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WHEAT STRAW BALE WALLS AS A SUSTAINABLE CONSTRUCTION SOLUTION: A STATE OF THE ART

MUROS DE FARDOS DE PAJA DE TRIGO COMO SOLUCIÓN SOSTENIBLE EN LA CONSTRUCCIÓN: UN ESTADO DEL ARTE

PAREDES DE FARDOS DE PALHA DE TRIGO COMO SOLUÇÃO SUSTENTÁVEL NA CONSTRUÇÃO: UM ESTADO DA ARTE

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ABSTRACT

Given the growing interest in reducing CO2 emissions from the construction sector, there has been a push in recent years to find sustainable alternatives using biomaterials. The aim of this research is to review the state of the art in bio-construction using wheat straw bale walls, addressing their components, structural systems, and properties. The article is based on a statistical analysis of existing scientific production, using scientometrics and bibliometrics as a methodology through the Bibliometrix tool and its Biblioshiny web interface. The results of the analyzed scientific publications demonstrate the feasibility and use of straw as a low-impact building material, environmentally speaking. It is also evident that several authors are interested due to its wide applicability. It is concluded that wheat straw bales are a sustainable alternative, and their application is supported by the International Residential Code, Professional Standards for Straw Construction, and the Straw Construction Guidelines: Sustainable Construction and Insulation with Straw.

Keywords
walls, building materials, construction systems

RESUMEN

Ante el creciente interés por reducir el nivel de emisiones de CO2 que genera el sector de la construcción se ha impulsado, en los últimos años, a la búsqueda de alternativas sostenibles mediante el uso de biomateriales. El objetivo de esta investigación se orienta al desarrollo del estado del arte sobre la bioconstrucción con muros de fardos de paja de trigo, se abordaron sus componentes, sistemas estructurales y propiedades. El artículo se basa en el análisis estadístico de la producción científica existente, se empleó como metodología la cienciometría y bibliometría mediante la herramienta Bibliometrix y su interfaz web Biblioshiny. Los resultados de las publicaciones científicas analizadas demuestran la viabilidad y aprovechamiento de la paja como material de construcción con un bajo impacto ambiental. Y, se evidencia que existe gran interés por parte de varios autores debido a su amplia aplicabilidad. Se concluyó que los fardos de paja de trigo son una alternativa sostenible y su aplicación está respaldada por el Código Internacional Residencial, Normas profesionales para la construcción con paja y la Guía de construcción con Paja: Construcción sostenible y aislamiento con paja.

Palabras clave
muros, materiales de construcción, sistemas constructivos

RESUMO

Diante do crescente interesse em reduzir o nível de emissões de CO2 geradas pelo setor da construção, nos últimos anos tem-se promovido a busca por alternativas sustentáveis por meio do uso de biomateriais. O objetivo desta pesquisa é apresentar o estado da arte da bioconstrução com paredes de fardos de palha de trigo, abordando seus componentes, sistemas estruturais e propriedades. O artigo baseia-se na análise estatística da produção científica existente, utilizando como metodologias a cienciometria e a bibliometria, por meio da ferramenta Bibliometrix e de sua interface web Biblioshiny. Os resultados das publicações científicas analisadas demonstram a viabilidade e o aproveitamento da palha como material de construção com baixo impacto ambiental. Evidencia-se, ainda, o grande interesse de vários autores devido à sua ampla aplicabilidade. Conclui-se que os fardos de palha de trigo são uma alternativa sustentável e que sua aplicação é apoiada pelo Código Internacional Residencial, pelas Normas profissionais para a construção com palha e pelo Guia de construção com palha: Construção sustentável e isolamento com palha.

Palavras-chave
paredes, materiais de construção, sistemas construtivos

INTRODUCTION

In 2025, the construction sector is one of the leading emitters of CO_2, currently accounting for 34% of global emissions (United Nations Environment Programme [UNEP] & Global Alliance for Buildings and Construction [GlobalABC], 2025), which means that it is far from meeting the goals of the Paris Agreement on decarbonization for 2030 and 2050 (United Nations, 2015). Between 2015 and 2023, CO_2 emissions from construction increased 5.4%, in contrast to the 28.1% reduction that was considered necessary to limit global warming to no more than 1.5°C (UNEP, 2022). And, although sustainable certifications showed an upward trend, they remain 7.7 percentage points below the necessary 9.8 (UNEP & GlobalABC, 2025). These indicators reflect the need to adopt green and sustainable building materials to meet global climate commitments (Durand et al., 2024).

Globally, in 2023, total wheat production was 777 million tons, generating approximately 1.5 tons of straw for every ton of grain harvested (Food and Agriculture Organization of the United Nations [FAO], 2023). And although some of it is used as animal feed or to improve the soil, more than 70% is destroyed by burning (Meireles et al., 2024; Zhang et al., 2022). For this reason, its application in construction provides a productive use and prevents the release of pollutants into the air, which represents a sustainable and much more beneficial alternative (Hu, 2023). Although straw can be obtained from cereals such as barley, rice, corn, oats, and rye, this study has been limited to wheat due to its high lignin content and the presence of silica, which guarantees suitable properties and greater durability of the material (Durand et al., 2024).

At the end of the 19th century, the first straw bale structure was built after the development of steam balers in Nebraska, United States (Koh & Kraniotis, 2020). It has been seen that, in addition to extensive availability and low cost (Peng et al., 2023), straw bales provide excellent thermal insulation, soundproofing, and fire resistance, without requiring complex industrial processing (Platt et al., 2020), providing an 89.06% decrease in total embodied emissions (Vanova et al., 2021). However, according to the 2021 International Residential Code (IRC, 2021), they must meet specific requirements: the moisture content must not exceed 20% of their weight, and the dry density must be at least 104 kg/m^3.

Straw bale construction systems use compacted straw in the form of blocks as the main component (H. Peng et al., 2021), which are used as load-bearing walls or for backfilling, often in combination with timber framing and cladding (Tlaiji et al., 2022a). In the Nebraska or self-supporting method (see Figure 1a), it is the straw bales themselves, previously compressed and stacked, that support the vertical roof loads as well as the horizontal wind and earthquake loads without requiring additional structural elements (Dimova & Georgiev, 2021). One of its advantages is that it does not require advanced technical knowledge (Njike et al., 2020); therefore, the construction cost is low (Kozień-Woźniak et al., 2021).

