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Review Article

A Systematic Review on the Performance Characteristics of Sustainable, Unfired Admixed Soil Blocks for Agricultural and Industrial Waste Management

Tarun Sharma,[1] Sandeep Singh ,[1] Parteek Singh Thind ,[2] Jasgurpreet Singh Chohan ,[3] Raman Kumar ,[3] Shubham Sharma ,[4] Wojciech Kaplonek,[5] Nima Khalilpoor ,[6] and Alibek Issakhov[7]

[1]*Department of Civil Engineering, Chandigarh University, Mohali-140413, Chandigarh, India*
[2]*Department of Civil Engineering, Punjab Engineering College, Chandigarh 160012, India*
[3]*Department of Mechanical Engineering, Chandigarh University, Mohali-140413, Chandigarh, India*
[4]*Deptt. of Mechanical Engg., IKG Punjab Technical University, Kapurthala 144603, India*
[5]*Department of Production Engineering, Faculty of Mechanical Engineering, Koszalin University of Technology, Racławicka 15-17, 75-620 Koszalin, Poland*
[6]*Department of Energy Engineering, Graduate School of the Environment and Energy, Science and Research Branch, Islamic Azad University, Tehran, Iran*
[7]*Faculty of Mechanics and Mathematics, Department of Mathematical and Computer Modelling, Al-Farabi Kazakh National University, Almaty, Kazakhstan*

Correspondence should be addressed to Shubham Sharma; shubhamsharmacsirclri@gmail.com and Nima Khalilpoor; nimakhalilpoor@gmail.com

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Unfired admixed soil blocks are composed of standard soil and a stabilizer or reinforcement material in the form of binder and fiber. This literature review systematically examines the performance characteristics of unfired admixed soil blocks made by using binders such as cement, lime, and other agricultural and industrial wastes available in the form of fibers and ash. A systematic search was carried out on Web of Science and SCOPUS using different keywords, and 313 records were found. After the screening and eligibility process as per PRISMA guidelines, 36 papers were eligible and hence selected to be reviewed and analyzed. This paper examines the performance characteristics of the blocks in terms of physical properties, mechanical properties, durability, microstructural evaluation, statistical analysis, cost analysis, energy consumption, and carbon dioxide emission. It was found that of the total 9 parameters considered for discussion, most of the studies using different admixtures (binder and fibers) in soil blocks were focused on compressive strength testing of blocks, water absorption, and durability by wetting drying cycles. However, other parameters like bulk density, maximum dry density and optimum water content, thermal conductivity, tensile strength, and flexural strength examined in recent studies are also reported in this paper. This systematic review proposes some research problems to be worked on various additional parameters like linear shrinkage, pull out test, erosion test, sorptivity test, porosity, efflorescence, water permeability, freeze/thaw test, and analysis of energy consumption and carbon dioxide emissions during the manufacturing of unfired admixed soil blocks using various binders and fibers for further study which the current literature lacks.

1. Introduction

Soil blocks are the building units that are manufactured by adding optimum water content to the soil of desired quality for achieving maximum density and compressing it using a suitable block-making machine. Block-making machines can be hand-operated or mechanically operated. Earth is abundant with soil and has been used as a source for building material for providing shelters to millions [1]. However, its application is more environmentally friendly in making compacted stabilized soil blocks than the fired earth bricks. The compacted stabilized soil blocks are different from fired earth bricks because it does not require brick kiln for the manufacturing of bricks which creates a lot of pollution. They are composed of soil and stabilizers in the form of binders [2, 3] or fibers, or a combination of both. The unfired admixed soil blocks have the potential to find their various applications in the field of civil engineering in the form of building blocks for the construction of walls, interlocking tiles for pavement, and other structures. The binders used by different authors in this systematic review are cement, lime, sugarcane bagasse ash, rice husk ash, etc. Different types of synthetic and natural fibers are also used by the authors as found during the analysis of papers. This paper systematically examines the effect of the inclusion of different agricultural [4] as well as industrial wastes on the performance properties of unfired admixed soil blocks. Furthermore, this review was selected to check the applicability and feasibility of using some other agricultural waste material and industrial waste material for research and application purposes with a scope for making economic, environment friendly, and light blocks as compared to traditional soil bricks.

2. Methodology

The systematic literature review is the most famous form of literature review, and it presents a clear picture to the researchers in a more transparent manner. This study follows the methodology proposed by PRISMA 2009, as shown in Figure 1. The phases of conducting systematic review are identification of articles, screening of articles as per criteria established, eligibility according to the content of the articles, and inclusion of final articles for the analysis.

2.1. Identification. The identification of articles is made in such a way that it can be reproduced if the search database is given to some other researchers. It also brings transparency to the review study. The articles related to the soil blocks published in the past 15 years, i.e., from 2005 to 2020, were looked at using the advanced search option of the Web of Science (WoS) and SCOPUS databases. The different keywords that were used for searching the relevant articles were "Soil blocks," "Compressed Earth bricks," "Compressed stabilized soil block," "Earth bricks," "Unburnt soil bricks," and "Compressed soil blocks." These specific keywords searching presented 313 papers that were sent to the screening process.

2.2. Screening and Selection Criteria. The identification process was followed by the screening process to select the relevant articles according to the theme. For this process to occur, selection criteria were made, as shown in Table 1. In this stage, duplicate articles were removed, leaving behind 182 records. Furthermore, 97 records were excluded based on the titles of the articles not relevant to the theme, and after reading the abstract of the remaining 85 articles, 27 more were excluded as per selection and rejection criteria, leaving behind58 articles. These 58 articles were sent to the next process of Eligibility. The screening phase, along with three other phases, is shown in Figure 1.

2.3. Eligibility of Full-Text Articles. After the process of screening, the remaining 58 full-text papers were further assessed for eligibility based on the content as per the criteria. All the articles were thoroughly read to check if the article focuses on any one of the physical, mechanical, and durability properties of the soil block.

2.4. Inclusion. The research articles selected for review were focused on the performance characteristics of soil blocks. All those articles focusing on the performance of soil admixed masonry, masonry wall made of soil blocks, and road pavements made of interlocking soil blocks were not included. So, finally, 36 papers were included for analysis.

2.5. Analysis of the Articles. The data of 36 articles selected for analysis were tabulated using Microsoft Excel. The collected data included author's affiliation, year of publication, journal name, publisher's name, binders and fibers used, the mixed proportion of binders, fibers in soil block, and the initial and maximum value of the physical, mechanical, and durability tests conducted on the soil block specimens.

3. Results and Discussion

3.1. Publication Trends. In this section, the author has discussed the publication of articles per year, journal- and publisher-wise distribution of articles, geographic locations of the study conducted, and author's affiliation-wise articles.

3.1.1. Year of Publication. In this section, the articles related to soil blocks published between 2005 and 2020 were taken into consideration. Here, the publication trend of only relevant publications is considered, which were included finally as per inclusion and exclusion criteria. The yearwise publication of the final 36 articles is shown in Figure 2.

It can be noted here that research towards the study of performance characteristics of soil blocks increased in year 2012. The lowest number of relevant publications was found in the initial years, i.e., between 2005 and 2011. However, from year 2012 onwards, a noticeable increase in the number of articles can be seen till year 2018, with a maximum number of articles ($n = 5$) in years 2014, 2015, and 2017. Year 2019 shows 3 relevant articles, and the year 2020 shows 2 relevant articles.

