has relatively high mechanical performance under compressive strength (5–60 MPa) when it is compared to other materials. Also, concrete is one of the most versatile materials used in buildings, allowing structural engineers to optimise application requirements with many possible structural configurations. Even more, fresh concrete is easy to mix, place and finish, increasing the workability. In spite of that, the increasing demand of concrete also generates pressure on the aggregates extraction, water and cement production [8,9].

The aggregate/cement/water ratio in the concrete production borders around 3/1/0.5 (volume/volume or *v/v*) depending on the construction application [10]. Fine aggregates 0.08–5 mm and coarse aggregates (>5 mm) that give stiffness to concrete are a natural resource, which is scarce, finite, and highly demanded. In the last 15 years, aggregates extraction have gradually increased, up to 17.5 Gton/year [11–14]. Meanwhile, Portland cement (95% $[3\,CaO \cdot SiO_2 + 2\,CaO \cdot SiO_2 + 3\,CaO \cdot Al_2O_3 + 3\,CaO \cdot Al_2O_3 \cdot Fe_2O_3]$ + 5% $CaSO_4$), which is chemically synthesized from clay/calcareous rocks, has reached production demand close to 4.1 Gton/year [15]. Despite the high mechanical performance and the technological advances in the concrete/cement industry, the production industry of cement is one of the most polluting industries [16,17].

As a building material, concrete generates up to 5% of CO_2-eq [18]. Also, concrete production is responsible for 9% (2 Gton/year) of industrial water withdrawals, corresponding to 1.7% of total world water extraction [12]. As a consequence, it is highly recommended to pursue in the innovation, testing, and analysis of the whole life cyclic assessment of novel construction materials [19]. Reuse of waste materials, the use of fly-ash to replace the cement content in the binder, and the use of organic residues are some of the solutions that can increase the sustainability of the construction industry. In this paper, we focused the bibliometric analysis in organic residues as a potential alternative in cementicious building materials considering mechanical and thermal properties.

2. The Production of Organic Residues

Worldwide, nearly 2010 million ton/year of residues are produced, of which 63% (1260 million ton/year) comes from organic residues [20]. One of the main sources of organic residues generation is the agricultural industry, whose generation has been growing at rates of 1.4%/year, reaching values of up to 37.5 million tons in 2019, value that could increase to 39.5 million ton/year by 2050 [21].

The evolution and generation of organic residues from 1980 to 2019 (by year) and by continent are shown in Figure 1. Here, the organic residues considered were barley, soy, rice husk, corn, wheat, and others. A clear incremental trend in the generation of agricultural residues can be seen during the last 40 years from Figure 1a. When it is separated by continent (Figure 1b), Asia and America show a generation of 45.8% and 29% of the total agricultural residues worldwide, respectively. Indeed, wheat production generates 9.9 million tons of organic residues, while maize, rice, and soy generates 9.3, 9.2 and 4.5 million tons, respectively [21].

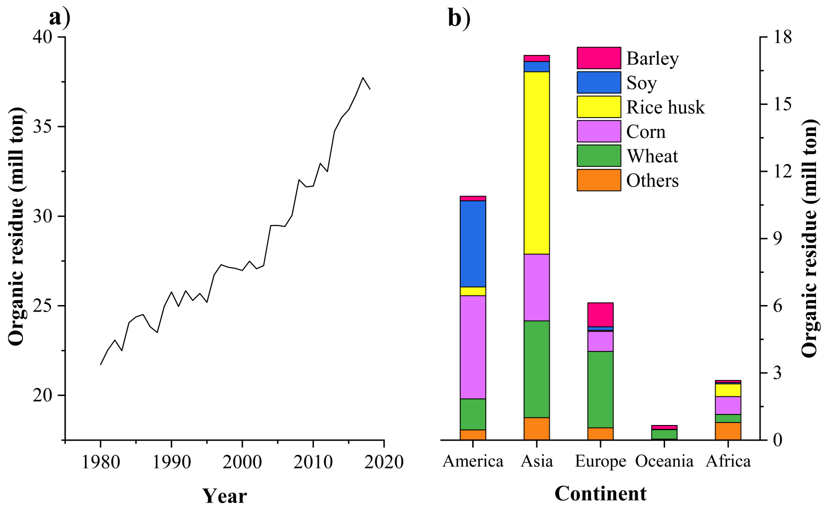


Figure 1. Generation of agricultural residues (1980–2019): (**a**) worldwide; and (**b**) by continent (Source: Figures created by the authors based on [21]).

Several authors have proposed novel techniques and materials to improve the buildings' thermal comfort [22–24]. Typical thermal barriers are placed in walls to prevent the heat to dissipate. Fiberglass, mineral (rock or slag) wool, plastic fibers, or natural fibers are used to insulate stud and joist spacing that is relatively free from obstructions. This solution, however, tends to be relatively inefficient if it is done by non-trained personal. Foam boards, to be placed on outside of wall (usually new construction) or inside of wall (existing homes) are used to insulate concrete walls, but requires specialized skills.