On the other hand, the Posts and Beams method is based on the transfer of the building's loads to a structural frame, usually made of wood, as shown in Figure 1b (Koh & Kraniotis, 2020), where straw bales fulfill an exclusively thermal and acoustic insulation role (Vanova et al., 2021). Finally, the GREB method, as seen in Figure 2, combines the rigidity of the lightweight wooden structure with the thermal efficiency of the straw (Mutani et al., 2020), characterized by the placement of formwork on both sides of the wall to pour the mortar that serves as a coat (Diaz Fuentes et al., 2020). This comprises a mixture of 4 parts sawdust, 3 parts sand, 1 part lime, and 1 part cement (Amir et al., 2024; Moraes Santanna, 2023).

Construction with straw bales is supported by various rules and regulations (Ramos Rodríguez & Viera Arroba, 2025). The IRC sets the minimum requirements for single- and two-family homes that incorporate this material (IRC, 2021). Appendix S: Construction with straw bales establishes fundamental parameters such as dimensions, density, moisture content, plasters, and fire resistance, among others (Viera Arroba, 2023). On the other hand, the "Professional Standards for straw construction (Règles CP)" establishes parameters similar to those analyzed in the IRC. In addition, they incorporate quality and control procedures with self-verification sheets, simplified calculation methods, and maps of climatic conditions, which allows the technique to be adapted to different regions (Sangmesh et al., 2023). Similarly, the "Straw Construction Guide: Sustainable construction and straw insulation (DIBt)" offers an analysis very similar to that of the French regulations, but extended to both new buildings and rehabilitations (Plothe, 2024).

Ultimately, the research aims to demonstrate that the incorporation of straw bales in construction represents an effective decarbonization and circular economy strategy, as it converts agricultural waste into a stable carbon reservoir, thus avoiding single-use concrete and steel (Shang et al., 2020; Taube & Morgenthal, 2024). By promoting short supply chains, transport emissions are reduced, generating

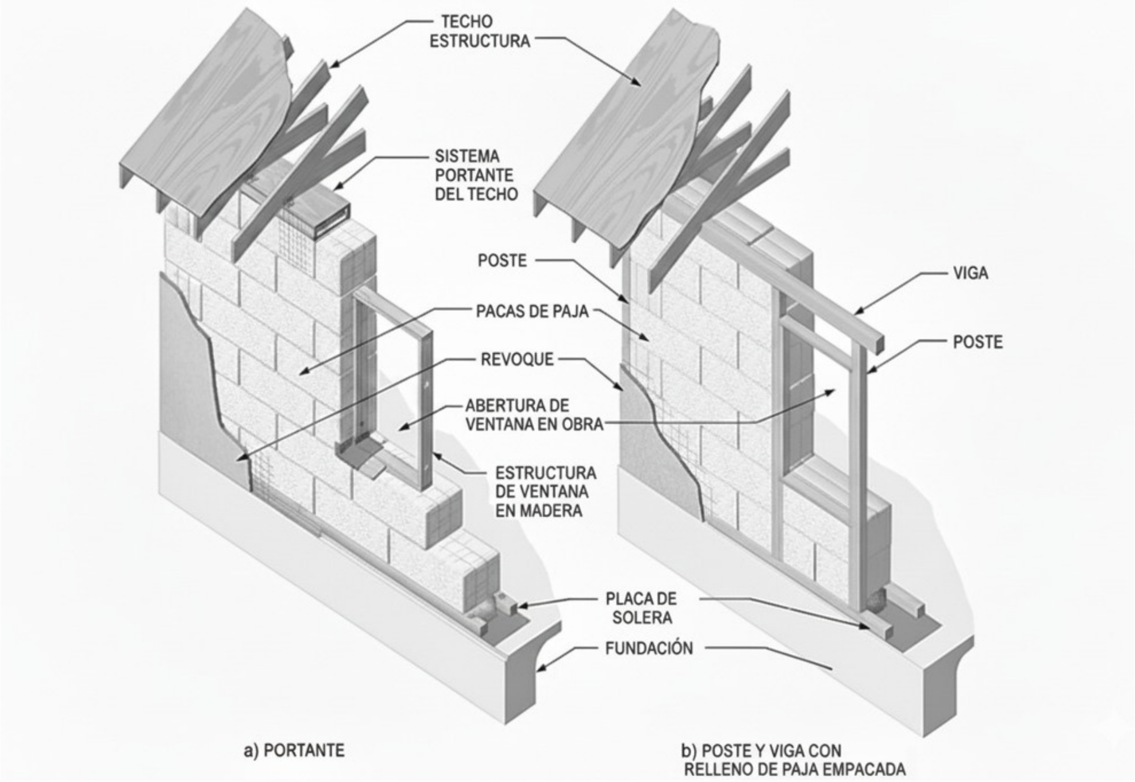

Figura 1. a) Método Nebraska o Load Bearing, b) Método Postes y Vigas. Fuente: Imagen extraída del IRC (2021).

Figure 2. GREB method. Source: Prepared by the authors.