3.1.2. Journal and Publisher. This section shows the classification of relevant published articles ($n = 36$) according to the journal and publisher. There are various journals and publishers in which researchers were interested in publishing their studies. A total of 22 journals and 19 publishers were reported during the data processing of 36 articles, as shown in Figure 3. From Figure 3(a), it can be seen that

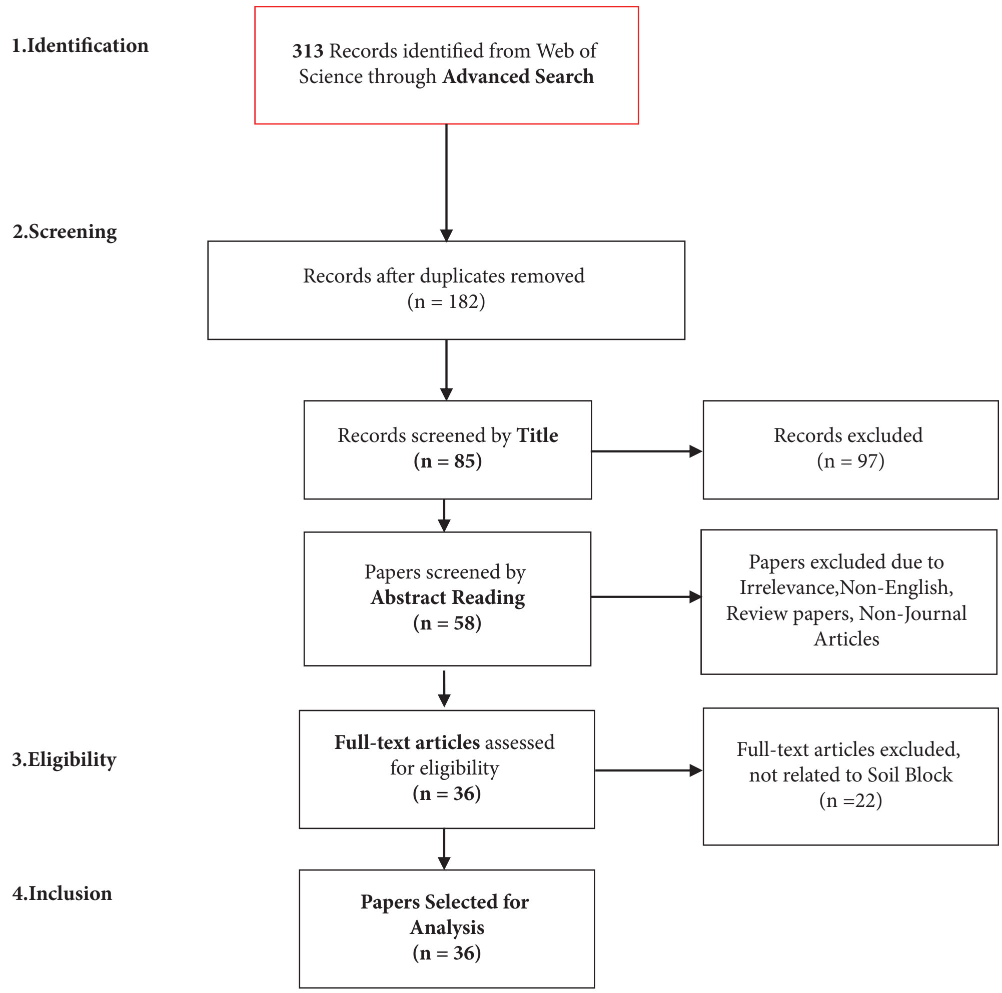

Figure 1: Different phases of the review to select the 36 papers for final analysis as per PRISMA 2009.

Table 1: Inclusion and exclusion criteria used for the selection of relevant papers.

Aspect	Inclusion criteria	Exclusion criteria
Paper type	From journal or conference	Nonjournal article, book chapter, editorial, and comments
Title	If related with the soil block or if the title contains the keywords	If does not have any relation with the soil block or if it does not contain the keywords
Abstract	If abstract addresses testing on soil block or soil bricks or as mentioned in keywords	If abstract does not address testing on soil block or soil bricks or as mentioned in keywords
Language	English	Non-English such as Portuguese, Spanish, Chinese, etc.
Availability of full text	If available	If not available
Content	Focus on physical properties of soil block Focus on mechanical properties of soil block Focus on durability properties of soil block	Focus on testing of masonry wall made using soil blocks Focus on testing of road pavements made using soil blocks Focus on design of block-making machine

Construction and Building Materials was among the topmost opted journals for publishing the articles related to performance characteristics of soil blocks, i.e., 31.25% of the total articles followed by the *Journal of Materials in Civil Engineering and Materials Science Forum*. Figure 3(b) shows that ELSEVIER was among the topmost opted publisher contributing 37.5% of the articles, followed by ASCE and Trans Tech Publications, Switzerland.

3.1.3. Author's Affiliation. It has been observed during data processing that authors from various countries took an interest in the field of soil blocks. The database used for the present study gathers information of articles published in the English language only. This indicates that the majority of articles that are analyzed belong to countries where the English language is primarily used for research and technical reports. Thus, the majority of articles are found in Brazil,

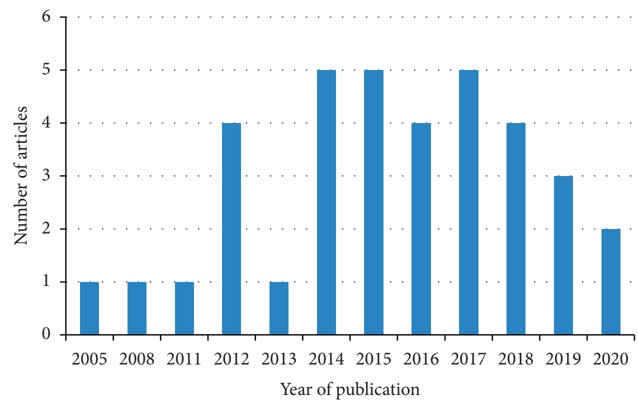

FIGURE 2: Number of articles under review ($n = 36$) published yearwise.

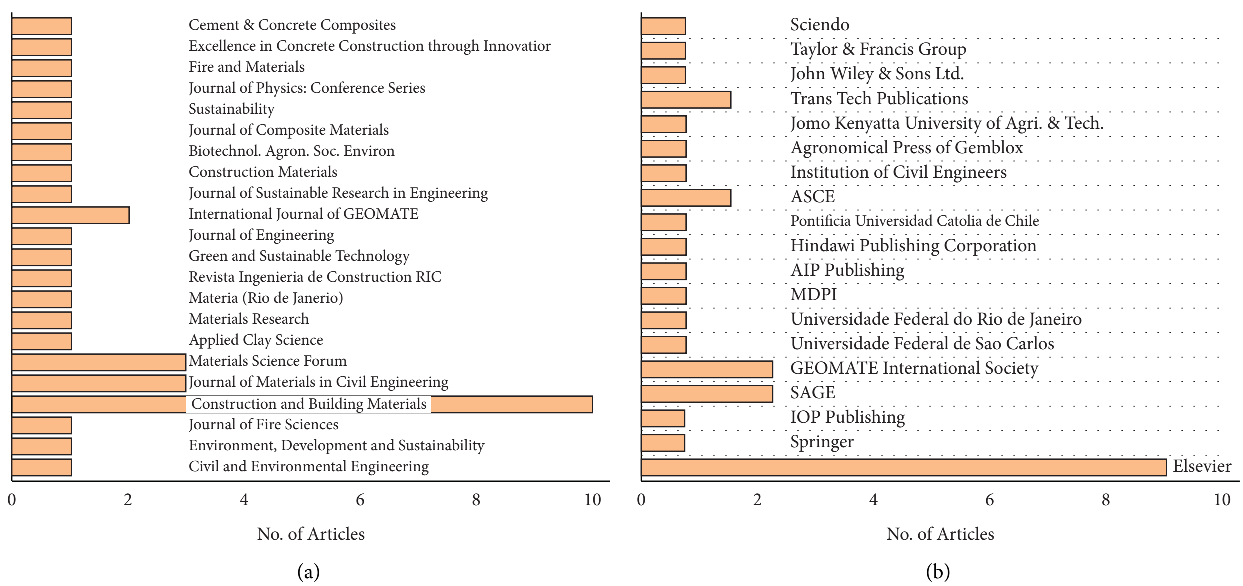

FIGURE 3: Number of relevant articles ($n = 36$) by (a) journals and (b) publishers.

followed by India. The distribution of authors, participating institutes, and countries may vary if articles of other languages are considered. The data were tabulated to classify the articles according to the author's affiliation, as shown in Table 2. It was found that authors from 54 different institutes/universities and 20 different countries had participated in conducting these studies of 36 articles. The maximum numbers of authors related to the published articles have their affiliation with Brazil (22%), followed by India and Thailand.

3.1.4. Geographic Location of Experimentation. After the categorization of articles according to the author's affiliation, the author has reported the distribution of articles according to a continent and country where experiments were carried out, as shown in Figures 4(a) & 4(b). In the case of research papers published in English, India and Brazil are leading in research in constructing admixed soil blocks. These countries have also created various technical codes and standards for the construction of soil blocks [5–7]. However, lead in research does not imply that these countries are prominent users of the admixed blocks.

It was found in some studies that there were six to seven authors in one research paper affiliated to more than two or three countries. Hence, to get an idea of the experiment's location of occurrence or location whose soil was used for making soil stabilized blocks, the author identified the country where experiments were carried out. Figure 4(a) reveals that most of the studies were conducted in Asia (47%), followed by South America (25%) and Africa (17%). North America contributed least with 5%, and no experiment was conducted in Australia as per relevant articles ($n = 36$).

