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Straw Bale Usage as Building Material

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Abstract

This study thoroughly investigates the use of straw bales as an alternative building material, capitalizing on their natural, eco-friendly, practical, and economical properties. Straw, utilized in construction for centuries, offers environmental and structural benefits, adjusting with sustainability practices. The global adoption of straw bale building emphasizes its advantages in thermal insulation, durability, fire resistance, low embodied energy, and sound insulation. While recognizing these benefits, the study addresses difficulties in moisture management and mold growth, stressing the need for careful consideration during implementation. Thus, this paper aims to contribute to the ongoing discourse on straw bale building, offering valuable insights and recommendations for architects seeking sustainable alternatives in the construction industry. Furthermore, the study underscores the importance of continuous research and innovation to overcome limitations and enhance the efficiency of straw bale architecture. By fostering a deeper understanding of the problems and opportunities associated with this eco-friendly building method, this paper tries to encourage the building industry to embrace sustainable practices and contribute to a greener future.

Keywords: *Architecture, straw bale, ecological material, ecological building, sustainability*

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Saman Balyasının Yapı Malzemesi Olarak Kullanımı

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Öz

Bu çalışma, saman balyalarının doğal, çevre dostu, pratik ve ekonomik özellikleri yönünden alternatif bir yapı malzemesi olarak kullanımını kapsamlı bir şekilde anlatmayı amaçlamaktadır. Yüzyıllardır inşaatlarda kullanılan saman, sürdürülebilirlik uygulamalarıyla uyumlu çevresel ve yapısal faydalar sunmaktadır. Dünya genelinde saman balyası inşaatının giderek daha yaygın bir şekilde tercih edilmesi, bu yapı yönteminin ısı yalıtımı, dayanıklılık, düşük enerji tüketimi, yangına dayanıklılık ve ses yalıtımı gibi çeşitli avantajlarından kaynaklanmaktadır. Bu avantajlar, yalnızca çevresel etkilerle sınırlı kalmayıp aynı zamanda enerji verimliliği ve yapısal sağlamlık gibi kritik faktörlere de odaklanarak, saman balyası inşaatının küresel çapta birçok avantaj sunduğunu göstermektedir. Çalışma, bu faydaları dile getirirken, nem yönetimi ve küf oluşumundaki zorlukları ele almakta ve uygulamada dikkatli olunması gerektiğini vurgulamaktadır. Dolayısıyla bu metin, inşaat sektöründe sürdürülebilir alternatifler arayan mimarlar için değerli bilgiler ve öneriler sunarak saman balyası yapımı konusunda süregelen tartışmalara katkıda bulunmayı amaçlamaktadır. Ayrıca sınırlamaların üstesinden gelmek ve saman balyası inşaatının verimliliğini artırmak için sürekli araştırma yapılmasının ve inovasyonun öneminin altı çizilmektedir. Sonuçta, bu derleme, çevre dostu bina yöntemiyle ilgili sorunların ve fırsatların daha iyi anlaşılmasını sağlayarak, inşaat sektörünü sürdürülebilir uygulamaları benimsemeye ve daha yeşil bir geleceğe katkıda bulunmaya teşvik etmeyi çalışmaktadır.

Anahtar Kelimeler: *Mimarlık, saman balyası, ekolojik malzeme, ekolojik yapı, sürdürülebilirlik*

