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Larisa Brojan, Peggi L. Clouston

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PREDNOSTI IN SLABOSTI UPORABE BAL SLAME PRI GRADNJI

ADVANTAGES AND DISADVANTAGES OF STRAW-BALE BUILDING

izvleček

V članku se osredotočamo na osnovne lastnosti bal slame kot gradbenega materiala. Bale slame so dokazano ustrezno gradivo, v kolikor se pri načrtovanju in izvedbi upošteva njegove specifične lastnosti. Kljub številnim realizacijam je še vedno navzoč dvom o uporabi tega alternativnega gradiva. Tehnike gradnje s tem gradivom so relativno enostavne in hitro priučljive, rezultati take gradnje pa z upoštevanjem smernic in zahtev nudijo številne kvalitete. Med največkrat izpostavljenimi kvalitetami uporabe bal slame pri gradnji je nizek ekološki odtis. Hkrati je bala slame učinkovita pri zagotavljanju ustrezne toplotne in zvočne izolativnosti stavbe.

Mnogo predhodnih raziskav je osredotočenih na preučevanje konstrukcijskih karakteristik, požarne odpornosti in vpliva vlage na bale slame. Upoštevanje omenjenih področij je pri načrtovanju objektov iz bal slame nujno, na ustrezno delovanje stene pa vplivamo tudi z izbiro ometa. Z vrsto ometa ne vplivamo le na ustrezno zaščito slame pred vlago, ampak zagotavljamo tudi požarno odpornost in konstrukcijsko stabilnost sten iz bal slame. Ena večjih pomanjkljivosti, vezanih na obravnavano gradivo, je tudi relativno nizko število opravljenih raziskav.

Članek je razdeljen na tri dele. V prvih dveh delih so predstavljene prednosti in slabosti uporabe bal slame pri gradnji. V tretjem delu so predstavljeni rezultati izvedene ankete, v kateri so uporabniki stavb iz bal slame opredmetili prednosti in slabosti obravnavane gradnje na osnovi osebnih izkušenj.

abstract

This paper is focused on general properties of straw bale as a building material which has been proven by buildings throughout the world to be an appropriate material choice. Still, there are many hesitations about using this alternative building material. The building techniques are relatively easy to learn and the performance of straw bale structures has a high value in terms of several aspects as long as general requirements are followed. The primary benefit of straw bale as a building material is its low embodied energy. It also has high thermal and sound insulation properties. Many previous research studies on straw bale building have been focused on structural stability, fire resistance and assessing moisture content in straw bales which is one of the major issues. Therefore, special attention needs to be devoted to details to insure proper building safety. Render selection is especially crucial and an extremely important step in straw bale building, not only in matters concerning moisture but also structural capacity and fire protection. A major disadvantage of straw bale construction is its lack of material research. The paper is divided into three parts in which advantages and disadvantages of such a building are discussed. In the third part, results are presented for a survey in which correspondents emphasized the advantages and disadvantages of living in a straw bale building.

ključne besede
prednosti, slabosti, bala slame, gradnja, anketa

key words
advantages, disadvantages, straw bale, building, survey

Introduction

Straw bale building is recognized and practiced worldwide. Since the construction of the first such building in the 19th century in USA, several straw bale building techniques have been developed and successfully implemented practically in every country in the world. Straw bale buildings are built by owners and investors as a result of their desire for natural and environmentally friendly buildings. The idiosyncrasies and perceptions of straw bale construction prevent its universal adoption in the building industry - its use being mainly restricted to suburban and rural applications.

Despite the positive qualities outlined by many researchers, there has yet to be a breakthrough of straw bale as a serious building material on a global scale. Recently, however, straw bale buildings have branched out from residential use and have been built for the commercial sector with the erection of buildings specific for public use. Beside many straw bale houses, many commercial buildings in larger scale (over 3 stories high and with useable area over 1000 m^2) have been erected. The most notable examples are the Gateway Building in UK (3100 m^2), (see Figure 1), North German Centre for Sustainable Construction in Germany (1800 m^2) and Sanierung Complemedis AG in Switzerland (3145 m^2).

The choice of basic building materials is an important part of each project and is usually based on professional judgment, taking into consideration the importance of various criteria such as economic, environmental, functional, aesthetic and health aspects. The priority varies depending on the needs, desires and abilities of each user/investor usually in agreement with the designer. Choice of basic building material is also based on consideration of many other factors and its properties. In this paper the most evident properties of straw bales as advantages and disadvantages.