Furthermore, Figure 4(b) shows the countrywise distribution of articles where experiments were conducted. It can be seen that a maximum number of experiments were done in Brazil (22%), followed by India (19%) and Thailand (11%). Experiments were also carried out in Ghana, Malaysia, the USA, Mexico, Oman, China, Philippines, Colombia, Portugal, France, and Indonesia.

Table 2: Number of papers published ($n = 36$) according to the author's institute and country of affiliation.

Reference(s)	Author's affiliation	Country	Number
[8]	King Mongkut's University of Technology Thonburi	Thailand	1
[9]	Kasetsart Univ Chalermphrakiat Sakonnakhon Province Campus	Thailand	1
[10]	Universitas Muhammadiyah Yogyakarta	Indonesia	1
[11]	Université de Toulouse French Regional Laboratory of Public Works	France	1
[12]	Universidade de Brasília Universidade de Aveiro	Brazil Portugal	1
[5]	Universidade Federal de Campina Grande Universidade Federal da Paraíba	Brazil	1
[13]	Grupo de Materiales y Construcción del Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional Instituto Tecnológico de Oaxaca ESFM-IPN Escuela Superior de Física y Matemáticas Universidad de la Sierra Sur	Mexico	1
[14]	Engineering Research Facility Indian Institute of Science, Bangalore	USA (2) India (3)	3
[15]	State University of the Northern Rio de Janeiro Military Institute of Engineering, Praça General Tibúrcio	Brazil	2
[17]	Universidade Federal Rural do Rio de Janeiro University of Wollongong Escola Superior de Propaganda e Marketing	Brazil Australia Brazil	1
[18]	Tshwane University of Technology	South Africa	1
[19]	CUSAT NSS College of Engineering	India	1
[20]	Chiang Mai University	Thailand	1
[6]	University of Portsmouth University of Education Winneba	UK Ghana	3
[25]	Pennsylvania State University	USA	1
[26]	Universidade Católica do Salvador Universidade Federal de Minas Gerais Universidade Federal da Bahia	Brazil	1€
[27]	Tagore Engineering College	India	1
[28]	Universidad de Antioquia UdeA	Colombia	1
[29]	Universiti Tunku Abdul Rahman Universiti Sains Malaysia	Malaysia	1
[30]	Sultan Qaboos University Asian Institute of Technology	Oman Thailand	1
[32]	Xi'an University of Architecture and Technology State Key Laboratory of Green Building in West China Norwegian University of Science and Technology SINTEF Building and Infrastructure	China Norway Norway	1
[23]	JKUAT University of South Wales	Kenya (2) UK (1)	2
[34]	Upper Uruguay Regional Integrated University Federal University of Santa Maria Federal University of Rio Grande do Sul	Brazil	1
[35]	SASTRA Deemed to be University	India	1
[36]	Universidade Estadual do Norte Fluminense Darcy Ribeiro Instituto Militar de Engenharia - IME	Brazil	1
[37]	De La Salle University	Philippines	1
[38]	Nakhon Ratchasima Rajabhat University	Thailand	1
[7]	Polytechnic Institute of Braganca	Portugal	1
[39]	University of Kelaniya	Sri Lanka	1
[40]	SSN College of Engineering Tagore Engineering College	India	1

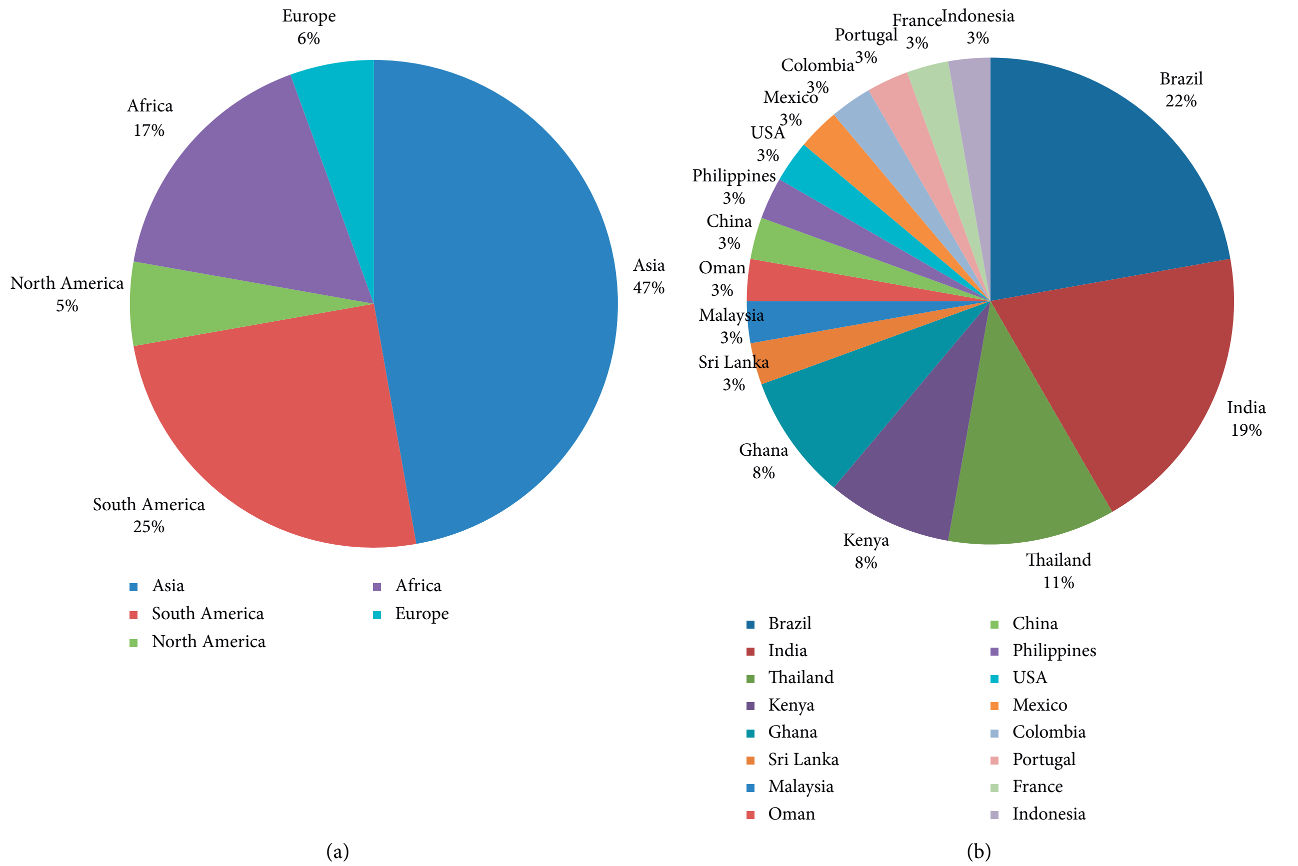

Figure 4: Distribution of relevant published articles ($n = 36$) according to different (a) continents (b) countries.

3.2. Unfired Admixed Soil Block. In this section, the author has discussed the different types of materials, i.e., binders and fibers being used in the making of soil blocks, frequency of the materials present in soil block, and the different types of tests conducted on soil blocks in the relevant articles ($n = 36$).

3.2.1. Manual and Mechanized Production. Table 3 shows the type of specimens used for the testing and the various manufacturing techniques adopted for the production of those blocks, as reported in the articles. The majority of the studies were conducted on solid blocks and hollow blocks, followed by cylindrical and cubic samples. The production equipment can be either manually or mechanically operated. The Ram comprises a box or mold filled with damp soil-cement and a lever-actuated piston that compresses the earth-binder mix for manual action. After the mold has been loaded with the appropriate amount of material, the machine's operator applies 30–45 kg of force to the long handle, resulting in a pressure of around 4–6 MPa on the soil being compressed. The majority of mechanized presses are set to create blocks with a pressure of 10 MPa, which is considered high pressure [11].

For block manufacturing, the soil mixture is placed in the press chamber. When a force is applied to the soil-cement mix, the material is compressed, reducing the amount of voids while increasing the density. The lesser the soil's porosity, the higher its density can be increased. The proctor test can be used to establish the ideal moisture content and Maximum Dry Density relation. The Proctor compaction test is a geotechnical laboratory test that determines the compaction qualities of soil. For a given quantity of compaction energy, the Proctor test reveals the link between optimum moisture content and optimum dry density. With increased compaction force, the optimal moisture content falls [8].