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Introduction

The aim of this paper is to offer a comprehensive analysis of the present state of straw bale construction, highlighting its sustainability as an alternative architectural model. Straw bale buildings have garnered considerable attention, particularly for their potential to offer superior thermal insulation and contribute to environmental sustainability. The roots of incorporating straw bales into modern construction projects trace back to the 1990s, marked by one of the earliest residential straw bale buildings by Bob Matthews (Guo et al., 2020). While the application has been predominantly concentrated in low-rise and single-story structures, their usage in urban environments and high-rise constructions remains limited (Thomson and Walker, 2014; Lawrence et al., 2009; Njike et al., 2021; Guo et al., 2020; Njike et al., 2020). Thus, despite their promising attributes, the integration of straw bales into mainstream architecture practices has been primarily confined to the self-build fringe sector, reflecting a notable absence of widespread adoption in urban settings (Lawrence et al., 2009). This limitation suggests potential barriers or hesitations within the industry or regulatory frameworks that impede the broader implementation of straw bale construction in urban landscapes. As the discourse on sustainable building practices continues to evolve, comprehensive exploration and dissemination of knowledge regarding the application of straw bales in diverse architectural settings may become actual. Research and educational initiatives should actively address potential issues and misconceptions, offering the way for a more informed and inclusive approach to the incorporation of straw bale architecture in contemporary urban landscapes.

Sustainability in building design, as outlined by Cornaro et al. (2020), provides integrating economic, environmental, and social aspects to develop structures that minimize environmental influence and meet future needs. This approach includes addressing factors like resource consumption limits and environmental effects within the building industry. The design procedure, rooted in sustainability, involves making economic choices regarding life-cycle and matrix costing, taking into account energy and efficiency, and planning architectural schedules. The aim is to promote a holistic approach to building design, encouraging architects to consider the broader implications of their decisions. This comprehensive perspective advocates for integrated building design and emphasizes the influential role of key actors, such as architects, in shaping construction strategies with a sustainability focus (Vaňová et al., 2021). Indeed, sustainability has become a critical concern amid rapid urbanization and industrialization, with the construction field emerging as a significant user of renewable assets. Globally, a substantial 30-40% of natural resources are allocated to the construction industry, particularly in industrialized nations (Pulselli et al., 2007, p. 620). This significant designation has become a primary driver of the rapid depletion of these resources, prompting urgent global considerations about the environmental issues of architectural practices.

Obviously, the depletion of natural resources has intensified energy crises, emphasizing the urgency for sustainable alternatives within the building sector. Therefore, the 20th century marked an important shift in the global narrative as sustainability gained prominence (Kidd, 1992, p. 2). At its essence, sustainability[3] requires the capacity of a system to meet the needs of future generations to ensure a balanced and responsible approach to resource application (Kuhlman and Farrington, 2010, p. 3437). In response, numerous developed and developing countries actively advocate for the use of local materials, aligning with efforts to fortify sustainable building practices. This signifies a transition towards conscious building, with the integration of local resources demonstrating a commitment to curbing the environmental influence of architectural projects (Yin et al., 2020). Notable instances of this global trend encompass the usage of straw bales in building practices in the USA and China, the favouring of bamboo as a sustainable building material in Ecuador, and the widespread embrace of earth roofs in diverse regions across Africa. These examples highlight successful initiatives in sustainable building construction, showcasing the potential positive influence of prioritizing local resources.

Besides, the meticulous selection of ecological materials has become a crucial aspect applicable across various architectural practices, providing a building technique that acts as a viable alternative to the environmental issues associated with carbon footprints and the carcinogenic nature of

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[3] Kidd (1992, p. 2) notes that the term “sustainability” was initially introduced in 1972 and gained academic recognition from 1978 onward.

chemicals commonly used in building processes (Tambouratzis et al., 2014, p. 508). On the other hand, bio-based materials like silk and wood from living creatures and plant-based materials like cellulose, hemp, bamboo from plants often encompass agricultural wastes as a primary component (Ashori and Nourbakhsh, 2010). These materials apply organic matter derived from agricultural sources, such as crop residues, straw, husks, and other by-products of farming activities. Repurposing this agricultural waste offers sustainable alternatives for various applications in construction, packaging, textiles, and other industries. Moreover, the usage of agricultural waste in bio-based and plant-based materials contributes to waste reduction, resource efficiency, and the promotion of circular economy principles (Shogren et al., 2019). In this context, agricultural by-products, notably straw, stand out as a noteworthy economical solution with versatile applications. Straw, often perceived as an agricultural waste product, has gained recognition as a sustainable building material. Its use in architecture matches with sustainability principles, presenting an eco-friendly substitute for traditional materials. The adaptability of straw as a building material is evident in its capacity for decomposition, integration into the soil for recycling purposes, or as a source of energy through controlled burning. Nevertheless, the practice of burning straw poses significant environmental problems, notably contributing to the emission of a substantial volume of CO2 into the atmosphere. This environmental concern has prompted regulatory bodies, such as the European Committee, to actively discourage farmers from participating in straw burning in fields, implementing measures like reducing financial support (NIDUS Team, 2021).