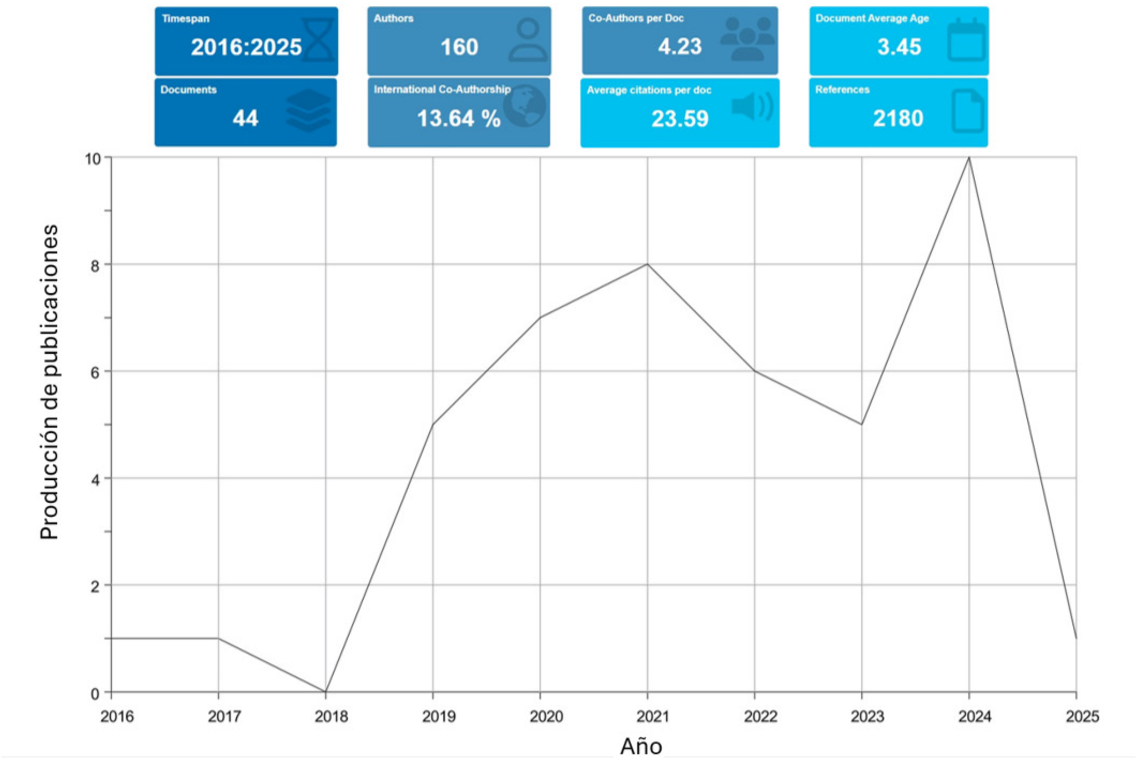

Figure 3. Information on the publications used in the study. Source: Prepared by the authors.

value in rural areas where straw used to be discarded or burned (Tashkov et al., 2024; Wang et al., 2023). Technically, straw walls offer thermal and acoustic insulation comparable to that of synthetic materials, which thus improves indoor comfort (Diaz Fuentes et al., 2020). And, the regulatory support guarantees the viability and safety of this system by favoring its adoption in sustainable construction projects (Lehner et al., 2021; Lehner & Brázdilová, 2022).

METHODOLOGY

To prepare this state-of-the-art, the Scopus database was used as the primary source of information, due to its recognized scientific track record and indexing of peer-reviewed publications. For this research, combinations of search terms such as "Straw" + "Characteristics", "Bales", "Walls", "Sustainable building", and "Bio-based materials" were used by limiting the results to publications between 2016 and 2025, to guarantee the relevance and quality of the information collected. On the other hand, a decision was made to examine each of them in detail manually because it is difficult to find research that covers all components, structural systems, and properties of wheat straw bale walls, thereby verifying that the investigation's goal is met.

To achieve a greater understanding of the research and facilitate the analysis of bibliographic sources, we have chosen to use "R", an environment and programming language with a statistical analysis approach, where Aria & Cuccurullo (2017) have developed Bibliometrix and its Biblioshiny web interface as a result of an academic collaboration, which is distributed under the MIT license. The program is loaded with the previous selection of information, and it uses scientometrics as a methodology, a discipline dedicated to the quantitative analysis of all scientific production, and one of its branches, bibliometrics, which specializes in the measurement and evaluation of publications.

RESULTS AND DISCUSSION

TEMPORAL ANALYSIS AND COUNTRIES OF ORIGIN OF THE PUBLICATIONS ON WHEAT STRAW BALE WALLS IN THE ESTABLISHED PERIOD

Figure 3 indicates that the publications analyzed within the established period have the participation of 160 authors and 2180 bibliographic references altogether. In addition, the average age of the publications is 3.45 years, confirming that this is a recent and constantly evolving field of study. In turn, 2024 is shown to be the most important year, as it had the highest research

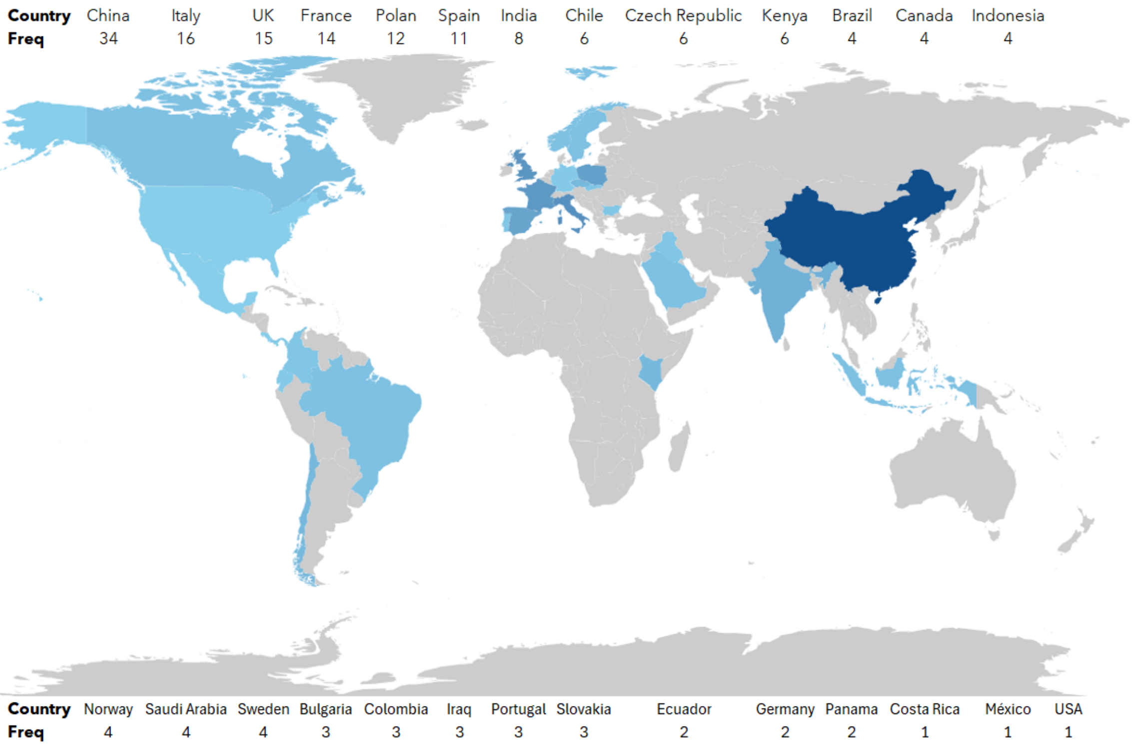

Figure 4. Worldwide distribution of the production of publications used in the study. Source: Prepared by the authors.

output, with 10 articles published in the Scopus database.