3.2.2. Binders and Fibers. The unfired admixed soil blocks consist of soil and binders or soil and fibers or a mixture of soil, binders, and fibers. So, the articles ($n = 36$) were further analyzed to find the materials used in each article and are presented in Table 4. The author of this study found that twenty-six studies used only binders, while four studies were found which used only fibers, and six studies used both binders and fibers in making soil blocks. It should be considered that the ashes by themselves are not significantly responsible for the stabilizing effect on soil blocks; they have to be combined with lime or cement to trigger the pozzolanic reactions, which leads to an increase in the strength of the blocks.

Table 3: Various manufacturing techniques used.

Ref.	Methods/techniques	Type of block/test specimens
[8]	CIN VA-Ram hand press under a certain amount of pressure (about 1.0 MN/m^2).	Hollow block
[9]	Hydraulic compressing machine.	Interlocking blocks
[10]	Hand-operated compression machine.	Solid block
[11]	The clay is mixed and crushed with sand and then mixed with 10–15% water. The fresh mixture is extruded to form a long cable of material that is cut into bricks of the desired length.	Solid block
[12]	TERSTARAM appro-techno. This machine produces two CEBs at each pressing and has a system to adjust the height and volume of the mold with steel plates.	Solid and smooth blocks
[5]	No machine was described for mixing.	Cylindrical samples
[13]	Motorized hydraulic press where it was compacted by a 24-ton load.	Solid block
[14]	Compacting the mixture at the optimum moisture content in a human-powered mechanical press.	Solid block
[15]	Automatic mixer, self-fitting, soil-cement blocks were fabricated by press-molding.	Hollow block
[16]	CSM mixer, the model V2 Vimaq manual 15-ton press.	Hollow block
[17]	Hydraulic press of 250 tons compression ratio according to NBR 10836 and NBR 10835.	Hollow block
[18]	Manual press with the following characteristics; Lever's arm: 1800 mm, internal dimension of the mold: 300 mm × 150 mm × 100 m, applied force: 1 kN, compression mode: static.	Hollow block
[19]	Molding (compaction) pressure was controlled by a digital compression testing machine, having a capacity of 1000 kN and least count of 100 N. Experiments were carried out for a molding pressure of 1.25–7.5 MPa at 1.25 MPa intervals.	Cylindrical samples
[20]	Hydraulic compressing machine.	Hollow block
[6]	The blocks were made with a pressure gauge hydraulic block-making machine with a constant pressure of 100 bars.	Solid block
[21]	BREPAC block-making machine with a constant pressure of 10 MPa.	Solid block
[22]	The machine is not described in the article. The blocks were cast by controlling the dry density of the blocks.	Solid block
[23]	CINVA-Ram press machine and manually pressed to produce the blocks.	Solid block
[24]	Compacting the mixture at the optimum moisture content in a human-powered mechanical press.	Solid block
[25]	Compaction of the wet mix was done in a heavy-duty steel mold using a test mark CM-500 series compression machine with a maximum compression capacity of 2224 kN.	Solid block
[26]	Manual compaction press (VIMAQ V2).	Solid block
[27]	Same as unconfined compression cylinders for testing soil specimens, the difference being that the sample was cast in the mold prepared for blocks.	Solid block
[28]	The hydraulic model with a capacity of 20 ton.	Solid block
[29]	40 times of hand tapping were performed for each layer with a steel rod. Then, the mold cover was locked, and forming pressure of 10 MPa was applied.	Not mentioned
[30]	A manual press manufactured by the Habitec Center at the Asian Institute of Technology, Thailand.	Hollow block
[31]	Tinius Olsen H50KS machine compressed at 10 MPa pressure.	Cylindrical and cubical samples
[32]	Samples were prepared by using a hydraulic press.	Cubic sample
[33]	CINVA-Ram press machine.	Solid block
[34]	Followed ABNT NBR 10833 and used hydraulic press.	Hollow block
[35]	Blocks were hand pressed at the optimum moisture content.	Solid block
[36]	Hydraulic press, under 15 tons of pressure.	Hollow block
[37]	Manual press using a mechanical molder.	Solid block
[38]	No machine was described for mixing.	Cubic sample
[7]	Hydraulic press and the compaction pressure were controlled and maintained.	Hollow block
[39]	Hydraulic press with compaction at $1.37 \times 109\ \mathrm{N/m^2}$.	Hollow block
[40]	Mix was loaded in the brick press for pressing blocks and molded into standard dimensions.	Not mentioned

3.2.3. Frequency of Binders and Fibers Used. As examined in the articles ($n = 36$) under this review, a total of 33 different types of materials (19 different types of binders and 14 different types of fibers) were used. The binders used were cement, sugarcane bagasse ash, bitumen emulsion, demolition residue, grit, limestone waste, rice husk ash, lime, granite waste, kaolin, Bacillus pasteurii KCTC 3558, green mussel shell powder, construction debris, calcium silicate, limestone residues, fly ash, and Effective Microorganisms (EM). The fibers used in the articles were kraftterra, fibers made out of waste mineral water bottles, fibers made out of waste carry bags, mineral wool waste, sisal fiber, pig hair fiber, bagasse fiber, coconut fiber, oil palm fiber, alkali-resistant glass fiber, polypropylene fiber, banana fiber, jute fiber, and macro synthetic polypropylene fibers "MasterFiber MAC Matrix." Table 5 reveals that articles ($n = 36$) have reportedly used eighty number of times, different binders and fibers in total. Cement was the most widely used binder reported in 26 articles in the making of unfired admixed soil blocks. Sugarcane bagasse ash and rice husk ash were among the most widely used binders in the category of agricultural waste. Among the fibers, both natural and

Table 4: Binders and fibers used for making unfired admixed soil blocks in published papers ($n = 36$).

Ref.	Binders used in the study	Fibers used in the study
[8]	Cement	Coconut fiber
[9]	Cement, sugarcane bagasse ash	
[12]	Cement	Kraftterra
[13]	Cement, sugarcane bagasse ash, hydrated lime	
[14]	Cement	
[17]	Cement, limestone waste, granite waste	
[18]	Cement, grit	
[19]	Cement, kaolin	
[6]	Cement	Fibers of waste mineral water bottles and waste carry bags
[25]	Cement, bacillus pasteurii KCTC 3558, effective microorganisms (EM)	
[33]	Cement	
[37]	Cement, rice husk ash	
[15]	Cement	
[30]	Cement, construction debris	
[32]	Cement, sugarcane bagasse ash	
[23]	Cement	Mineral wool waste, sisal fiber
[34]	Cement, bitumen emulsion, calcium silicate, slaked lime	
[35]	Cement, produced water from oil fields	
[36]	Cement	
[38]	Cement, rice husk ash, lime	
[7]	Cement	
[40]	Cement, limestone residues	
[16]	Cement, green mussel shell powder	Pig hair fibers
[20]	Sugarcane bagasse ash	
[10]	Rice husk ash, lime	
[5]	Demolition residue, lime	
[26]		Bagasse fiber, coconut fiber, oil palm fiber
[27]		Sugarcane bagasse, coconut husk, oil palm fruit
[28]		Sugarcane bagasse, coconut husk, oil palm fruit
[39]		Alkali- resistant glass, polypropylene, banana, and jute
[29]	Cement	Macro synthetic polypropylene fibers, master fiber MAC matrix
[21]	Fly ash, rice husk ash	
[22]	Cement, kaolin	
[24]	Cement, rice husk ash	
[31]	Fly ash, lime	

synthetic fibers were used in different studies in which coconut fiber was the most used fiber reported in 4 articles, followed by bagasse fiber and oil palm fiber.

3.2.4. Types of Tests Conducted. The focus of the author is to study the performance characteristics of unfired admixed soil blocks as reported in the published articles under review. The types of tests were broadly classified into physical properties, mechanical properties, durability properties, microstructural evaluation for microanalysis and failure analysis, energy consumption and CO_2 emissions, statistical analysis, and cost analysis. The author found that a total of 124 tests were carried out on soil blocks, as shown in Table 6. The majority of articles focused on studying mechanical properties, followed by the physical properties of soil blocks. Comparatively, a lesser number of studies were carried out on durability (21 times) and microstructural evaluation (17 times). However, commonly used methods for microstructural evaluation were Scanning Electron Microscopy and X-ray Diffraction tests. Furthermore, the SEM analysis was used for compressed block characterization, and XRD analysis was conducted on raw materials. Moreover, statistical analysis was carried out by authors of 7 articles only, cost analysis by authors of 2 articles, and analysis of energy consumption and CO_2 emissions were carried out by authors of only 1 article out of 36 articles. Also, it can be seen that the most popular tests of soil blocks among all were compressive strength (26 articles) in the mechanical properties section, water absorption (17 articles) in the section of physical properties, and wetting/drying cycle method (7 articles) of durability in the section on durability properties.