Anthropologically, the use of straw as a building material dates back approximately 40,000 years, with evidence from the Palaeolithic Age in Africa (Marks, 2005, p. 11). Furthermore, Magwood et al. (2005, p. 5) state that they are as old as humanity. In these early instances, Africans ingeniously employed straw by skilfully knitting and interlocking the material, establishing a pioneering practice in architectural history. Following the ground-breaking use of straw in African structures, its prevalence expanded across various cultures and regions. Thus, the adaptability of straw as a building material allowed for its incorporation into diverse architectural traditions, displaying its enduring significance throughout human history as an eco-friendly and versatile resource. However, the first modern documented straw bale buildings emerged in the mid-19th century in American western Nebraska (Li, 2012, p. 3815), marking the inception of a global trend. Subsequently, this innovative method spread worldwide. According to Mutani et al. (2020), the timeline of straw bale houses continued to evolve, with France witnessing its first in the 1920s, England in the 1970s, and Italy in the 2000s. Actually, straw bale construction gained popularity in the 1980s, and since then, it has spread to over 50 countries worldwide (CASBA[4], 2019, p. 1). In Northern Europe, thatch and straw are commonly found to be used in roofing and wall building, often combined with soil, clay, and sand to enhance structural integrity (Shaffer, 1993). Eastern Europe, particularly in Poland, embraces straw in the roofs of traditional houses. Advancing eastward to China, historical building techniques demonstrate the enduring application of straw in roofing and wall components. According to Dudzinska and Staszowska (2021, p. 818), the modern adoption of straw bale technology in northern China dates back to 1998, illustrating the adaptation of ancient practices to contemporary architecture. This presents the enduring relevance of straw as a versatile and sustainable building material across various global contexts. Today, its popularity continues to grow worldwide, especially in Europe, driven by its eco-friendly and economically viable attributes, positioning it as a compelling alternative in the architectural sector.

Method

The methodology adopted for this study employs desk research, specifically through an extensive literature review, which falls under secondary research that relies on previously published materials (Woolley, 1992, p. 227). Therefore, the study will primarily concentrate on gathering information about straw bale, an ecological material commonly used in architecture, from published sources, rather than acquiring first-hand data. This approach focuses on the systematic collection and analysis of existing data and information from diverse sources, including books, journals, online databases, and reports related to the use of straw bales as an ecological building material. By exploring the existing body of knowledge on the subject, the research tries to provide a detailed and insightful analysis of the sustainability aspects associated with the usage of straw bales in

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[4] An acronym for California Straw Building Association

construction and architecture. The outcomes of this literature review aim to contribute valuable insights to the broader discourse on sustainable building practices.

Characteristics of Straw Bale

At its core, straw represents the residual stalk material left after seed crop harvesting. Distinguishing it from hay, which is finer grass used for feeding livestock (Hollis, 2005, p. 6), the choice of straw type significantly affects its suitability for building. Common styles include wheat, oats, rye, barley, and rice, the latter showcasing higher silica content. However, the key factor is not the specific form but rather the moisture content, typically ranging from 12% to 15%. Dry, uniformly baled, and well-compacted straw is deemed suitable for construction purposes. Conversely, hay bales are discouraged in buildings due to their higher moisture content, softer composition, and increased cost compared to straw. Therefore, the crux of straw's suitability lies in its dryness, regular shape and firm compaction. Meeting these criteria, various straw types can effectively serve as building materials, illustrating the adaptability and accessibility of this resource.