Despite the many techniques available in the market, the thermal performance of insulation is very dependent on proper installation and the skills of the insulation company. Therefore, the thermal performance of the material needs to be improved to avoid additional solutions. On the other hand, thermal improvements using non-degradable materials could give non-inert (toxic) properties to construction wastes (i.e., concrete) that are considered inert during the demolition [25]. Multiple studies have focused on evaluating the alternative use of organic residues as a total or partial replacement, or as an additive to conventional building materials. Indeed, various organic residues, such as wheat, paper, hemp, rice, wood, mollusks, olives, walnuts, coconut, among others have been studied [26–34]. In addition, different constructive manufacturing or replacement of materials (aggregates or cement) using organic residues have been reported, such as concrete, mortar, blocks, bricks, panels and asphalt and also in replacement of materials [35–38].

There is robust bibliography available that deals with the use of organic residues as a total or partial replacement of cement, fine or coarse aggregates in the cement paste and concrete (>100 journals). In general, studies have established reuse of some of these organic materials, towards construction applications with a focus on thermal improvement with a large amount of incorporated organic material (65%, *v/v*). Meanwhile, structural application reports use a lower amount of organic residues in its composition (1%, *v/v*) [39,40]. However, no systematic or statistical analysis on the use of organic residues as an alternative building material has been reported. In this review paper, the use of organic residues as building material is analyzed bibliometrically through a meta-analysis of the state-of-the-art (systematic) and statistical analysis of existing scientific information. Conclusions are presented to correlate the mechanical and thermal properties of the construction material with physicochemical properties of the organic residue. Comparisons on the origin of the organic residue as a potential replacement of cement or aggregate is also presented.

3. Methodology

This section describes the procedure used in the identification of the most suitable database as well as methods of database analysis.

3.1. Database Collection

A preliminary bibliometric analysis was carried out using the scientific journal repository Scopus from Elsevier. The selected repository offers a more comprehensive coverage when compared to Web of Science in fields outside of medicine and physical sciences [41,42]. In order to narrow the potential keywords to be used in the search engine, specific criteria were defined in terms of start date and applications. The keyword used for this preliminary analysis was "organic residue as building material". This search generated 654 results (scientific publications). Additional documents were excluded from this search based on the documentation type. For instance, short surveys, notes, reports, and erratas were not considered.

After the bibliometric analysis using Scopus database, a more specific analysis was carried out using Science Direct. The analysis consisted in three different phases. First, an exploring phase was performed to inspect journals while using the same keyword as input in the search engine. This phase is called exploring phase. The final searching process gave 62,893 results, including scientific publications from different topics and knowledge areas.

A second phase, named identification phase, was implemented by using the most compatible journal. This analysis determined that the three journals with the most compatible research topic were Construction and Building Materials (19.8%), Journal of Cleaner Production (3%), and Journal of Science of the Total Environment (1.4%). The percentages given here are the amount of available scientific publications in each selected journal with respect to the total search. The keyword used for this analysis was "organic residue". This phase gave 1448 results (scientific publications). Finally, a third phase called *confirmation phase*, considered the inclusion and exclusion criteria described in Table 1, reaching 158 results (scientific publications).

Table 1. Constraining criteria of bibliometric analysis (confirmation phase).

Criteria Type	Inclusion	Exclusion
Temporality	1992–2020	<1992
Residue type	Organic	Inorganic
Application	Building material	Energy or agriculture
Specific information	Physicochemical, mechanical and/or thermal properties	No information

3.2. Processing Information

In this section, general and specific information were obtained from the confirmation phase described before (158 scientific publications). The general information analysis, as well as the specific information are described in Table 2. For each analysis, the information was processed by objective, factor, variable, and analysis type. On the one hand, preliminary bibliometric analysis used VOSviewer (version 1.6.16, Centre for Science and Technology Studies, Leiden University, The Netherlands) from Scopus database, where a co-occurrence network was performed to analyze the selected keywords (refer to Figure 2a). This technique offers graphic (visual) representation of co-occurrence networks to be visualized and to infer regarding relationships between entities. In this case, the size of each node represents the appearance co-occurrence, and its color represents links that connect different entities related to the topic.