Finally, Figure 4 provides a visual representation of the geographical distribution of scientific production, analyzed using the full-count method, with intensity indicated by color. In this case, the dark tones reflect a higher level of research, while the light tones indicate a lower level of recorded activity. It is considered that publications with international collaboration are attributed to each author's country of origin. For example, China, Italy, and the United Kingdom stand out as the countries with the highest scientific production, with 34, 16, and 15 publications, respectively. In contrast, Costa Rica, Mexico, and the USA have only 1 for each. It should be noted that this does not necessarily imply the absence of research in these countries, but may be due to limitations in the database used or to the selection criteria applied during data collection.

PROPERTIES OF STRAW BALES

a) Moisture content

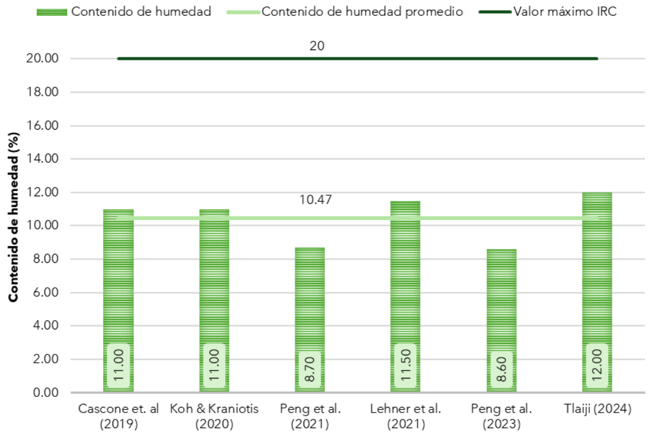

Figure 5. Moisture content in wheat straw bales. Source: Prepared by the authors.

In Figure 5, the results demonstrate how the moisture content of the straw bales, analyzed in the research, is maintained within an optimal range, from 8.6% to 12%, the average being 10.47%, below the limit of 20% established by the IRC, and in addition, the recommendation of not exceeding 15% (Cascone et al., 2019), allowing them to guarantee the integrity of the straw and prevent its degradation caused by mold and other biological agents. In addition, it is observed that in the studies of H. Peng et al. (2021) and Peng et al. (2023) work with lower moisture contents, in the range of 8% to 9%. In the other investigations, these values increase slightly, ranging from 11% to 12%. This difference is attributed to the fact that the straw bales used come from regions with drier climates during harvest (Khalife et al., 2024) and to the processes of packaging, transportation, and storage. It is important

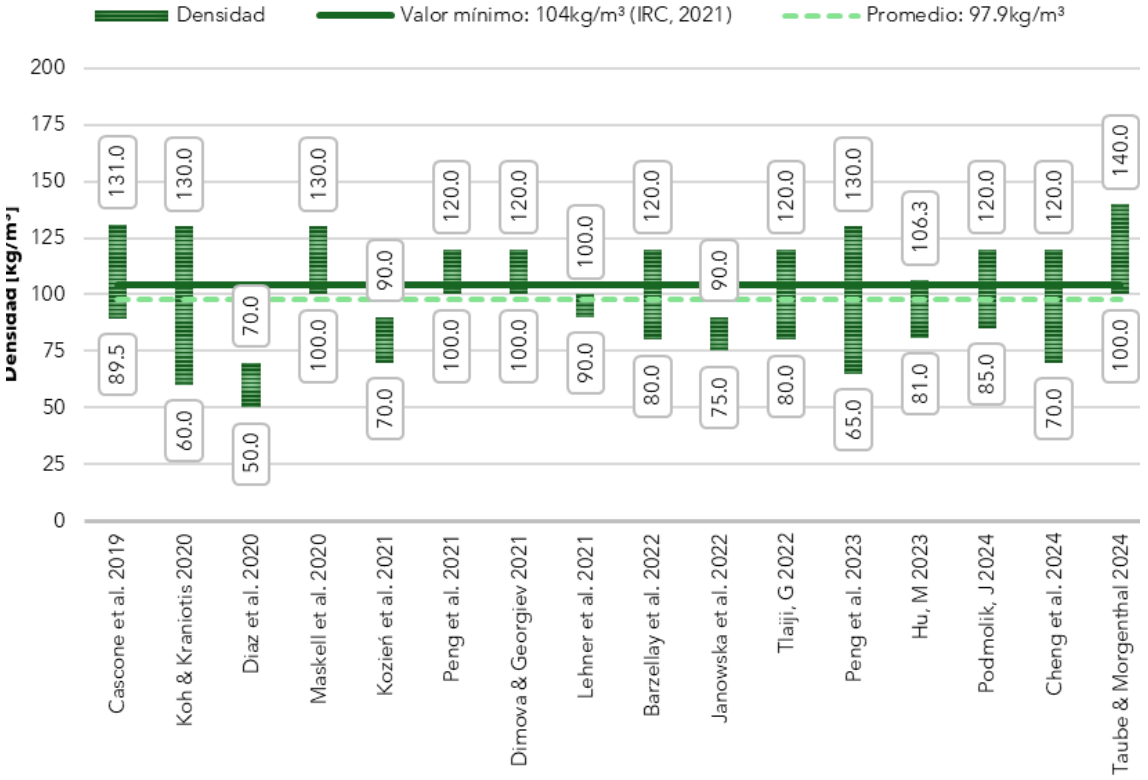

Figure 6. Accepted values for straw bale density. Source: Prepared by the author.

to note that although a low moisture content is sought, no research has established a specific lower limit.

b) Density

This parameter directly influences thermal, acoustic, and structural performance. According to the IRC, a minimum density of 104kg/m^3 should be achieved to ensure proper behavior. In Figure 6, it is observed that these values vary across investigations. Some authors, such as Diaz Fuentes et al. (2020), Kozień-Woźniak et al. (2021), Lehner et al. (2021), and Janowska-Renkas et al. (2022), work with bales whose density is below the limit established by the IRC. On the contrary, the other researchers use bales with densities spanning a wider range, with lower and upper limits of 60 and 140kg/m^3, respectively. According to Fąfara et al. (2022), low-compaction materials are mainly used as fillers, whereas for structural applications, higher magnitudes are required. In addition, it is important to consider that straw bales are compacted by their own weight during the construction process (Walker et al., 2020).