Indeed, the exercising of straw bales in architecture has gained prominence owing to its eco-energy-saving characteristics (Li, 2012). In this context, Walker et al. (2016, p. 130) highlight that wheat straw is widely used for straw bale construction in Europe because of its abundance, whereas rice straw is more frequently employed in the United States and Asia. This regional distinction in straw selection demonstrates the adaptability of this resource to local agricultural contexts. However, the origins of straw bale building in the USA in the late 19th century, as emphasized by D'Alessandro et al. (2017), can be traced back to the invention of mechanical baling machines as displayed in Figure 1. This technological breakthrough revolutionized straw utilization, enabling efficient and standardized bale production. The relatively recent history of straw bale building in the USA contrasts with its long-standing presence in European agricultural practices, illustrating the dynamic evolution of this sustainable building method over time.

Figure 1. Example of mechanical straw balers (Lehner et al., 2021).

To comprehend the composition of straw, it is essential to distinguish between its two main components: nodes and internodes. Walker et al. (2016, p. 131) explain that nodes indicate the locations where a plant's leaves emerge, while internodes make up the hollow tube sections characteristic of dried cereal straw. This dual structure is fundamental to the overall composition of straw, consisting of three primary chemical compounds: cellulose, hemicellulose, and lignin. Together, these constituents make up approximately 90% of the dry mass of straw. Harper and Lynch (1981) further highlight that the remaining portion includes water-soluble elements and ash. Notably, the insoluble ash fraction contains silica, a crucial element that imparts various advantages to the usage of straw in architecture. The presence of silica in straw offers specific benefits, affecting how it burns and its digestibility. According to Harper and Lynch (1981), the silica content presents challenges in the combustion of straw, particularly in applications such as power generation, aligning with current environmental concerns related to pollutant emissions. Additionally, the reduced digestibility associated with silica content points to the potential longevity and durability of straw-based architecture, making it resistant to certain forms of degradation. Also, according to Brojan et al. (2015, p. 99), building using straw bales offers a sustainable, renewable, and tested substitute for conventional building techniques. Thus, the inherent renewability of straw positions straw bale as a viable solution in the pursuit of sustainable building practices. This approach disputes with conventional methods, presenting a proven alternative that adjusts with environmental and resource conservation objectives.

The benefits of straw bale construction extend beyond mere sustainability, encompassing significant advantages in terms of costs, human health, and environmental influence (Cascone et al., 2019, p. 1). Notably, cost-effectiveness is a key advantage, as straw is often an agricultural by-product readily available at a low cost. In this manner, the affordability of straw bales contributes to the economic viability of projects, reducing overall costs compared to traditional building materials. Furthermore, the use of straw bales in architecture positively influences human health. Unlike traditional materials that may emit harmful substances, straw bales are non-toxic and do not contribute to indoor air pollution. This characteristic enhances indoor air quality, promoting a healthier and safer living environment.

Straw Bale as Building Material

As stated before, the usage of straw bales in architecture has gained significant scrutiny, mainly due to their high quality for enhancing sustainable and energy-efficient building practices. This pioneering effort catalysed a growing interest in exploring the myriad possibilities that straw bale offers in the realm of eco-friendly and economic architecture. On the other hand, extensive research indicates that straw bale walls exhibit commendable insulating performance, boasting high thermal inertia. Their suitability for green buildings is further accentuated by the fact that straw obviates the need for industrial processes and is inherently degradable (Mutani et al., 2020). Notably, Prefabricated Straw Bale Construction (PSBC) has emerged as an exceptionally efficient method, particularly in cold climate regions, to achieve low-energy buildings with minimal environmental issues (Yin et al., 2020).

The suitability of climates for straw bale buildings emerges as a crucial factor in their construction, with research emphasizing the adaptability of this method across diverse environmental conditions. A key focus revolves around factors such as moisture levels, temperature, and relative humidity to ensure optimal performance. However, existing research has placed a significant emphasis on identifying climatic conditions suitable for straw bale buildings, with a particular focus on severe cold regions (Cascone et al., 2019).