To measure the influence of the organic residue on the potential use as building material, a variance analysis using the two-way ANOVA test was performed to a group of data ($n = 557$) to determine the influence the specific keyword has on the potential use. Factors (type of organic residue and constructive use) and variable (compressive strength) were considered. Normality (Shapiro-Wilks test) and variance homogeneity (Levene test) were previously verified, considering database parametricity. Therefore, parametric (Tukey test) or non-parametric (Kruskal Wallis test) variance analysis were used. Infostat 2020e software for ANOVA analysis and a significance level of 0.05 were used. This software is used for both descriptive statistical and advanced methods of statistical modeling and multivariate analysis. Database is only limited by available memory, admitting ordinal, and nominal variables. Relationship between properties (physicochemical, mechanic, and thermal) were based on multiple correlation analysis. Physicochemical properties, such as density (kg/cm^3), ash content (%, weight/weight or *w/w*), extractive content (%, *w/w*), lignin (%, *w/w*), cellulose (%, *w/w*), hemicellulose (%, *w/w*), moisture content (%, *w/w*), and pH were evaluated. Meanwhile, mechanic properties, such as compressive strength (kgf/cm^2), flexural strength (kgf/cm^2) and tensile strength (kgf/cm^2) were considered. Finally, thermal conductivity was established as thermal property. These properties were evaluated for organic residues and/or compounds (organic residue + traditional building material). Normality (Shapiro-Wilks test) was previously verified, considering database parametricity. Parametric (Pearson test) or non-parametric (Spearman test) multiple correlation were considered as appropriate. Correlation coefficient ($r < 0.5$) and significance ($p < 0.05$) were considered to establish regression trends ($r^2 > 0.5$). OriginPro 2020b (Version 2021, Northampton, MA 01060, United States) software for correlation analysis was used. This software allows performing multivariate correlation analysis with parametric and non-parametric tests, offering summary tables that show correlation and significance coefficients. In addition, it has applications for peak fitting, surface fitting, statistics, and signal processing. It also offers excellent graphing and representation of results.

Table 2. Processing information phases.

Objective	Factor	Variable	Analysis
Bibliometric analysis	Year of publication	Number of scientific publication	Co-ocurrence and state-of-the-art
Residue vs. use	Organic residue and constructive use	Compressive strength	two-way ANOVA
Constructive application	Physicochemical properties (organic residue or compound)	Mechanical properties Thermal properties	Multiple correlation

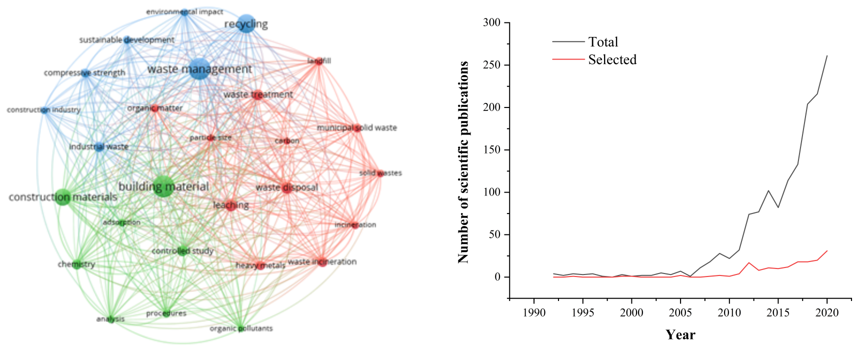
4. Results

4.1. Bibliometric Analysis

Bibliometric analyses conducted in VOSviewer software were employed to synthesize patterns of knowledge production in the organic residues literature. Specific keyword was used in order to analyze the research trend, that have evolved in this knowledge base. The analysis calculates the number of times that an specific keyword has been declared in the review database. Because this analysis scanned the use of organic residues rather than any other co-citation, its results reflect patterns of using organic residues as construction material in the 'broader literature'. Thus, to some extent, this analysis overcomes a limitation of 'traditional citation analysis' limited to a particular document repository (e.g., Scopus, Web of Science).

Co-citation analyses have also been used as the basis for the 'visualization of similarities' (VOS), a powerful approach to network mapping [43]. Co-citation analysis assumes that when two scholars are frequently 'cited together' by other authors, they tend to share a similarity in theoretical perspective [44]. Author co-citation analysis in VOSviewer transforms patterns of author co-citation into a social network map that visualizes similarities among the authors in a particular literature [43]. In this research, bibliometric network to describe the co-occurrence map of the selected database (organic residues as building material) was established. Figure 2a describes the co-occurrence map generated using VOSviewer. The most prevalent keywords, due to their occurrence and represented by their larger size were: building material, waste management, recycling, and construction materials. These keywords are closely related to the topic addressed in this study, and represent 54% of the scientific publications. The keywords that are not directly related to the topic of this study were: incineration, heavy metals, leaching, landfill, adsorption, among others. These keywords correspond to 46% of the total amount of scientific publications. Therefore, there is a significant amount of publications that address the issues raised in this study within the Scopus database, focusing on building materials and the use of residues in construction applications.

Figure 2b shows the temporal evolution of studies (scientific publications) between 1992 and 2020. The solid black line represents the total number of scientific publications ($n = 1416$). The selected database (solid red line) corresponds to articles that fulfilled the previously detailed selection phases, corresponding to 11% of the total ($n = 158$) (see Appendix A which contains all database for the criteria defined in Table 2). From 2007, the number of studies show an annual average growth rate of 28.7%. The year 2020 is the year with the largest number of studies selected with a total of $n = 31$ scientific publications that represents the 12%. Most of the scientific publications were published between 2012 and 2020, representing the 92% of the total database.