3.3. Physical Properties of Soil Blocks. This part of the study focuses on the physical properties of the soil blocks as reported by authors of related articles. The analysis of bulk density, water absorption, thermal conductivity, MDD (Maximum Dry Density), and OMC (Optimum Moisture Content) was carried out after data processing of all the relevant articles as discussed below.

Table 5: Frequency of binders and fibers present in soil block that has been reported in the articles ($n = 36$) reviewed.

Binders	Number of articles	Fibers	Number of articles
Cement	26	Kraftterra	1
Sugarcane bagasse ash	4	Fibers made out of waste mineral water bottles	1
Bitumen emulsion	1	Fibers made out of waste carry bags	1
Demolition residue	1	Mineral wool waste	1
Grit	1	Sisal fiber	1
Limestone waste	1	Pig hair fibers	1
Produced water from oil fields	1	Bagasse fiber	3
Rice husk ash	5	Coconut fiber	4
Sand (nonbinder)	10	Oil palm fiber	3
Lime	6	Alkali-resistant glass	1
Granite waste	1	Polypropylene	1
Kaolin	2	Banana	1
Bacillus pasteurii KCTC 3558	1	Jute	1
Construction debris	1	Macro synthetic polypropylene fibers "MasterFiber MAC matrix"	1
Calcium silicate	1		
Limestone residues	1		
Effective microorganisms (EM)	1		
Green mussel shells powder	1		
Fly ash	2		

3.3.1. Bulk Density. The bulk density of the soil block is measured by the ratio of the mass of the soil block to the volume of the soil block. So, bulk density has a direct relation with the mass of material being used in the soil or with the specific gravity of the material. Generally, fibers have comparatively low specific gravity than the soil, and binders have mostly more specific gravity than soil [32, 38]. This test is performed as per standard codes depending on the location of the study. ASTM C 134-94 and BS 1377: 1990 part 4 are a few of them used in the articles under review. Table 6 presents the influence of binders and fibers content on the bulk density of the soil block as reported in the articles. Bulk density test was carried out only using 7 binders and 9 fibers admixed soil blocks out of a total of 19 different binders and 14 different fibers used in the articles. Those studies (reported in Table 7) using only binders in soil block have seen an increase in bulk density except for the lime, and the ones using only fibers in the soil block saw a decline in bulk density from the initial value. For instance, [28] found a slight decrease in the density of the soil block due to the addition of sisal fiber because of its low specific gravity than the soil, and the addition of mineral wool tends to the formation of hydrated products with cement leading to mechanical resistance and hence increase in density. A similar phenomenon was observed in other studies [8, 35]. Danso et al. [21] reported a decrease in bulk density with an addition of organic fibers such as coconut, jute, banana, polypropylene, and sugarcane bagasse as shown in Table 7. The bulk density values of soil blocks incorporating mineral wool waste and banana, jute fiber was found to be suitable in the category of all fibers as their inclusion did not affect the initial values. The addition of binders like cement, fly ash, bitumen emulsion, and calcium silicate also lead to an increase in bulk density values from 4.1% to 8.21%. However, there are many other binders and fibers found during the literature review on which this test can be performed.

3.3.2. Water Absorption. The water absorption test is considered to be very important while determining the physical properties of soil blocks. As per IS 3495 (Part 2):1992, initially, the soil stabilized block is oven-dried at 105°C to 115°C till we get the constant mass. Afterward, the sample is cooled at room temperature, and the initial weight is noted. In the next step, the sample is dipped in purified water maintained at room temperature (27.2°C) for one day. Finally, the sample is taken out, cleaned with a damp cloth, and weighed after 3 min. The water absorption is calculated as the difference in the two weights expressed as a percentage of dry weight. This test is conducted as per standard codes of the location of the experiment. The maximum value of water absorption recommended by standard codes as found in the reviewed articles is 20%. Table 8 shows the effect of binders and fibers on water absorption values of soil admixed blocks. It shows that water absorption values in all the studies are within the permissible limits, i.e., less than 20%, except in the case of [23] where the sample failed for the water absorption test. The fibers were found to be more effective than the binders in reducing water absorption of the soil block except for cement. It was postulated by Danso et al. [21, 28, 35, 41] that reduction in water absorption might be due to the fact that inclusion of fibers reduces the shrinkage cracks of soil blocks due to the drying process. As fiber reinforcement has a modulus of elasticity to absorb shrinkage stress before cracks, it also characterizes better ductility, impact resistance, and toughness. The reduced cracking restricts the water absorption as cracks help in providing passage to the

Table 6: Types of tests conducted by the researchers as found in the published articles.

	Physical properties							Mechanical properties					Durability properties									Microstructural evaluation (chemical composition, microanalysis, failure analysis)					Other Tests		
Ref.	Bulk density	Porosity	Water absorption	Sorptivity	OMC and MDD	Linear shrinkage	Thermal conductivity	Compressive strength	Tensile strength	Flexural strength	Pull out test	Efflorescence	Shrinkage Cracks after compressive strength	Dry and saturated state	Freeze/ thaw	Wetting/ drying cycles	Fire resistance	Abrasion resistance	Rainwater tightness	Water permeability	Erosion	XRD	SEM	EDS	Computerised tomography (CT scan)	Computerised optical microscopy (OM)	Energy consumption and CO_2 emissions	Statistical analysis	Cost analysis
[8]	□						□	□																					
[9]			□					□																					
[12]																	□												
[13]								□		□				□								□	□				□		
[14]																													
[15]			□					□								□						□							
[16]			□					□																					
[17]			□					□																					
[19]			□	□																									
[20]								□															□					□	
[22]							□																					□	
[23]			□		□			□																					□
[24]								□																					
[26]			□					□								□													
[27]			□					□				□																	
[28]	□		□		□			□		□								□			□	□	□	□					
[29]	□				□			□																					
[30]								□																					
[32]	□	□					□	□														□	□						
[33]			□					□										□											
[34]																	□		□	□									
[36]			□					□								□						□	□						
[37]								□		□											□							□	
[11]															□														
[18]								□					□																
[10]			□					□		□												□							
[5]																□						□							
[6]								□	□														□					□	
[21]	□		□			□		□	□							□					□		□					□	
[31]											□												□		□	□			
[35]	□		□			□		□	□	□						□					□								□
[25]										□																			
[38]	□	□	□				□	□															□					□	
[7]							□																						
[39]	□		□					□													□							□	
[40]			□					□				□				□													
Total	8	2	17	1	3	2	5	26	3	6	1	2	1	1	1	7	2	2	1	1	5	7	7	1	1	1	1	7	2
	38	38	21	17	1	7	2																						
	124																												

Table 7: Bulk density of unfired admixed soil blocks as reported in the reviewed articles.

Ref.	Binders/fibers	Binder/fiber content (% range)	Initial/unstabilized bulk density (kg/m^3)	Max. bulk density after stabilization (kg/m^3)	Percentage increase (+)/percentage decrease (−)
[8]	Cement Sand Coconut fiber	1–1.5 1–2.0 0.4–0.8	1913.17	1754.94	−8.27
[28]	9% cement + mineral wool waste	0–4.0	1782	1800	1.01
	9% cement + sisal fiber	0.1–0.4	1782	1764	−1.01
[29]	Cement	5.0–15.0	1854	1930	4.10
	10% cement + bitumen emulsion	2.0–10.0	1904	1968	3.36
	10% cement + calcium silicate	0.5–2.0	1904	2034	6.83
	Slaked lime	5.0–15.0	1836	1817	−1.03
[32]	Cement	3.0–9.0	1547	1674	8.21
[21]	Sugarcane bagasse	0.25–1.0	1951	1867	−4.31
	Coconut husk	0.25–1.0	1951	1857	−4.82
	Oil palm fruit	0.25–1.0	1951	1889	−3.18
[35]	Alkali-resistant glass	0.25–1.0	2040.6	1865.29	−8.59
	Polypropylene	0.25–1.0	2040.6	1812.12	−11.20
	Banana	0.25–1.0	2040.6	1985.18	−2.72
	Jute	0.25–1.0	2040.6	1979.49	−2.99
[38]	Fly ash: rice husk ash	100 : 0–0 : 100	2023.42	2153.33	6.42
[39]	Cement: clay oil Rice husk ash	1 : 15 0–20	1812	1795	−0.94

Table 8: Water Absorption values of unfired admixed soil blocks as reported in the reviewed articles.