Studies on the usage of lime render have revealed its effectiveness in sustaining appropriate breathability and establishing favourable hygrothermal conditions for the straw enclosed in straw bale walls, particularly in the extremely cold climates of China (Yin et al., 2020). Thorough examinations have also studied the effect of passive ventilation on the interstitial hygrothermal environment within straw bale walls. These studies underline the critical role of wisely managing moisture levels across diverse climatic conditions, with an acknowledgment of the unique issues posed by different environmental contexts (Holzhueter and Itonaga, 2014). While the versatility of straw bale construction has been demonstrated across various climates, a critical consideration remains the long-term durability characteristics, especially in specific climatic regions. This emphasis is crucial to ensure the sustained viability of straw bale building as a low-carbon, energy-efficient method (Yin et al., 2020). Therefore, comprehensive evaluations of climatic conditions become integral in determining the success and resilience of straw bale architecture over time.

Furthermore, straw bales may not be suitable for regions prone to extreme and persistent wet conditions, as excessive moisture can compromise the structural integrity and thermal performance of the straw bales (Costes et al., 2017). In such climates, alternative building materials or additional moisture management strategies may be more appropriate. However, researchers have conducted comprehensive monitoring of moisture levels within straw bale walls, revealing the straw's capacity to act as a moisture buffer. This particular characteristic contributes significantly to fostering a healthier internal environment while adeptly managing humidity levels within the building structure. Such findings highlight the multifaceted and adaptive nature of straw bale constructions in addressing climate-specific considerations and maintaining optimal conditions for both the building and its occupants (Lawrence et al., 2009).

Based on the available references, it becomes evident that the safety of straw bale buildings in earthquake-prone regions is a nuanced and intricate matter, demanding a meticulous examination of diverse contributing factors. It should be kept in mind that the existing references do not explicitly study the suitability of straw bale buildings in seismic regions. The predominant focus of these references tends to centre around the thermal, acoustic, and environmental aspects of straw bale buildings, offering limited direct discourse on their safety implications in the context of earthquakes. This notable gap in the literature suggests the need for further investigation and comprehensive understanding to address safety concerns in seismic-prone areas.

Figure 2. Straw bale house
(Source: https://www.hollowayconstruction.nz, URL 1)

Actually, integrating straw bales instead of bricks or blocks into wall building demands a precise examination of their properties[5]. Laboratory investigations have studied assessing the bearing capacity of straw bales, particularly for low-rise building applications. This emphasizes the critical role of the strength of straw bale walls, especially in supporting the roofs of single-story structures (Cao et al., 2021). Furthermore, experimental investigations have concentrated on using straw bales as load-bearing components in constructions with contemporary approaches to improve the characteristics of traditional building materials (Lehner et al., 2021). While the promise of straw bale architecture is evident, problems associated with its implementation have not been overlooked. In this regard, the rapid development of straw bale walling systems has been highlighted, with potential solutions to address risk issues. This development holds the promise of providing the foundation for comfortable and sustainable buildings, emphasizing the importance of adapting appropriate solutions to mitigate potential risks (Goodhew et al., 2010).

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[5] Amazon Nails (2001) mentions that straw bales are much more cheaper than bricks and blocks.

According to FASBA[6] (2020), as seen in Table 1, the size of straw bales in construction is primarily determined by the dimensions of the press channel used during the baling process, specifically its height and width. While the length of straw bales can vary, even within the same press, the cross-section of the press channel plays a crucial role in shaping the dimensions of the bales. Typically, small straw bales measure approximately 36 cm x 48 cm, with lengths reaching up to about 1.10 m, although they are often around 85 cm long, and weigh about 15 kg (Lecompte and Duigou, 2017; FASBA, 2020). On the other hand, large straw bales are commonly found in dimensions of 70 cm x 120 cm or 90 cm x 120 cm, with lengths averaging around 2.40 m. While it is feasible to produce small bales from large round bales, the quality of the straw bales is typically higher when they are pressed directly into small bales in the field.