(**a**) (**b**)

Figure 2. Bibliometric analysis based on the specific keyword "organic residues as building materials": (**a**) VOSviewer map displaying the most prevalent keywords for $n = 654$; and (**b**) temporal evolution of studies related to organic residues in the construction industry between 1992 and 2020 for $n = 1416$.

The results on organic residues have been categorized and shown in Figure 3. This group of scientific publications were divided depending on the construction implementation or use, the origin of the organic residues, and the type of organic residue. Figure 3a describes the constructive use given to the organic residue in the scientific publication analyzed. The results showed that the organic residues have been used as a replacement of cement powder in mortar and concrete (∼60%), and also as a replacement/reinforcement in blocks and bricks. To a lesser extent, organic residues have been implemented as partial replacement of the constitutive component in insulating panels (12.7%). Figure 3b illustrates the origin of the organic residue studied in this research. In this regard, 81.7% of the scientific publications declare to study residues coming from the agricultural industry, whereas 8.9% comes from the fishing industry, 6.3% from sludge coming from wastewater treatment plants, and 3.2% from the livestock industry. In this paper, the effect of different sources of organic residues on the mechanical/thermal properties was taken into account to establish a statistical relationship with the physicochemical property. These sources correspond to agricultural, farming, fishing, sludge and livestock residues. In order to measure the influence of the type of the organic residue as a potential construction material, we use the average compressive strength of compounds using these organic residues. On the other hand, thermal properties were related to the physicochemical properties of the organic residues from all sources. Since the agricultural industry is the primary source of organic residues, a more detailed analysis of it is made. In Figure 3c, the different types of organic residues used as potential building material from the agricultural industry are shown. The first three major type of agricultural industry are: rice industry that represents the 14.6%, wood industry with the 9.5%, and the paper industry with the 9.5% of the total agricultural residues. These studies constitute 33.5% of all the scientific publications analyzed. Less frequently, there are organic residues from the production of sugar cane (7.6%), oil palm (5.1%), biomass (3.8%), hemp (3.8%), and coconut (3.8%), which have been studied as building material.

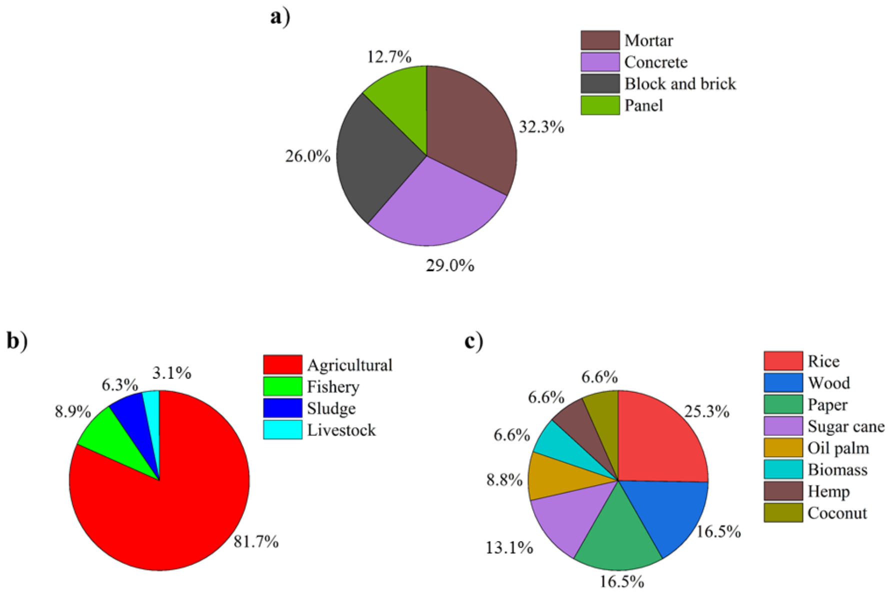


Figure 3. Categorization of organic residues ($n = 158$) by: (**a**) constructive use; (**b**) origin; and (**c**) type of agricultural residue.

In summary, the bibliometric analysis showed that 54% of the scientific publications identified with the specific keyword were related to the potential use of organic residues as building material. In addition, the amount of scientific publications related to the revaluation of residues in construction presented an annual growth rates of ∼30%. Specifically, 32% of the scientific publications evaluated as potential constructive use of organic residues have an specific application in mortar compounds, followed by concrete, blocks and bricks, and panels. Finally, 82% of the scientific publications analyzed used organic residues from the agricultural industry (rice, wood and paper), followed by those from the fishing industry and the wastewater sanitation sector (sludge).