PROPERTIES OF STRAW BALE WALLS

a) Water vapor permeability

This is a property that determines the ability of a material to allow the passage of water vapor (δ), opposite to the water vapor diffusion resistance factor (μ), which indicates its difficulty in traversing it in relation to air. Lime or clay-based cladding is the most recommended due to its high porosity (Walker et al., 2020). In Table 1, four research projects are presented where the authors examine the relationship between the density of straw bales and their vapor transfer properties, δ and μ. Marques et al. (2020) show that, while the density decreases (from 100 to 80kg/m3), the permeability increases (from 3.61E-11 to 6.11E-11kg/(m*s*Pa)) and the diffusion resistance decreases (from 5.47 to 3.25). Consequently, less compaction promotes steam flow inside, but this relationship is not always observed. Additionally, reference values of the μ factor for a density of 100kg/m^3, established by the DIBt and RFCP of 2 and 1.5, respectively, are also included. In contrast to the results of H. Peng et al. (2021) and Tlaiji et al. (2022a), these have very close values of 2.4 and 1.15, respectively. This indicates that, on having a density close to that established in the IRC, it has good permeability.

b)Thermal conductivity

This is a physical property that represents the ease with which heat is transferred in a material. The use of straw bales is one of the characteristics that stands out the most for its excellent insulation capacity, which takes wall width into account (Dimova & Georgiev, 2021; Mohammed et al., 2024). In Table 2, from several investigations, a range between

Table 1. Permeability and resistance factor to the diffusion of water vapor. Source: Prepared by the authors.

References	Density [kg/m^3]	Water vapor permeability [δ] [kg/(m*s*Pa)]	Water vapor diffusion resistance factor [μ]
(Marques et al., 2020)	80	6.11E-11	3.25
(Marques et al., 2020)	100	3.61E-11	5.47
(S. Peng et al., 2021)	75	3.6E-11	5.25
(S. Peng et al., 2021)	100	1E-10	2.4
(S. Peng et al., 2021)	110	4.4E-11	4.8
(S. Peng et al., 2021)	120	4.2E-11	5
(Tlaiji et al., 2022b)	100	-	1.15
(Tlaiji et al., 2022b)	350	-	2.92
(Tlaiji, 2022)	80.6	1.19E-10	1.65
(Tlaiji, 2022)	92.9	1.53E-10	1.3
(Tlaiji, 2022)	97.5	1.04E-10	1.9
DIBt	100	-	2
RFCP	100	-	1.5

0.035 and 0.097 W/m*k of thermal conductivity is observed (λ), which proves that there is no linear correlation with density. While Rojas et al. (2019) report 0.047 W/(m·K) with bales of 105-112 kg/m^3, Tlajli (2022), with a similar density of 100 kg/m^3, has a noticeably higher conductivity of 0.078 W/(m·K). This is due to other characteristics such as packing quality, moisture content, fiber orientation, and wall width (Koh & Kraniotis, 2020). In general, the thermal conductivity decreases when the direction of heat flow is perpendicular to the fibers (Rota Front et al., 2024). Finally, the use of straw bales is very beneficial, considering that they have a great potential to reduce energy consumption by up to 25% (Barzellay Ferreira da Costa et al., 2022).

Table 2. Thermal conductivity as a function of density and wall width. Source: Prepared by the authors.

Reference	**Density [kg/m3]**	**Wall width [cm]**	**Thermal conductivity [W/mk]**
(Koh & Kraniotis, 2021)	60-120	50	0.053-0.062
(Njike et al., 2021)	75	46	0.06
(Platt et al., 2020)	129	-	0.056
(Dimova & Georgiev, 2021)	100	30	0.052-0.07
(Evola et al., 2019)	75	20	0.069
(Díaz Fuentes et al., 2020)	60	-	0.067
(Tlaiji et al., 2022a)	140-160	25	0.059-0.064
(Walker et al., 2020)	120	50	0.064
(Fąfara et al., 2022)	90	45	0.06
(Kozień-Woźniak et al., 2021)	80	26	0.052
(Vanova et al., 2021)	-	36	0.056-0.097
(Janowska et al., 2022)	75-90	-	0.056-0.078
(Podmolik, 2024)	85-120	-	0.045
(Sun et al., 2023)	70-120	-	0.056
(Hu, 2023)	81-106	-	0.063
(Li et al., 2024)	-	-	0.035-0.051
(Rojas et al., 2019)	105-112	-	0.047
(Mutani et al., 2020)	100	37	0.038
(Tlaiji, 2022)	100	40	0.078

c)Fire resistance

The high density with which the straw bales are packed minimizes the entry of oxygen and helps slow combustion, generating a layer that carbonizes and protects the core (Platt et al., 2020). In addition, the raw material has a high silica content, which is considered a natural fire retardant (Podmolik, 2024). The most common types of cladding and the average fire resistance time of several research projects are presented in Figure 7. In addition, a prefabricated straw-based panel is included, consisting of a lightweight wooden structure with straw bale filling covered by an airtight and breathable membrane, on which a wooden fiber board is placed (Podmolik, 2024). From these results, it is evident that cement-based plasters exhibit the best fire behavior at 120 minutes. However, they are not ideal for this type of