Table 1: Straw Bale Size in Construction (FASBA, 2020).

Size (cm)	**Height**	**Width**	**Length**
Small Bale	36 cm	48 cm	Up to 110 cm (usually up to 85 cm)
Large Bale	70 cm	120 cm	Up to 240 cm

It should be noted that straw bale construction covers the direct use of straw bales as a key building material in structural and insulation applications as foundational components in building walls. In addition to using straw bales as standalone building components, the straw can also be used as a binder or aggregate in other construction materials such as adobe bricks or in compressed straw panels. Obviously, the growing usage of straw bales in construction can be attributed to a myriad of benefits that they offer, positioning them as a promising element in contemporary building practices. Their significance lies in their remarkable thermal insulation properties, characterized by a greater thickness compared to many conventional insulating materials (Mehravar et al., 2022; Teslík, 2021). This attribute renders straw bales particularly suitable for load-bearing walls in lightly loaded low-rise buildings (Thomson and Walker, 2014). One of the defining aspects of straw bales is their status as a renewable raw material, in architecture with minimal environmental problem (Vaňová et al., 2021). As mentioned before, extensive

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[6] Straw Bale Construction Association in Germany

research has stated the efficacy of straw bales in providing excellent insulation, high thermal inertia, and facilitating energy-economic savings. In this regard, the structural composition of straw bales, teeming with millions of tiny air pockets, effectively traps heat within walls, ensuring superior thermal comfort throughout a building. Notably, the larger thickness of straw bales compared to conventional insulating materials enhances their thermal insulation capacity, rendering them especially appealing in cold climates and arranging with energy efficiency goals (Costes et al., 2017; Cascone et al., 2019). Consequently, they emerge as fitting components for the making of green buildings (Mutani et al., 2020). When considering the durability aspect, straw bale architecture has demonstrated pretty mechanical properties, positioning it as a viable choice for small buildings (Njike et al., 2020). However, it is imperative to acknowledge that the load-carrying capacity of plastered straw bale assemblies impose limitations, confining their use predominantly to single-story structures (Njike et al., 2021). Research has examined the long-term durability characteristics of straw bale construction, especially in specific climatic regions, ensuring its viability as a low-carbon method (Yin et al., 2020). In this regard, exploring the integral relationship between plastering materials and the thermal performance of straw bale building models has been a focal point of inquiry. This underscores the significance of careful consideration of the materials used in conjunction with straw bales to optimize their overall performance (Adedeji et al., 2018). Additionally, the implementation of passive ventilation has emerged as a strategic approach to mitigate excessive moisture in straw bale buildings, especially in specific regions (Holzhueter and Itonaga, 2014).

However, it is imperative to acknowledge potential handicaps, particularly related to moisture content and the risk of mold growth within straw bale walls under specific environmental conditions (Lawrence et al., 2009; Holzhueter and Itonaga, 2010). Addressing these problems through careful design and architecture techniques becomes crucial to ensure the sustained and long-term performance of straw bale buildings. Furthermore, its limited adoption in the self-build fringe sector and concerns about misconceptions and the scarcity of skilled labour contribute to the disadvantages associated with straw bale (Lawrence et al., 2009; Koh and Kraniotis, 2020; Erbil et al., 2018). Demonstrating these problems necessitates strategic solutions to enhance the overall performance and acceptance of straw bale construction. This can be accomplished through the incorporation of additional insulation materials or the implementation of specific techniques designed to improve the walls' thermal inertia (Cascone et al., 2019). To counteract the uneven distribution of straw within bales during building, proper handling and processing of straw before use become crucial aspects of the solution.