4.2. Influence of Type of Organic Residue on Its Potential Constructive Application

Figure 4 shows the behavior of compressive strength measured for compounds made up of mixed between organic residues and conventional materials (i.e., cement, aggregates) at ranges from 5 to 30% (v/v). Figure 4a displays how the compressive strength varies, according to the different constructive uses ($n = 557$). The average compressive strength of the mortar is 309.4 Kgf/cm^2; while that, concrete, block/brick, and insulating panels report average compressive strengths of 263.8, 142.1, and 40.7 Kgf/cm^2, respectively. Therefore, in terms of constructive application, insulating panels tend to show significantly the least compressive strength ($p < 0.05$) with respect to the other applications.

Figure 4b shows behavior of compressive strengths respect to the origin of the organic residue ($n = 557$). The average compressive strength of compounds using organic residues from livestock industry corresponded to 359.6 Kgf/cm^2, followed by agricultural (215.6 Kgf/cm^2), fishing (211.2 Kgf/cm^2) and finally wastewater sanitation (202.2 Kgf/cm^2). The livestock industry presented significantly the most compressive strengths ($p < 0.05$) with respect to the agricultural, fishing and wastewater sanitation (sludge) industries. Figure 4c represents the values obtained for compressive strength, according to organic residues from agricultural industry ($n = 430$). The most reported agricultural residues were rice, wood, paper, sugar cane, oil palm, hemp, wheat with average compressive strenght of 220, 200, 120, 300, 410, 90, and 205 Kgf/cm^2, respectively. Therefore, there is differences between the compressive strengths depend on the type of agricultural residue. Indeed, oil palm is the only residue that presents the most significant differences ($p < 0.05$) with respect to the other agricultural residues.

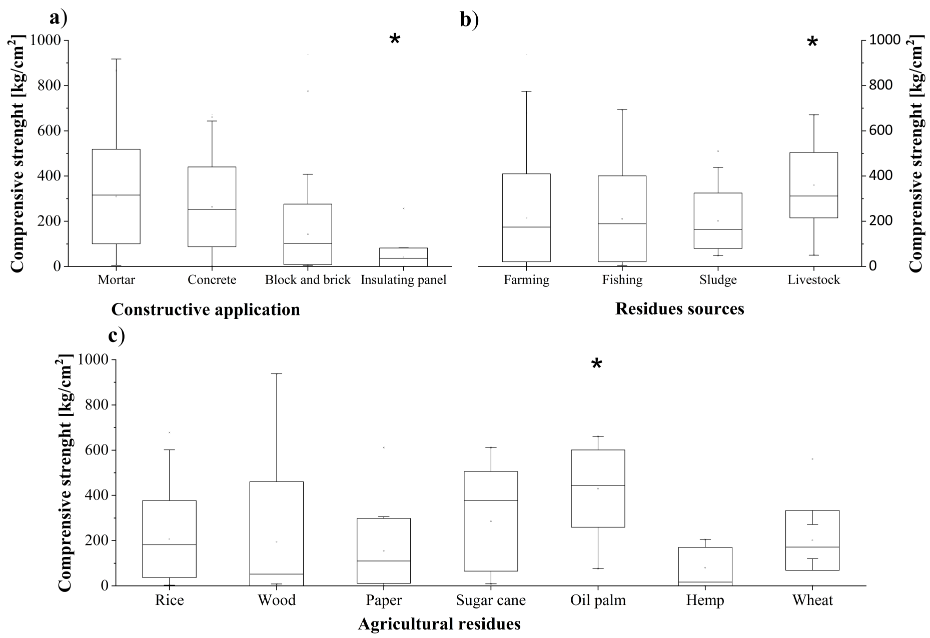


Figure 4. Compressive strength behaviour by (**a**) constructive use; (**b**) industry; and (**c**) agricultural industry. (n = 557). (*) there are significant differences ($p < 0.05$).