Ref.	Binders/fibers	Binder/fiber content (% range)	Initial/unstabilized absorption (%)	Min. absorption(%) after stabilization	Percentage increase (+)/percentage decrease (−)
[9]	Sugarcane bagasse ash	0–40	11.29	11.38	0.80
[15]	Cement Limestone waste Granite waste Sand	5 3.0–5.0 60–65 27–30	Not reported	18	NA
[16]	Cement Grit	12 81	Not reported	15.3	NA
[17]	Cement Sand Kaolin	9 9.0–77.0 14	21	19	−9.52
[19]	Cement	5.0–15.0	12.4	7	−43.5
	Cement + fibers	0.1–0.2	13.8	9.8	−28.99
	Cement + fibers	0.1–0.2	12.7	9.1	−28.35
[23]	Cement Rice husk ash	0–8.0 0–20	Failed	Failed	NA
[26]	Construction debris + sand + cement	20–30	14.39	15	4.24
[27]	Cement Sugarcane bagasse ash	4.0–10.0 4.0–8.0	5.84	6.95	19.01
[28]	9% cement + mineral wool waste	0–4.0	18	11	−38.89
	9% cement + sisal fiber	0.1–0.4	18	12	−33.33
[33]	Cement	4.8–6.0	13.8	12.1	−12.32
	6% cement + rice husk ash	1.0–5.0	12.1	8.5	−29.75
	6% cement + lime	1.0–4.0	12.1	11.8	−2.48
[36]	10% cement + limestone residues	30–50	15	13	−13.33

Table 8: Continued.

Ref.	Binders/fibers	Binder/fiber content (% range)	Initial/unstabilized absorption (%)	Min. absorption(%) after stabilization	Percentage increase (+)/percentage decrease (−)
[10]	Sand Rice husk ash Lime	30 5.0–15.0 5.0–15.0	3.1	1.2	−61.29
[21]	Sugarcane bagasse	0.25–1.0	8.1	10.4	28.40
	Coconut husk	0.25–1.0	8.1	9.8	20.99
	Oil palm fruit	0.25–1.0	8.1	9.4	16.05
[35]	Alkali-resistant glass	0.25–1.0	20	11.4	−43.00
	Polypropylene	0.25–1.0	20	6.5	−67.50
	Banana	0.25–1.0	20	8.9	−55.50
	Jute	0.25–1.0	20	10.4	−48.00
[38]	Fly ash: rice husk ash	100 : 0–0 : 100	11.76	7.70	−34.52
[39]	Cement: Clay oil Rice husk ash	1 : 15 0–20	17.45	15.25	−12.61
[40]	Lime Fly ash	10 10–16	Not reported	4.87	NA

water/moisture inside the soil blocks. The percentage decrease in water absorption of 48%, 55%, and 67% was found on the addition of jute, banana, and polypropylene fiber, respectively, as reported in Table 8. Sugarcane bagasse, coconut husk, and oil palm fruit increased the water absorption by 28%, 20%, and 16% because of the high void volume in natural fibers [35].

3.3.3. MDD and OMC. The maximum dry density of the stabilized soil required for making blocks is found by the standard proctor test (IS 2720 (part 7):1980) and the corresponding moisture content is called optimum moisture content. This test is conducted as per standard codes of the location of experiments, and it is an important parameter to find out because the preparation of soil block is done by using Optimum Moisture Content to achieve the Maximum Dry Density by compaction. The values found in the articles under review are shown in Table 9. The addition of binders like cement and lime leads to an increase in MDD and OMC due to higher specific gravity and hydration reactions, respectively. The inclusion of fibers had minimal effect on OMC but led to a decrease in MDD due to lower specific gravity.

3.3.4. Thermal Conductivity. The thermal conductivity of the soil block indicates the ease with which heat transfer occurs through it. The lower value of thermal conductivity implies its usage as a preferable heat insulation material. This test is conducted as per standard codes of a particular location of experiments. ASTM C1113-99 and JIS R 2618 are a few of them used in the articles under review. The values of thermal conductivity are reported in Table 10. Only 4 out of 36 articles conducted this test. This might be due to the complexity and cost of the equipment required to carry out this test, and very few research institutes have that equipment. The general trend of decrease in thermal conductivity was found with the inclusion of binders and fibers, which is due to the fact that thermal conductivity is inversely proportional to the porosity [22, 32]. Only 3 binders (cement, fly ash, rice husk ash) and 1 fiber (coconut fiber) out of a total of 19 binders and 14 fibers admixed soil blocks in the articles reviewed went through a thermal conductivity test. So, there is a lot of scope in conducting thermal conductivity tests on soil blocks admixed with other binders and fibers.

3.4. Mechanical Properties of Soil Blocks. This part of the study focuses on the mechanical properties of the soil blocks as reported by authors of related articles. The analysis of compressive strength, tensile strength, and flexural strength was carried out after data processing of all the relevant articles, as discussed below.

3.4.1. Compressive Strength. Compressive strength is the most important parameter of the mechanical properties of soil blocks. This test is reported the maximum number of times (23 out of 36 articles) in the articles reviewed. The effect of different types of binders and fibers on the compressive strength of soil admixed blocks is shown in Table 11. The minimum value of compressive strength recommended as per standard codes (IS 3495 (Part1): 1992) is 2 MPa. A general trend of increase in the compressive strength of soil blocks can be seen with the inclusion of binders and fibers. Except for the study conducted by Danso et al. [6], the compressive strength of all the other unfired admixed soil blocks is more than 2 MPa with cement admixed soil block showing the highest value of 23.5 MPa (Alavéz-Ramírez R et al.) [13] because of high cement content and high pozzolanic activity. Moreover, binders and fibers in the category of agricultural and industrial wastes also showed promising values of compressive strength.

3.4.2. Tensile Strength. The tensile strength test was conducted as per standard codes of a particular location of experiments and IS 5816 : 1999 is one of them which can

Table 9: MDD and OMC values of unfired admixed soil blocks as reported in the reviewed articles.

Ref.	Binders/fibers	Binder/fiber content (% range)	Initial/unstabilized MDD (kg/m^3) and OMC (%)	Max. MDD (kg/m^3) and OMC (%) after stabilization	Percentage increase (+)/percentage decrease (-)
[23]	Cement Rice husk ash	0–8.0 0–20	1382, 15.8%	1238, 26.5%	−10.42, 67.72
[28]	9% cement + mineral wool waste	0–4.0	1774, 14.70%	1740, 15.40%	−1.92, 4.76
	9% cement + sisal fiber	0.1–0.4	1774, 14.70%	1757, 14.55%	-0.96, -1.02
[29]	Cement	5.0–15.0	12%	14%	16.67
	10% cement + bitumen emulsion	2.0–10.0	12%	12%	0.00
	10% cement + calcium silicate	0.5–2.0	12%	13%	8.33
	Slaked lime	5.0–15.0	12%	14%	16.67

Table 10: Thermal conductivity of unfired admixed soil blocks as reported in the reviewed articles.

Ref.	Binders/fibers	Binder/fiber content (% range)	Type of equipment used for test (testing standard)	Initial/unstabilized thermal conductivity (W/m K)	Min. thermal conductivity after stabilization (W/m K)	Percentage increase (+)/percentage decrease (−)
[8]	Cement Sand Coconut fiber	1–1.5 1–2.0 0.4–0.8	Equipment not mentioned (JIS R 2618)	1.482	0.651	−56.07
[22]	Cement	5.0–16.0	Transient hot wire method using QTM-500 (ASTM C1113-99)	0.842	1.076	27.79
[32]	Cement	3.0–9.0	Hot disk apparatus, TPS-2500 S (code not mentioned)	0.91	0.89	−2.20
[38]	Fly ash: Rice husk ash	100 : 0–0 : 100	Direct measuring instrument with surface probe ISOMET2114 (code not mentioned)	1.9524	1.5366	−21.30

Table 11: Compressive strength of unfired admixed soil blocks as reported in the reviewed articles.