Besides, the potential degradation of straw bales due to exposure to high humidity and liquid water calls for the implementation of appropriate moisture barriers and building techniques. Safeguarding straw bales from moisture intrusion ensures their longevity and sustained structural integrity (Goodhew et al., 2005; Yin et al., 2020). Additionally, presenting the lack of common information and realizations of straw bale architecture involves educational initiatives aimed at increasing awareness and understanding of the method. To address problems related to moisture management in straw bale, architects and builders have proactively adopted passive ventilation strategies, underscoring the importance of effective moisture control in the process (Holzhueter and Itonaga, 2014). Below in Table 2, the advantages and disadvantages of straw bale construction are summarised:

Table 2: Advantages and Disadvantages of Straw Bale Construction

Advantages	Disadvantages
Excellent thermal insulation properties	Risk of mold growth in specific environmental conditions
Renewable and sustainable material	Limited adoption in the self-build fringe sector
Low embodied energy	Concerns about misconceptions and scarcity of skilled labour
High durability and load-bearing capacity	Moisture content issues may affect performance and longevity
Eco-friendly and contributes to circular economy	Potential degradation due to exposure to high humidity and liquid water
Low-carbon building material	Uneven distribution of straw within bales during building
Sophisticated aesthetic appeal	Limited common information and awareness of straw bale architecture
Fire resistance	
Acoustic insulation benefits	

Construction Methods with Straw Bale

The construction of buildings utilizing straw bales involves a nuanced interplay of methods and considerations, reflecting the multifaceted nature of this sustainable building practice. Principally, straw bales find a niche in serving as load-bearing elements for lightly loaded low-rise buildings (Thomson and Walker, 2014). This endeavour encompasses diverse techniques, including the direct filling of walls, the compression of straw into straw-clay building blocks, and the prefabrication of straw-brick walls (Luo and Lu, 2020). The incorporation of these diverse methods and considerations not only matches with sustainability goals but also reflects the versatility of straw bale as a conscious choice in the building sector (Yin et al., 2020). Furthermore, the sophisticated appeal of straw bale construction extends to its recognized attribution of durability, aesthetic appeal, and fire resistance (Ashour, 2010). In this respect, Koh and Kraniotis (2020) claim that well plastered straw bales exhibit remarkable fire resistance, making them a safe choice for homeowners. Beyond the properties, ongoing studies bolster confidence in straw bale as a low-carbon building material, contributing to mainstream practices (Lawrence et al., 2009). The acoustic benefits of sound insulation further enhance the indoor environment, ensuring a comfortable living space (Teslík et al., 2017). Specialized techniques for integrating straw bale with conventional house building components, including floors, timber wall-frames, ceilings, and roof framing, exemplify the versatility and adaptability of this construction method (Hodge, 2006).

Apart from prefabricated straw bale houses[7], straw bale construction generally falls into two main methods: load-bearing (Figure 3) and infill (Figure 4) which are applied to wall building. Load-bearing construction, also known as the Nebraska style, covers using straw bales as an integral part of the building's structural support system. The bales are placed on a solid foundation and serve as support for the roof. They are typically coated with a layer of clay or lime plaster to protect them from weathering (Peng et al., 2021).

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[7] Prefabricated straw houses are constructed using pre-made components made from straw bales, providing an eco-friendly and sustainable building option.

Figure 3: Load-bearing Straw Bale House Construction. Photo Virko Kade (Fromm, 2022).

The primary advantage of load-bearing approach is its simplicity. This method offers considerable design flexibility which requires minimal craftsmanship and is therefore popular among owner-builders seeking a modest home with a lower ecological footprint. On the other hand, non-load-bearing straw bale construction, or infill, involves using straw bales as additional insulation within a conventional wood or steel frame structure (Figure 6). The bales are placed between the wood or steel beams and serve as thermal insulation (Maskell et al., 2015). An outer protective layer, such as clay or plaster, is applied afterward. This method combines the benefits of straw bale construction with the flexibility of other building techniques.

Figure 4: Load-bearing Straw Bale Wall (left). Photo Z Architektur (Fromm, 2022), and infill Straw Bale Wall (right). Photo Bruno Mader (Jeske, 2021).