In general, a key parameter that characterize any material utilized in the construction industry is the compressive strength. Therefore, the comparison of this universal parameter for classify building materials, allows to establish differences between different materialities. In this research, the influence of type of organic residue on compressive strength (constructive application) was observed. In fact, an average of 287 Kgf/cm^2 was obtained for compounds used as mortar or concrete. Typical values of compresive strengths for mortar and concrete vary between 50.8 and 611.8 Kgf/cm^2 [5]. Therefore, organic residues generate similar compressive strengths to typical. However, compressive strength ranges (0.8–629 Kgf/cm^2) for compounds used as concrete were slightly smaller than mortar. It was observed mainly when organic residues were used as aggregates replacement. This could be improved, if they replace to the cement, thanks to the fact that some organic residues (e.g., sludge ash, 76.2% [$3\,CaO \cdot SiO_2 + 2\,CaO \cdot SiO_2 + 3\,CaO \cdot Al_2O_3 + 3\,CaO \cdot Al_2O_3 \cdot Fe_2O_3$]) have close chemical characteristics to the Portland cement (93–95% [$3\,CaO \cdot SiO_2 + 2\,CaO \cdot SiO_2 + 3\,CaO \cdot Al_2O_3 + 3\,CaO \cdot Al_2O_3 \cdot Fe_2O_3$]) [15,45]. On the other hand, lower compressive strengths can be found in block and brick, as well as in insulating panels, as expected. Typical compressive strengths for blocks, bricks, and insulating panel vary between 37 and 205 Kgf/cm^2, which are similar to reported by compounds in this research [32,46]. Finally, the agricultural residues from the livestock industry presented the most compressive strenght (60–650 Kgf/cm^2), thanks to its similar inorganic chemical composition when the organic material is volatilized ($T > 500$ °C) (e.g., manure ash, 78.4% [$3\,CaO \cdot SiO_2 + 2\,CaO \cdot SiO_2 + 3\,CaO \cdot Al_2O_3 + 3\,CaO \cdot Al_2O_3 \cdot Fe_2O_3$]) to other conventional material as the cement [47]. Therefore, a key factor in determining their constructive use is in its composition.

4.3. Influence of Organic Residue Composition on Its Constructive Application

Table 3 resumes the correlation analysis (Spearman multiple correlation) established between physicochemical (organic residue) and mechanical/thermal (compounds) properties of n = 595 scientific publications. Of these relationships, those that meet the database robustness requirements ($p < 0.05$) and correlation ($r > 0.5$) correspond to 18.7%. Of the latter, the correlations between organic residue (physicochemical properties) with their compounds (mechanical/thermal properties) reached 53% and relationships, being the following: mechanical—physicochemical, mechanical—thermal, physicochemical—physicochemical, physicochemical—mechanical, and physicochemical—thermal. These last two correlations are those of main interest for this research.

The density and lignin content were well correlated with compressive, flexural and tensile strengths (physicochemical—mechanical properties). Meanwhile, the density and extractives content were well correlated with the thermal conductivity (physicochemical—thermal properties).

Table 3. Analysis of correlation and regression between physicochemical, mechanical and thermal properties.

Variable		Correlation Analysis		Regression Analysis		
Dependent	**Independent**	***p*-Value**	***r***	**Coefficients**	**Equation**	**R^2**
Residue density—RD (g/cm^3)	Compressive strength—CS (kg/cm^2)	<0.01	0.67	$a = 29.440 \pm 21.212$ $b = 186.185 \pm 23.246$	$CS = a + b(RD)$	0.40
Residue density—RD (g/cm^3)	Tensile strength—TS (kg/cm^2)	<0.01	0.72	$a = 6.764 \pm 2.315$ $b = 16.124 \pm 1.725$	$TS = a + b(RD)$	0.73
Lignin content—LC (%/, *w/w*)	Flexural strength—FS (kg/cm^2)	<0.01	−0.95	$a = 120.130 \pm 14.214$ $b = -3.295 \pm 0.639$	$FS = a + b(LC)$	0.84
Residue density—RD (g/cm^3)	Thermal conductivity—TC (W/Km)	<0.01	0.54	$a = -0.143 \pm 0.072$ $b = 2.563 \pm 0.261$ $c = -1.691 \pm 0.199$	$TC = a + b(RD) + c(RD)^2$	0.68
Extractives content—EC (%, *w/w*)	Thermal conductivity—TC (W/Km)	0.01	−0.72	$a = 0.100 \pm 0.030$ $b = -0.525 \pm 0.227$ $c = 0.578 \pm 0.146$	$TC = a + b * c^{EC}$	0.89

4.3.1. Physicochemical Properties (Organic Residue) with Respect to Mechanical Properties (Compounds)

Figure 5 shows the linear correlations obtained between the physicochemical properties of the organic residue and the mechanical properties of the compounds. Figure 5a shows the relationship between the residue density (0.08–2.52 g/cm^3) and the compressive strength of the compound (0.09–611.83 kg/cm^2), reaching adequate levels of correlation ($r = 0.669$; $p = 0.001$).

4.3.2. Physicochemical Properties (Organic Residue) with Respect to Thermal Properties (Compound)

Figure 6 shows the non linear correlations between the physicochemical properties of the residue and the thermal properties of the compound. Figure 6a indicates the relationship between the residue density (0.08–1.4 g/cm^3) and the thermal conductivity of the compound (0.05–1.13 W/mK), obtaining adequate correlation indicators ($r = 0.537$; $p = 0.001$). Figure 6b shows the relationship between the extractives content from organic residue (1.5–15.58%), *w/w*) and the thermal conductivity of the compound (0.09–0.33 W/mK), which showed adequate correlations ($r = -0.176$; $p = 0.006$). Therefore, materials made up of organic residues with a density between the ranges 0.08 and 0.25 g/cm^3 and 1.18 and 1.45 g/cm^3 have a lower thermal conductivity (0.05–0.34 W/mK). Whereas, in materials with incorporation of organic residues with high extractives contents (12–15.6%, *w/w*), lower values are also obtained in the thermal conductivity (0.09–0.14 W/mK).