Ref.	Binders/fibers	Binder/fiber content (% range)	Initial/unstabilized strength (MPa)	Max. strength after stabilization (MPa)	Percentage increase (+)/percentage decrease (−)
[8]	Cement Sand Coconut fiber	1–1.5 1–2.0 0.4–0.8	8.34	5.79	−30.58
[9]	Sugarcane bagasse ash	0–40	8.06	8.89	10.30
[13]	Cement	0–10	0.64	23.5	3571.88
	Lime	0–10	0.64	16.5	2478.13
	Lime + sugarcane bagasse ash	10 + 10	0.64	21.3	3228.13
[15]	Cement Limestone waste Granite waste Sand	5 3.0–5.0 60–65 27–30	0.9	3	233.33
[16]	Cement Grit	12 81	0.9	2	122.22
[17]	Cement Sand Kaolin	9 9.0–77.0 14	11.4	14	22.81
[20]	Cement + *Bacillus pasteurii* KCTC 3558	-	6.23	6.69	7.38
	Cement + effective microorganisms (EM)	-	6.23	6.84	9.79

Table 11: Continued.

Ref.	Binders/fibers	Binder/fiber content (% range)	Initial/unstabilized strength (MPa)	Max. strength after stabilization (MPa)	Percentage increase (+)/percentage decrease (−)
[23]	Cement Rice husk ash	0–8.0 0–20	0.8	2.8	250.00
[24]	Cement	7	-	7.43	NA
[26]	Construction debris + sand + cement	20–30	8.9	10.61	19.21
[27]	Cement Sugarcane bagasse ash	4.0–10.0 4.0–8.0	5.42	5.85	7.93
[28]	9% cement + mineral wool waste 9% cement + sisal fiber	0–4.0 0.1–0.4	3.23 3.23	4.13 3.78	27.86 17.03
[29]	Cement 10% cement + bitumen emulsion 10% cement + calcium silicate Slaked lime	5.0–15.0 2.0–10.0 0.5–2.0 5.0–15.0	1.6 1.6 1.6 1.6	16 10 11.55 7	900.00 525.00 621.88 337.50
[32]	Cement	3.0–9.0	0.9	9.1	911.11
[33]	Cement 6% cement + rice husk ash 6% cement + lime	4.8–6.0 1.0–5.0 1.0–4.0	0.9 0.9 0.9	3.5 2.9 4.1	288.89 222.22 355.56
[36]	10% cement + limestone residues	30–50	3.2	4.4	37.50
[37]	Cement Green mussel shell powder Pig hair fibers	5 0–10 0–1.0	2.36	4.16	76.27
[18]	Sugarcane bagasse ash	0–10.0	2.3	3.8	65.22
[10]	Sand Rice husk ash Lime	30 5.0–15.0 5.0–15.0	11.2	18.6	66.07
[6]	Bagasse fiber (aspect ratio)	(25–125) (1%)	0.83	1.1	32.53
	Coconut fiber (aspect ratio)	(25–125) (1%)	1.07	1.35	26.17
	Oil palm fiber (aspect ratio)	(25–125) (1%)	0.96	1.14	18.75
[21]	Sugarcane bagasse Coconut husk Oil palm fruit	0.25–1.0 0.25–1.0 0.25–1.0	2.1 2.1 2.1	2.82 2.93 2.95	34.29 39.52 40.48
[35]	Alkali-resistant glass Polypropylene Banana Jute	0.25–1.0 0.25–1.0 0.25–1.0 0.25–1.0	3.5 3.5 3.5 3.5	6.87 9.91 13.59 18.04	96.29 183.14 288.29 415.43
[38]	Fly ash: rice husk ash	100 : 0–0 : 100	6.5513	12.88	96.60
[39]	Cement: Clay oil Rice husk ash	1 : 15 0–20	3.37	4.06	20.47
[40]	Lime Fly ash	10 10–16	Not reported	3.12	NA

be used in India. The addition of fibers helps in altering the tensile strength of the soil admixed block. That is why those studies contributed to tensile strength testing in which only fibers were added, as shown in Table 12. However, the study of tensile strength could also be done in those cases where both binders and fibers were used. A general trend of increase in tensile strength of soil blocks can be seen with the inclusion of fibers as reported in Table 13 because the presence of fibers helps in providing an interlock between soil binders and fibers or soil and fibers, which increases its tensile strength. Jute fiber showed the highest rate of increase (415%) in tensile strength, followed by banana fiber (288%) and polypropylene fiber (183%).

Table 12: Tensile strength of unfired admixed soil blocks as reported in the reviewed articles.

Reference(s)	Fibers	Fiber content (% range)	Initial/unstabilized strength (MPa)	Max. strength after stabilization (MPa)	Percentage increase (+)/percentage decrease (−)
[6]	Bagasse fiber (aspect ratio)	(25–125) (1%)	0.21	0.28	33.33
	Coconut fiber (aspect ratio)	(25–125) (1%)	0.18	0.29	61.11
	Oil palm fiber (aspect ratio)	(25–125) (1%)	0.25	0.3	20.00
[21]	Sugarcane bagasse	0.25–1.0	0.26	0.3	15.38
	Coconut husk	0.25–1.0	0.26	0.32	23.08
	Oil palm fruit	0.25–1.0	0.26	0.36	38.46
[35]	Alkali-resistant glass	0.25–1.0	1.92	3.99	107.81
	Polypropylene	0.25–1.0	1.92	5.44	183.33
	Banana	0.25–1.0	1.92	7.46	288.54
	Jute	0.25–1.0	1.92	9.89	415.10

Table 13: Durability by wetting/drying cycles of unfired admixed soil blocks as reported in the reviewed articles.

Ref.	Binders/fibers	Binder/fiber content (% range)	No. of cycles (standard used)	Max. strength (MPa) or mass loss (%) before wetting/drying cycles	Max. strength (MPa) or mass loss (%) after wetting/drying cycles
[15]	Cement	5	90 cycles, each cycle of 24 hours (NBR 13554)	3 MPa	2 MPa
	Limestone waste	3.0–5.0			
	Granite waste	60–65			
	Sand	27–30			
[26]	Construction debris + sand + cement	20–30	6 cycles, each cycle of 48 hours (NBR 13554)	0.45%	0.42%
[36]	10% cement + limestone residues	30–50	6 cycles, each cycle of 48 hours (NBR 13554)	7.3%	4.8%
[5]	10% lime + demolition residue	25–75	12 cycles, each cycle of 48 hours (standard not mentioned)	4.25 MPa	6.5 MPa
	Lime	10		3.8 MPa	5.5 MPa
[21]	Sugarcane bagasse	0.25–1.0	12 cycles, each cycle of 24 hours (ASTM D559-03)	11%	8.20%
	Coconut husk	0.25–1.0		11%	7.80%
	Oil palm fruit	0.25–1.0		11%	9.10%
[35]	Alkali-resistant glass	0.25–1.0	12 cycles, each cycle of 24 hours (ASTM D559-03)	18%	10.50%
	Polypropylene	0.25–1.0		18%	6.10%
	Banana	0.25–1.0		18%	5.20%
	Jute	0.25–1.0		18%	1.20%
[40]	Lime + fly ash	10 + 10	3 cycles, each cycle of 48 hours (standard not mentioned)	2.45 MPa	1.8 MPa
		12 + 10		2.5 MPa	1.95 MPa
		14 + 10		3.1 MPa	2.4 MPa
		16 + 10		3 MPa	2.2 MPa

3.4.3. Flexural Strength. The flexural strength of the soil admixed block tells about the highest stress borne by it just before it yields. This test was conducted in 6 studies, and the values of flexural strength are shown in Table 14. The flexural strength test was conducted as per standard codes of a particular location of experiments, and IS 4332(6):1972 is one of them which can be used in India. A general trend of increase in flexural strength can be seen with the inclusion of binders and fibers because the presence of fibers helps in providing an interlock between soil binders and fibers or soil and fibers, making a tougher matrix which increases its flexural strength (Sujatha ER and Selsia Devi S) [35]. Cement admixed soil block showed the highest rate of increase (1681% increase) in flexural strength from the initial value, followed by the mixture of cement, and mineral wool waste (957% increase) admixed soil block. Only 6 binders and 8 fibers admixed soil blocks went through this test out of a total of 19 binders and 14 fibers reported in the articles reviewed. So, this test can be performed on soil blocks admixed with other binders and fibers.

3.5. Durability Properties of Soil Blocks. This section focuses on the durability properties of the soil blocks as reported by authors of related articles. The analysis of durability by the method of wetting/drying cycles was carried out after data processing of all the relevant articles, as discussed below.

Table 14: Flexural strength of unfired admixed soil blocks as reported in the reviewed articles.