Below, in Figure 5, depicted are load-bearing and infill walls characteristic of straw bale construction (Cascone et. al., 2019). Common elements shared between both types of walls include the foundation, sill plates, plaster, and the straw bales themselves. These foundational components form the basis of straw bale construction, providing stability and support to the structure. However, the infill walls feature an additional element: the beam and post. These structural elements are integral to the infill construction method, providing further reinforcement and support to the building's framework.

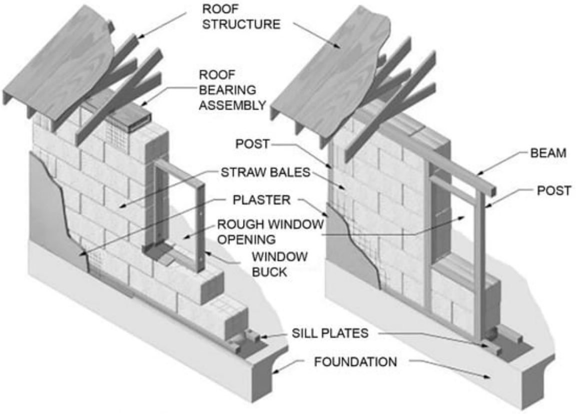

Figure 5. Load-bearing (left) and infill (right) straw bale walls (Cascone et. al., 2019).

One of the essential aspects of straw bale construction is the choice of plaster materials used to cover and protect the straw bales. Among the most commonly applied plaster materials are cement, lime-based, and clay-based plasters (Ashheim et al., 2015). These plaster types are favoured for their unique properties, including breathability, durability, and the availability of experienced applicators. Breathability is particularly crucial in straw bale construction as it allows moisture to escape, preventing the accumulation of moisture within the walls, which could lead to mold or decay. Additionally, durability ensures the longevity of the plaster, protecting the underlying straw bales from weathering and damage. The availability of experienced applicators further enhances the appeal of these plaster materials, ensuring proper application and a high-quality finish for straw bale structures (Brojan and Clouston, 2014). Consequently, the careful selection of plaster materials is paramount in ensuring the success and longevity of straw bale construction projects.

Figure 6. House of Straw. Constructed with infill method (qtd. Gallagher, 2022).

Actually, constructing a straw bale house is a hands-on process that varies depending on whether to choose common methods or prefabricated straw bale systems. Generally speaking, the actual assembly of straw bale walls takes several days to weeks, while the entire project—which includes preparing foundations, installing electrical and plumbing, and finishing the interior—can span months to years, depending on the complexity of the design and the skill level of the builders. Thus, constructing a straw bale house traditionally is a lengthier endeavour, whereas prefabricated systems may speed up the process, but precise timing depends on the specific project.

Conclusion

This study has reviewed the use of straw bales in construction, exploring their historical significance, ecological benefits, and global adoption. Obviously, straw and straw bales emerge as compelling alternatives in the realm of sustainable building materials. The renewable nature, low cost, and positive effect on human health make straw an attractive option for eco-conscious architecture. When formed into straw bales, these materials offer a proven and sustainable alternative to mainstream building methods, fostering a cost-effective, and health-conscious approach to construction, matching with the global movement towards environmentally responsible practices. However, despite the benefits in insulation and environmental sustainability, the current application of straw bale buildings is primarily limited to low-rise and single-story structures. Further research and development are necessary to address structural requirements for integrating straw bale architecture into urban environments and high-rise buildings. Nevertheless, straw bales show promise for sustainable, energy-efficient, and low-carbon building solutions, supported by their thermal insulation properties, renewable nature, and potential for energy savings.

The construction of buildings with straw bales involves various methods, such as load-bearing, infill, and prefabricated straw-brick walls. Ensuring the long-term durability, thermal performance, and moisture management during the process are essential to consider the viability and sustainability of straw bale construction. Moreover, while there are indications that the deformations of straw bales may reduce structural damage after earthquakes, specific safety considerations during seismic events require further research. Conducting comprehensive structural assessments and adhering to building codes and regulations for seismic regions are essential to ensure the safety of occupants in straw bale buildings during earthquakes.

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