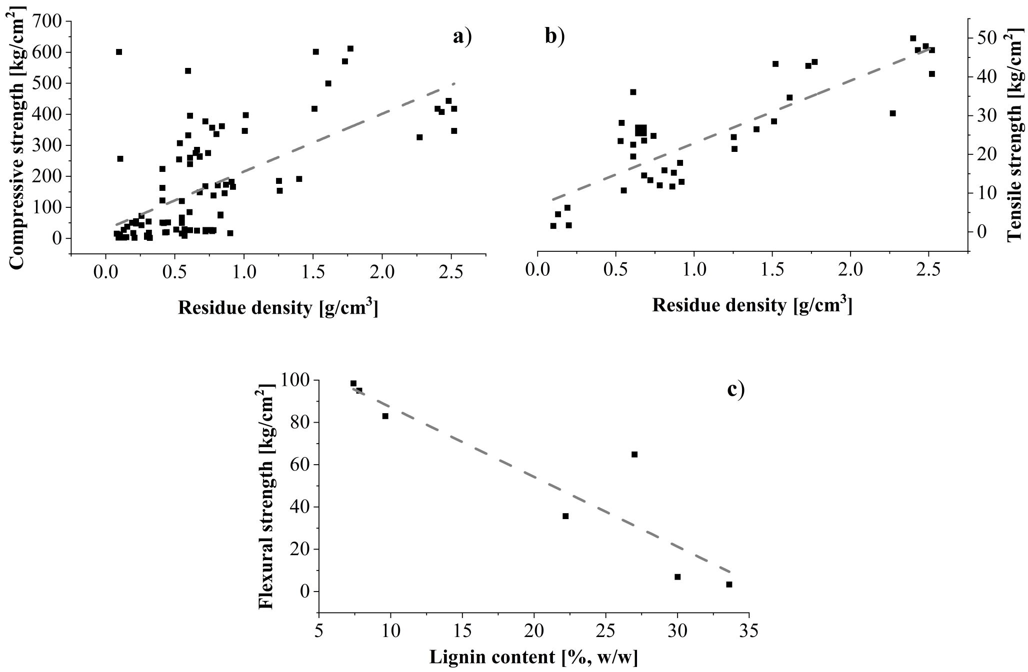


Figure 5. Physicochemical and mechanical properties correlations. (**a**) Residue density-compressive strength; (**b**) Residue density-tensile strength; and, (**c**) Lignin content-flexural strength.

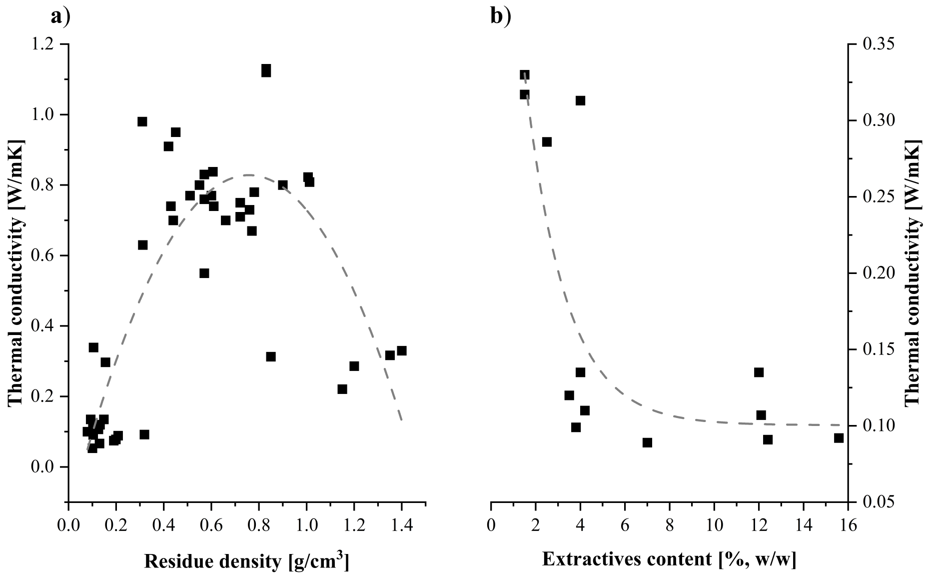


Figure 6. Physicochemical and thermal properties correlations. (**a**) Residue density-thermal conductivity; and (**b**) Extractives content-thermal conductivity.