Slika 1: Vstopni objekt, Nottinghamska univerza, VB.
Figure 1: Gateway Building, University of Nottingham in UK.

Low impact on the environment is one of the key benefits of straw bale building [Brojan et al., 2013; Sodagar et al., 2011; Garas et al. 2009]. Straw bale houses rendered with loam and lime have demonstrated excellent results in terms of fire and earthquake resistance, heat and sound insulation values - (almost ten times as much as wood and bricks), energy efficiency, and they require minimum maintenance [El Gowini, 2002]. Yet, there are still many concerns among potential investors and builders who address most of the concerns to fire safety, moisture problems, structural stability etc. of straw bale building.

Methods

The aim of this paper is to investigate the advantages and disadvantages of straw bale building. The properties being discussed have also been verified with survey results. The research is divided into three parts. In the first two parts, advantages and disadvantages are discussed and a descriptive research method is used. In the third part, an empirical research method is used and a survey results are presented in which correspondents emphasized the advantages and disadvantages of living in a straw bale building. For the purpose of ongoing research, a survey was created and over 30 questions were sent to over 500 straw bale building owners. The survey questions followed the format of previously conducted surveys on similar topics of natural building [Wihan 2007, Thompson 2006]. Altogether, 166 responses were received.

Advantages

For the purposes of this paper, the most noticeable advantages of straw bale as a building material are presented:

Straw availability

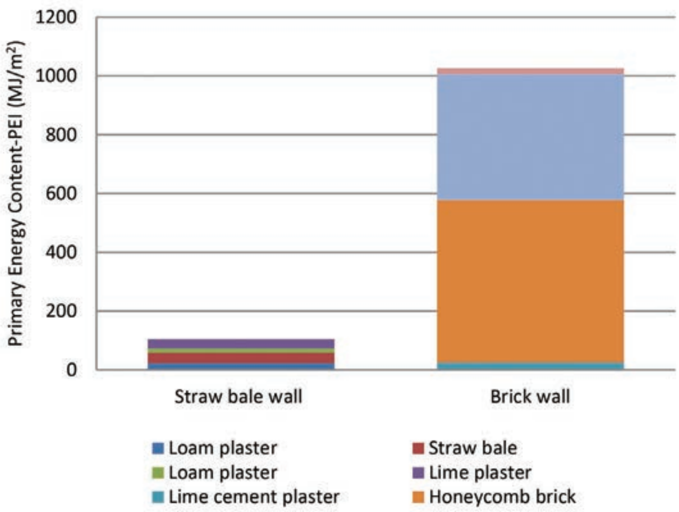
Remains of grain harvesting are insured annually in enormous amounts [FAOSTAT, 2013]. Even in a bad year millions of tons of straw have no use and have to be ploughed back; for example, in 2007, rain ruined the harvest and 2.37 million tons (40% of all produced) straw was wasted [Barbara Jones 2009: 20],. With this amount of straw in Britain alone, more than 420 000 houses with area of 150 m^2 could be built [Jones, 2007: 13]. With annually produced straw in Germany, over 350000 single family houses (150 m^2) could be built [Minke in Mahlke, 2005: 11], in Slovenia over 17 000 houses.

Ecology aspect

Alcorn et al. [1995] affirmed that using biomaterials, such as straw, timber, and emission-reducing technologies, for house design and construction reduces CO_2 emissions towards net zero. This was shown using a life cycle analysis of different house designs with comparison of the effectiveness of biomaterials with CO_2 - minimizing technologies. Furthermore, Garas et al., [2009] presented an ecological and economical aspect of building with straw bales. Their main focus was comparison between a load bearing wall unit built with locally produced rice straw bales and a traditional load bearing wall unit built with cement bricks. One finding r was that a cost saving could be achieved in favor of straw bale building of about 40 % of the total construction cost, in addition to the indirect cost saving in energy consumption and thermal insulation. Sodagar et al. [2011] compared whole-life performance of load-bearing straw-bale wall construction with alternative conventional external wall systems. Evidence demonstrated the viability and performance benefits of straw-bale housing for rural communities. Brojan et al. [2013] also studied comparative environmental impact by calculating different parameters (PEI, GWP and AP) for two types of walls (straw bale and brick) with an area of 1 m^2. The results confirmed a much lighter environmental footprint for straw bale. Regarding the environmental impacts of the discussed walls, the results show that the brick wall requires 985,65 MJ of primary energy (PEI), which is approximately 10 times more than the straw bale wall, where the energy consumption is 104,83 MJ, Figure 2 [Brojan et al., 2013].