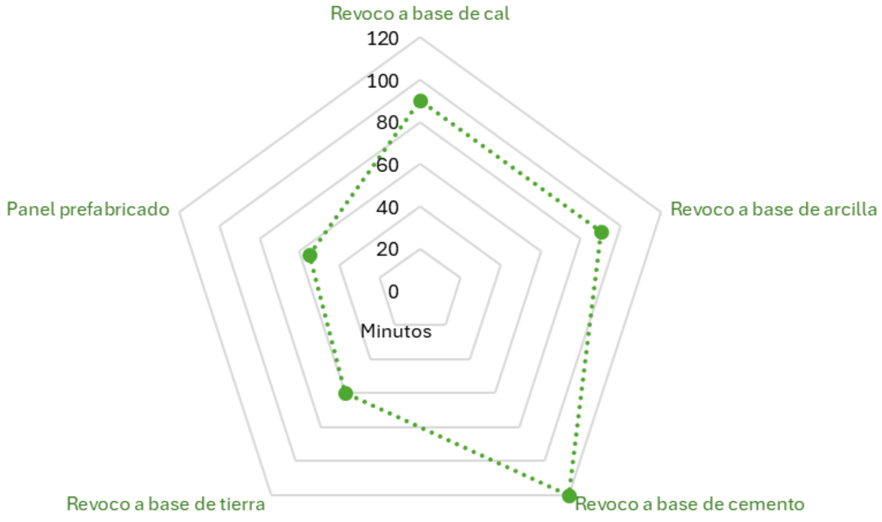

Figure 7. Fire resistance. Source: Prepared by the authors

construction, as they are considered low-permeability materials. Therefore, the best option is clay or lime-based plaster with 90 minutes, which complies with the 60 minutes defined in section AS107: IRC Fire resistance.

CONCLUSIONS

The IRC has a minimum density for straw bales of 104kg/m^3. However, achieving this value is often complicated by the near absence of suitable equipment; most balers are designed for agricultural use, which makes it challenging to meet the size, mooring, and density requirements specified in the standard. Several studies have sought to show that there is an acceptance range between 80 kg/m^3 and 120 kg/m^3. Unlike density, the maximum moisture content of 20% is met in all the analyzed investigations, which register an average of 10.4%, proving its easy obtainment.

The density acceptance depends on the straw bales' role. When the structure is Nebraska-type, the bale is a structural element that directly supports all the weight, necessitating high density. On the other hand, in the system of Posts and Beams or GREB, the bale is a filling element, and the value of this property may be reduced. It is considered that densities that are too low (60kg/m^3) or excessively high (160kg/m^3) usually generate unfavorable λ values, which reduce the insulating capacity of the wall. However, the thermal insulation of the wall not only depends on λ, but is also influenced by the wall's width. A larger dimension provides superior insulation, though it is not constructively efficient, as it reduces the living area. Consequently, a density range is insufficient to guarantee insulation; a deeper understanding of variables such as packing quality, moisture content, fiber orientation, and wall width is required to optimize performance.

Contrary to what is commonly believed, straw bale walls have good fire performance. According to the IRC, fire resistances of 60 to 120 minutes can be achieved, depending on the type of plaster. The results of the analyzed research show that clay and lime-based plasters are the most demanded in bio-construction, due to their good reaction to fire and thermal insulation, which depends on the thickness they can reach. In fact, this type of plaster offers 90 minutes of fire resistance, falling within the safety range established by the standard. Despite this, there are no studies that establish a specific dosage at which the expected performance is guaranteed.

In conclusion, the permeability of the walls to water vapor is a parameter that does not depend solely on the density of the bales. Other factors, such as the moisture content of the bales, porosity, and the thickness of the plaster, also significantly influence the results. Although they are not always included in the research, they must be considered. Even for equal densities, variability is observed. For their analysis, the DIBt and RFCP present values of the water vapor diffusion factor, a property that measures the difficulty of diffusion through a material; the lower the μ, the greater the δ. For bales with 100kg/m^3, μ values of 2.4 and 1.15 are reported in certain studies, as they are close to the regulatory recommendations of 2 and 1.5. This determines that elements with densities within the acceptable range offer optimal breathability.

Finally, for a wheat straw bale wall to be accepted in the construction sector, it is recommended that its elements meet some parameters: the plaster must be based on clay or lime, and the bales must have a moisture content of less than 15% and a density between 80 and 120kg/m3. It is imperative that, for good thermal insulation, the direction of heat flow in the wall is perpendicular to the straw fibers. In addition, the recommended plasters are ideal not only for their fire resistance of approximately 90 minutes, but also for their porosity and adjustable thickness, which allow obtaining a resistance factor μ between 2.4 and 1.15. All these criteria align with various international standards, whose primary purpose is to establish guidelines that guarantee the safety of occupants, the integrity of the construction, and long-term durability.

CONTRIBUTION OF AUTHORS CRediT

Conceptualization, H.R., L.G. & J.L.; Data Curation, H.R., L.G. & J.L.; Formal analysis, H.R., L.G. & J.L.; Acquisition of financing, H.R., L.G. & J.L.; Research, H.R., L.G. & J.L.; Methodology, H.R., L.G. & J.L.; Project Management, H.R., L.G. & J.L.; Resources, H.R., L.G. & J.L.; Software, H.R., L.G. & J.L.; Supervision, H.R., L.G. & J.L.; Validation, H.R., L.G. & J.L.; Visualization, H.R., L.G. & J.L.; Writing - original draft, H.R., L.G., & J.L.; Writing - revision and editing, H.R., L.G. & J.L.

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BIBLIOGRAPHIC REFERENCES

Amir, F., Maricar, S., Mallisa, Z., & Pravita, N. (2024). Compressive strength of mortar with addition of sawdust. IOP Conference Series: Earth and Environmental Science, 1355(1), 012028. https://doi.org/10.1088/1755-1315/1355/1/012028

Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. Journal of Informetrics, 11(4), 959-975. https://doi.org/10.1016/j.joi.2017.08.007

Barzellay Ferreira da Costa, B., Diminic, A. L., Guedes Sias Thompson, S. J., & Naked Haddad, A. (2022). Análisis de la perspectiva del usuario con respecto a los edificios con fardos de paja: Un estudio de encuesta. *Informes de la Construcción, 74*(568), e469. https://doi.org/10.3989/ic.89959

Cascone, S., Rapisarda, R., & Cascone, D. (2019). Physical Properties of Straw Bales as a Construction Material: A Review. Sustainability, 11(12), 3388. https://doi.org/10.3390/su11123388

Diaz Fuentes, C. X., Pérez Rojas, M. C., & Mancilla, J. J. (2020). Physical-thermal straw properties advantages in the design of a sustainable panel-type construction system to be used as an architectural dividing element. *Journal of Physics: Conference Series, 1587*, 012032. https://doi.org/10.1088/1742-6596/1587/1/012032

Dimova, V., & Georgiev, D. (2021). Optimizing the thickness of a straw outer wall of a building for sows in a view to achieving cost-effective heat insulation. Agricultural Science and Technology, 13(2), 167-175. https://doi.org/10.15547/ast.2021.02.028