Reference(s)	Binders/fibers	Binder/fiber content (% range)	Initial/unstabilized strength (MPa)	Max. strength after stabilization (MPa)	Percentage increase (+)/percentage decrease (−)
[13]	Cement	0–10	0.11	1.96	1681.82
	Lime	0–10	0.11	1.12	918.18
	Lime + sugarcane bagasse ash	10 + 10	0.11	1.4	1172.73
[28]	9% cement + mineral wool waste	0–4.0	0.035	0.37	957.14
	9% cement + sisal fiber	0.1–0.4	0.035	0.64	1728.57
[37]	Cement Green mussel shell powder Pig hair fibers	5 0–10 0–1.0	0.106	0.768	624.53
[10]	Sand Rice husk ash Lime	30 5.0–15.0 5.0–15.0	0.022	0.056	154.55
[35]	Alkali-resistant glass	0.25–1.0	0.498	0.551	10.64
	Polypropylene	0.25–1.0	0.498	0.611	22.69
	Banana	0.25–1.0	0.498	0.626	25.70
	Jute	0.25–1.0	0.498	0.678	36.14
[25]	8% cement + macro synthetic polypropylene fibers “master fiber MAC matrix”	0–1.0	0.47	0.84	78.72

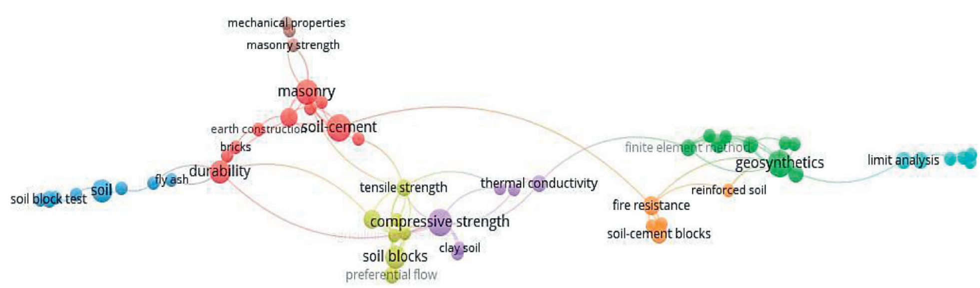

Figure 5: Keyword network analysis.

3.5.1. Wetting/Drying Cycles. This is the most widely used durability method conducted on soil admixed block, as found in the articles. This test can be done (IS 4332(4):1968) in two ways, i.e., (1) percentage mass loss and (2) decrease in compressive strength after saturation or after all the wetting and drying cycles. The results of the durability of the wetting/drying cycle method are shown in Table 13. The values in percentage represent percentage mass loss, and others are compressive strength values. In general, the strength increment in the first cycle was observed because additional moisture increases the pozzolanic reactions, but after the first cycle, the strength loss was found due to excessive moisture (James J and Saraswathy R) [40]. Durability studies were also reported only in 6 articles out of 36 articles reviewed, i.e., with very few binders and fibers. So, there is a lot of scope in carrying out this test also with a different combination of binders and fibers admixed in the soil block.

4. Scientometric Analysis

Scientometric analysis has been performed to identify the critical research areas and research gaps in the domain of soil block production using different types of wastes. Vosviewer analytical tool has been utilized to perform both keyword analysis and countrywise analysis. The network of keywords has been shown in Figure 5, which depicts that compressive strength and tensile strength are performed on soil blocks in most of the studies. Also, the durability and masonry strength of different mixtures has been extensively studied.

However, limited studies have been performed in the area of finite element methods, fire resistance, and limit analysis of soil blocks. Hence, future studies must be concentrated in these areas as well as preferential flow. On the other hand, the countrywise analysis indicates that the USA and China have a maximum number of research collaborations with other nations during the analysis of soil blocks using different types of wastes (see Figure 6). However, Portugal, Oman, and Scotland have not extensively shared their research and development activities with researchers from other countries. The developing nations such as Vietnam, Thailand, and Taiwan are also slowly increasing their research activities and collaborations with other countries.

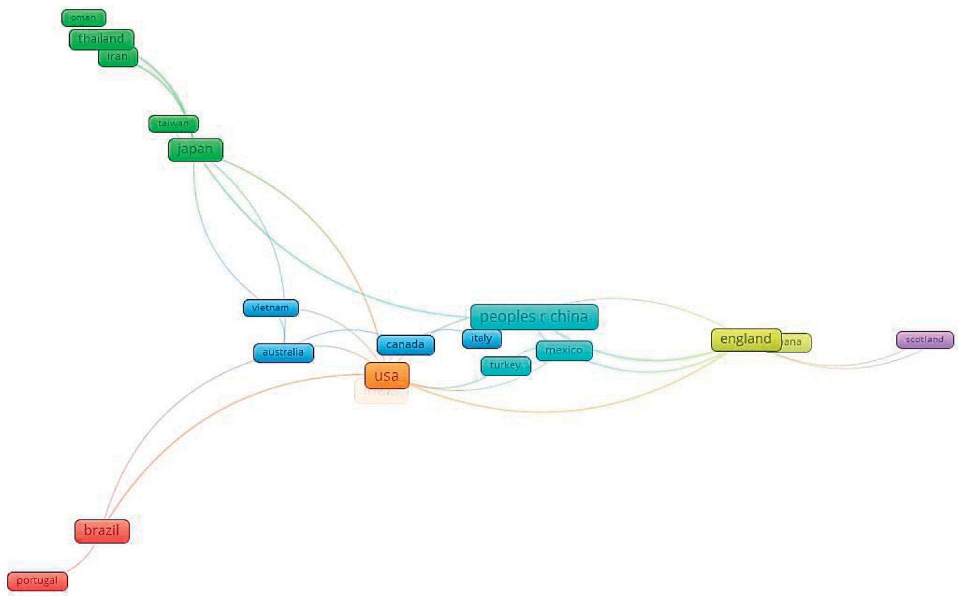

Figure 6: Countrywise analysis.

5. Conclusions

Earth is the oldest and cheapest construction material available on Earth. Right from ancient times human civilization cannot be deliberated without soil usage, even in the modern era too. The present attempt focused on the formation of compressed earth blocks, using a variety of admixtures and fibers. The compressive and tensile strength is a measure of the ability of earth blocks to be used in the construction of load-bearing structures. Fiber inclusion causes the reinforced soil matrix to act as a more ductile material and also restricts the formation of large cracks. So, the study concluded that there is a clear indication towards the beneficial effects of fiber inclusion on the thermal performance of stabilized blocks, and hence, future research needs to concentrate on this aspect for better understanding and certainty. The specific finds of the study are detailed as under. The conclusions of this study are the following:

(i) The compressive strength, water absorption, and wetting/drying cycle method of durability tests were among the most frequently conducted tests in the articles under review. It was found that except few, most of the unfired admixed soil blocks reported in this study satisfied the permissible criteria of these tests and can be used as a replacement to fired clay bricks in desired conditions from compressive strength and water absorption perspectives.

(ii) The tensile strength, flexural strength, and thermal conductivity tests are also important parameters but are reported in very few articles. There are also other parameters that can influence the properties of soil block like linear shrinkage, pull out test, erosion test, sorptivity test, porosity, efflorescence, water permeability, and freeze/thaw test, which have been reported in only one or two articles out of the 36 articles reviewed. Researchers can focus their studies on evaluating these properties by using other binders and fibers in soil blocks. Those studies using only binders in soil block have seen an increase in bulk density except for the lime, and the ones using only fibers in the soil block saw a decline in bulk density from their initial value. So, this aspect should be considered to focus upon in future studies on soil blocks.

(iii) The fibers were found to be more effective than the binders in reducing water absorption of the soil block because the inclusion of the fibers reduces the shrinkage cracks due to the drying process of soil blocks. The presence of fibers also helps in acting as an interlock between soil binders and fibers or soil and fibers, which increases its tensile strength and flexural strength. Hence, future research needs to focus on this aspect for better understanding of the fiber reinforcement mechanism.

(iv) It can be concluded that there is a clear indication of the beneficial effects of fiber inclusion on the thermal performance of stabilized blocks, and hence, future research needs to concentrate on this aspect for better understanding and certainty. In the durability test, the strength increment in the first cycle was observed because additional moisture increases the pozzolanic reactions, but after the first cycle, the strength loss was found due to excessive moisture in all the relevant studies.

(v) In addition, section 3.2.4 reveals that only 8 articles were concerned about conducting the microstructural evaluation, i.e., chemical composition of the materials used in soil block, microanalysis, and failure Analysis. Also, statistical analysis was found in 7 articles only. The analysis of energy consumption and carbon dioxide emissions during the manufacturing of unfired admixed soil blocks was reported in only 1 article. Cost analysis of the soil block making was also found in 2 articles. These are the gaps found in the present literature review, which can be worked upon in future research.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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