Thermal conductivity is the physical property that measures the ability of materials to conduct heat through its mass. Therefore, the less the thermal conductivity a material generates, the better insulating properties in construction applications it has. Indeed, conventional building materials, such as cement and aggregates forming concrete reach thermal conductivities up to 1.7 W/mK, being increased up to 2.2 W/mK when water saturation ratio has reached 100%, *v/v* [48]. In this bibliometric analysis, compounds using organic residues (≥0.5%, *v/v*) reached thermal conductivities from 0.1 to 1.9 W/mK. Moreover, the moisture content of these residues (≥70%, *v/v*) increases their density and therefore decreases their insulating properties. Effectively, the obtained polynomial regression shown in Figure 6a displays that this behavior only occurs for densities close to the water density (approx. 1.0 g/cm^3). On the other hand, low thermal conductivity are obtained when densities are greater than 1.0 g/cm^3. This can be explained due to the a greater amount of extractives within the organic residues composition.

The extractives from organic residues are natural polymers, that is, macro molecules formed by monomers joined by covalent bonds that prevents the free flow of electrons. Therefore, a higher extractives content ($\geq$2%, *w/w*) could improve thermal properties, reaching values between 0.35 and 0.09 W/mK (refer to Figure 6b). In specific, non wood biomass offers better thermal conditions than wood biomass, due to its extractives content (5–15%, *w/w*) [49,50].

5. Conclusions

The bibliometric analysis in this engineering sciences field establishes that 54% of the scientific publications that study organic residues and building materials focus on the reuse and revaluation of organic residues, incorporating them as additives or as replacement, total or partial, to the conventional materials (i.e., cement, aggregates, and water). The number of studies that address these issues show an annual growth rate of 30%. Mortar is presented as the most recurrent construction use (32%), followed by concrete, blocks and bricks, and insulating panels. 82% of the organic residues studied come from the agricultural industry. Regarding the results obtained on the compressive strength of the compounds, mortar (309 Kgf/cm^2) is projected as a potential structural constructive use of organic residue with compounds percentages between 5 and 30%), *v/v*. The tensile strength of cement based materials was statistically correlated with materials incorporating organic residues. To measure this mechanical parameter properly, density of the residue was used as a dependent parameter. To this end, the proportion of the variance for the dependent variable in our regression model was interpreted as the R^2 value of 0.73. The residue density is directly related with the extractives content within the vegetable biomass composition. As a consequence, as the extractive content increases, the density of the organic residue increases, and the tensile strength also increases. The opposite outcome is found for organic residues with high moisture content, where density usually decreases. The relationship between the lignin content (dependant variable) of the residue and the flexural strength of the compound (independent variable) was established using a regression analysis as shown in Table 3 and Figure 5c. The proportion of the variance for the dependent variable in the regression model was interpreted as the R^2 value of 0.84, which demonstrate good correlation. From this results, organic residues with lower lignin content (7.4–9.6%, *w/w*), have higher flexural strength (83–99 kg/cm^2). In specific, lignin is an amorphous molecule that contains an internal structure with aliphatic chains (polyphenolic polymer), which gives rigidity to the plant cell wall. Consequently, organic residues from herbaceous biomass (lignin content from hard/soft woods range between 21 and 32%) have better chances of improving flexural properties in compounds. On the other hand, the use in panels (41 Kgf/cm^2) would be the most relevant application for non-structural purposes. The identification of the physicochemical properties of the organic residues allow us to predict the mechanical and thermal behavior that the material composed of this residue will have. The statistical analysis carried out showed adequate levels of correlation ($r > 0.5$, $p < 0.05$) between some physicochemical properties (density and lignin content) of organic residues and mechanical/thermal properties (compressive strength, tensile strength, flexural strength, and thermal conductivity) of the compounds.

Author Contributions: Conceptualization, S.Y. and C.A.V.-A.; methodology, S.Y. and C.A.V.-A.; experimental data acquisition and processing, S.Y., C.M., B.V., and C.A.V.-A.; formal analysis, S.Y., C.M., B.V., and C.A.V.-A.; investigation, S.Y. and C.A.V.-A.; resources, S.Y. and C.A.V.-A.; writing—original draft preparation, S.Y. and C.A.V.-A.; writing—review and editing, S.Y. and C.A.V.-A.; visualization, S.Y. and C.A.V.-A.; project administration, S.Y. and C.A.V.-A.; funding acquisition, S.Y. and C.A.V.-A. All authors have read and agreed to the published version of the manuscript.

Funding: S.Y. acknowledges the financial support from Universidad de Santiago de Chile, Usach, through project DICYT N° 052018YC, Dirección de Investigación Científica y Tecnológica, Dicyt. C.A.V.-A. and S.Y. acknowledge financial support from Universidad de Santiago de Chile, Usach, though project grant DGT-TR2007. C.A.V.-A., C.M. and B.V. acknowledge the financial support from Fondecyt (project grant 11190352).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We want to pay a fair tribute with our work, to all the people who have suffered and died from COVID-19, in addition to the medical staff, for their work and dedication in these difficult times.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. List of References Used in This Review Article

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