Durand, K., Daassi, R., Rodrigue, D., & Stevanovic, T. (2024). Study of Purified Cellulosic Pulp and Lignin Produced by Wheat Straw Biorefinery. *Macromol, 4*(3), 650-679. https://doi.org/10.3390/macromol4030039

Evola, G., Cascone, S., Sciuto, G., & Parisi, C. (2019). Performance comparison between building insulating materials made of straw bales and EPS for timber walls. *IOP Conference Series: Materials Science and Engineering, 609*(7), 072020. https://doi.org/10.1088/1757-899X/609/7/072020

Fąfara, M., Łukaszewski, Ł., Owczarek, E., & Źrebiec, I. (2022). Life cycle assessment (LCA) and environmental comparison of selected construction methods of residential buildings in traditional and straw cubes technology: A case study. *Archives of Civil Engineering, 68*(3), 241–255. https://doi.org/10.24425/ace.2022.141883

Hu, M. (2023). Exploring Low-Carbon Design and Construction Techniques: Lessons from Vernacular Architecture. *Climate, 11*(8), 165. https://doi.org/10.3390/cli11080165

International Residential Code [IRC]. (11 de enero de 2021). Apéndice como Construcción con Pacas de Paja. https://codes.iccsafe.org/content/IRCSP2021P1/apendice-as-construccion-con-pacas-de-paja

Janowska-Renkas, E., Król, A., Pochwała, S., Pałubski, D., Adamska, M., & Klementowski, I. (2022). The Fire Resistance and Heat Conductivity of Natural Construction Material Based on Straw and Numerical Simulation of Building Energy Demand. *Energies, 15*(3), 1155. https://doi.org/10.3390/en15031155

Khalife, E., Sabouri, M., Kaveh, M., & Szymanek, M. (2024). Recent Advances in the Application of Agricultural Waste in Construction. *Applied Sciences, 14*(6), 2355. https://doi.org/10.3390/app14062355

Koh, C. H., & Kraniotis, D. (2020). A review of material properties and performance of straw bale as building material. *Construction and Building Materials, 259*, 120385. https://doi.org/10.1016/j.conbuildmat.2020.120385

Koh, C., & Kraniotis, D. (2021). Hygrothermal performance, energy use and embodied emissions in straw bale buildings. *Energy and Buildings 245*, 111091. https://doi.org/10.1016/j.enbuild.2021.111091

Kozień-Woźniak, M., Fąfara, M., Łukaszewski, Ł., Owczarek, E., & Gierbienis, M. (2021). Life cycle assessment of composite straw bale technology in residential buildings in the context of environmental, economical and energy perspectives – case study. En Archives of Civil Engineering 67(2), 49-65. https://doi.org/10.24425/ace.2021.137154

Lehner, P., & Brázdilová, H. (2022). Inverse Analysis of Straw Bale Mechanical Parameters in Load-Bearing Structures Based on a Finite Element Model. *Buildings, 12*(12), 2157. https://doi.org/10.3390/buildings12122157

Lehner, P., Horňáková, M., Vlček, P., & Teslík, J. (2021). Experimental Investigation of Two Test Setups on Straw Bales Used as Load-Bearing Elements of Buildings. *Buildings, 11*(11), 539. https://doi.org/10.3390/buildings11110539

Li, A., Guo, C., Gu, J., Hu, Y., Luo, Z., & Yin, X. (2024). Promoting Circular Economy of the Building Industry by the Use of Straw Bales: A Review. *Buildings, 14*(5),1337. https://doi.org/10.3390/buildings14051337

Marques, B., Tadeu, A., Almeida, J., António, J., & Brito, J. de. (2020). Characterisation of sustainable building walls made from rice straw bales. *Journal of Building Engineering, 28*, 101041. https://doi.org/10.1016/j.jobe.2019.101041

Meireles, I., Martín-Gamboa, M., Sousa, V., Kalthoum, A., & Dufour, J. (2024). Comparative environmental life cycle assessment of partition walls: Innovative prefabricated systems vs conventional construction. *Cleaner Environmental Systems, 12*, 100179. https://doi.org/10.1016/j.cesys.2024.100179

Mohammed, M. A., Budaiwi, I. M., Al-Osta, M. A., & Abdou, A. A. (2024). Thermo-Environmental Performance of Modular Building Envelope Panel Technologies: A Focused Review. *Buildings, 14*(4), 917. https://doi.org/10.3390/buildings14040917

Moraes Santanna, T. (2023). Construcción con balas de paja: Materiales tradicionales para respuestas actuales [Tesis de pregrado, Universitat Politècnica de València]. Repositorio Institucional UPV. https://riunet.upv.es/handle/10251/199603

Mutani, G., Azzolino, C., Macrì, M., & Mancuso, S. (2020). Straw Buildings: A Good Compromise between Environmental Sustainability and Energy-Economic Savings. *Applied Sciences, 10*(8), 2858. https://doi.org/10.3390/app10082858

Njike, M., Oyawa, W. O., & Abuodha, S. O. (2020). Structural Performance of Straw Block Assemblies under Compression Load. *The Open Construction & Building Technology Journal, 14*. https://doi.org/10.2174/1874836802014010350

Njike, M., Oyawa, W. O., & Abuodha, S. O. (2021). Enhancement of Straw Bale Performance Using Gum Arabic. The Open Construction and Building Technology Journal, 15, 189-195. https://doi.org/10.2174/1874836802115010189

Organización de las Naciones Unidas para la Alimentación y la Agricultura [FAO]. (2023). *Perspectivas alimentarias.* https://www.fao.org/giews/reports/food-outlook/es/

Peng, H., Walker, P., Maskell, D., & Jones, B. (2021). Structural Characteristics of Load Bearing Straw Bale Walls. *Construction and Building Materials, 287*, 122911. https://doi.org/10.1016/j.conbuildmat.2021.122911

Peng, S., Luo, Q., Zhou, G., & Xu, X. (2021). Recent Advances on Cellulose Nanocrystals and Their Derivatives. Polymers, 13(19), 3247. https://doi.org/10.3390/polym13193247

Peng, H., Walker, P., & Maskell, D. (2023). Compressive load resistance of straw bale assemblies under concentric and eccentric loading. *Construction and Building Materials, 397*, 132434. https://doi.org/10.1016/j.conbuildmat.2023.132434

Platt, S., Maskell, D., Walker, P., & Laborel-Préneron, A. (2020). Manufacture and characterisation of prototype straw bale insulation products. *Construction and Building Materials, 262*, 120035. https://doi.org/10.1016/j.conbuildmat.2020.120035

Plothe, M. (28 de noviembre de 2024). Leitfaden Strohbau – Nachhaltig Bauen und Dämmen mit Stroh. Fachagentur Nachwachsende Rohstoffe. https://www.fnr.de/presse/pressemitteilungen/aktuelle-mitteilungen/aktuelle-nachricht/leitfaden-strohbau-nachhaltig-bauen-und-daemmen-mit-stroh

Podmolik, J. (2024). *Review of the CUT technique* [Tesis de Magister, Lund University]. LUP Student Papers. https://lup.lub.lu.se/student-papers/search/publication/9162802

Ramos Rodríguez, H. A., & Viera Arroba, L. P. (2025). Caracterización de Paneles de Paja y su Evaluación Estructural en una Edificación de Tres Pisos. *Revista Politécnica, 55*(1), 29-40. https://doi.org/10.33333/rp.vol55n1.03

Rojas, C., Cea, M., Iriarte, A., Valdés, G., Navia, R., & Cárdenas-R, J. P. (2019). Thermal insulation materials based on agricultural residual wheat straw and corn husk biomass, for application in sustainable buildings. *Sustainable Materials and Technologies, 20*, e00102. https://doi.org/10.1016/j.susmat.2019.e00102

Rota Front, F., Ciriano Nogales, Y., Temes Mendoza, D., Vallbé Mumbrú, M., Barbeta Solá, G., & De Felipe Blanch, J. J. (2024). Thermal Performance of a Straw Bale Building in Relation to Fiber Orientation: A Case Study. *Sustainability, 16*(23), 10304. https://doi.org/10.3390/su162310304

Sangmesh, B., Patil, N., Jaiswal, K. K., Gowrishankar, T. P., Karthik Selvakumar, K., Jyothi, M. S., Jyothilakshmi, R., & Kumar, S. (2023). Development of sustainable alternative materials for the construction of green buildings using agricultural residues: A review. *Construction and Building Materials, 368*, 130457. https://doi.org/10.1016/j.conbuildmat.2023.130457

Shang, X., Song, S., & Yang, J. (2020). Comparative environmental evaluation of straw resources by LCA in China. *Advances in Materials Science and Engineering*, *2020*(1), 4781805. https://doi.org/10.1155/2020/4781805

Sun, C., Gu, J., Dong, Q., Qu, D., Chang, W., & Yin, X. (2023). Are straw bales better insulation materials for constructions? A review. *Developments in the Built Environment, 15*, 100209. https://doi.org/10.1016/j.dibe.2023.100209

Tashkov, L., Zlateva, P., & Penkova, N. (2024). Reducing the carbon footprint in the construction sector by replacing ceramic bricks with alternativa materials. *Journal of Chemical Technology and Metallurgy, 59*(6), 1347-1352. https://doi.org/10.59957/jctm.v59.i6.2024.9

Taube, C., & Morgenthal, G. (2024). Experimental investigation of the biaxial load-bearing and deformation behaviour of wheat straw big bales for construction *Construction and Building Materials, 433*, 136630. https://doi.org/10.1016/j.conbuildmat.2024.136630

Tlaiji, G. (2022). Multi-scale study of straw buildings hygrothermal, environmental and mechanical behavior [Doctoral Thèse, Université Clermont Auvergne]. HAL Theses. https://theses.hal.science/tel-04416366v1

Tlaiji, G., Biwole, P., Ouldboukhitine, S., & Pennec, F. (2022a). A mini-review on straw bale construction. *Energies, 15*(21), 7859. https://doi.org/10.3390/en15217859

Tlaiji, G., Ouldboukhitine, S., Pennec, F., & Biwole, P. (2022b). Thermal and mechanical behavior of straw-based construction: A review. *Construction and Building Materials, 316*, 125915. https://doi.org/10.1016/j.conbuildmat.2021.125915

United Nations. (2015). *Acción por el Clima. El Acuerdo de París*. https://www.un.org/es/climatechange/paris-agreement

United Nations Environment Programme [UNEP]. (2022*). Informe sobre la situación mundial de los edificios y la construcción en 2022*. https://www.unep.org/es/resources/publicaciones/informe-sobre-la-situacion-mundial-de-los-edificios-y-la-construccion-en

United Nations Environment Programme [UNEP]. & Global Alliance for Buildings and Construction [GlobalABC]. (2025). Not just another brick in the wall: The solutions exist—Scaling them will build on progress and cut emissions fast. Global Status Report for Buildings and Construction 2024/2025. https://wedocs.unep.org/20.500.11822/47214

Vanova, R., Vlcko, M., & Stefko, J. (2021). Life Cycle Impact Assessment of Load-Bearing Straw Bale Residential Building. *Materials, 14*(11), 3064. https://doi.org/10.3390/ma14113064

Viera Arroba, L. P. (2023). Factibilidad constructiva de viviendas con muros portantes de fardos de paja energéticamente eficientes y sismo resistentes en la zona andina del Ecuador [Tesis Doctoral]. Universitat Politècnica de València. https://doi.org/10.4995/Thesis/10251/196654

Walker, P., Thomson, A., & Maskell, D. (2020). Straw bale construction in K. A. Harries & B. Sharma (Eds.), Nonconventional and vernacular construction materials. Characterisation, Properties and Applications (2 ed., pp. 189–216). Woodhead Publishing Series in Civil and Structural Engineering. https://doi.org/10.1016/B978-0-08-102704-2.00009-3

Wang, Y., Jiang, Z., Li, L., Qi, Y., Sun, J., & Jiang, Z. (2023). A Bibliometric and Content Review of Carbon Emission Analysis for Building Construction. *Buildings, 13*(1), 205. https://doi.org/10.3390/buildings13010205

Zhang, L., Larsson, A., Moldin, A., & Edlund, U. (2022). Comparison of lignin distribution, structure, and morphology in wheat straw and wood. *Industrial Crops and Products, 187*(B), 115432. https://doi.org/10.1016/j.indcrop.2022.115432