Insulation properties

Combining straw bales and solar orientation can create a very comfortable and efficient building [Garas et al. 2009: 54]. As confirmed by many tests, the thermal conductivity of straw bales is comparable to values of other insulation materials; for example, a bale thickness of 45 cm provides 0,05 W/mK [Waldland, 2013]. Furthermore, the acoustic insulation of the same thickness ranges between 43 and 55 db [Minke in Mahlke, 2005]. The thermal transmission (U) of a straw bale wall easily meets the standard of passive house for which U is required to be lower than 0,15 W/m^{2}K [Zabšnik-Senegačnik, 2007] or more often lower than 0,10 W/m^{2}K. Brojan et al., [2013] calculated U of a clay plaster – straw bale – clay and lime plaster wall composition to be 0,12 W/m^{2}K. Therefore, neither heating nor cooling of straw bale building is challenging, assuming that the floor plan design is well designed (eg. in terms of position and size of openings/windows) and details are appropriately considered and built.



Slika 2: Vrednost primarne vgrajene energije za steno iz bal slame in steno iz opeke.
Figure 2: PEI value comparation by layers for researched walls.

Slika 3: Hiši iz bal slame v Šulincih (a) in Celovcu (b).
Figure 3: Straw bale house in Šulinci (a) and in Celovec (b).

Design options

Straw bale makes a unique structure that is appealing to many, and is especially suited to the owner-builder. Straw bale modular construction allows for a faster wall erection and a flexible design, such as, integrating deep windows, deep overhangs, curves, etc. Straw can also be incorporated into modern architectural plans because of its adaptability and applicability, see Figure 3 a) and b). This is proven by many straw bale buildings around the world, which all present a variety of design solutions in combination with other materials such as, timber, clay, steel, concrete and glass. Applications such as these create contemporary architecture and enable a wide range of designs [Brojan, 2013]. The design is completely flexible when straw bales are used as infill; whereas, load bearing straw bale design is more rigid and strict, particularly in the matter of wall dimensions and opening sizes.

Disadvantages – drawbacks

The most often discussed and highlighted problems of straw bale building are its vulnerability to moisture, fire and structural instability. Many tests related to these problems have been conducted for which findings conclude that if care is taken, problems can be overcome. Test results have led to certifications of straw bale as an appropriate infill building material. The most recent such certificate (Z-23.11-1595) was issued by DIBt – German Centre of Competence for Construction (Deutschen Institut für Bautechnik) in June 2014 [FASBA, 2014].

Humidity and moisture

Moisture control is critical for straw bale builders because of the moisture sensitivity of the materials [Straube, 2006]. Without proper design and building procedures, straw will rot. Straw bales must be kept dry, both during and after construction. The highest acceptable range of moisture content is between 20-25% [Wihan, 2007]. But, as practice shows, most builders use straw bales with moisture content around 10 % [Morrison, 2012]. Straw bale walls should remain breathable, and protected with good anti-moisture barriers. Straube [2006: 139] outlines the four major sources of moisture and the wetting mechanisms involved for a building's enclosure as follows:

1. Precipitation, especially driving rain, whether wicked, leaking through the cladding, or splashed upward from grade.
2. Water vapor in the air transported by diffusion and/or air movement through the wall (from either the interior or the exterior).
3. Built-in and stored moisture.
4. Ground water, in liquid and/or vapor form, wicked up through the foundation or through cladding that touches the ground.

According to Straube, [2006: 141], moisture is usually removed from an enclosure by:

1. Evaporation of water transported by capillarity to the inside or outside surfaces.
2. Vapor transport by diffusion, air leakage, or both, either outward or inward.
3. Drainage, driven by gravity.
4. Ventilation (ventilation drying), which is not usually effective for straw bale enclosures.

It is important to provide a separation between foundations and straw bales (i.e. toe-ups) to prevent ground water from reaching the straw bales. The first layer of straw bales should be kept at a minimum of 20 cm from the ground level. Wihan [2007] reported that appropriate plaster should be selected based on the building location and the average relative air humidity. He further concluded that earth plaster seems to be the favorite wall cover for both sides of straw bale walls. Straube [2014] also tested different plasters (i.e. cement, lime, earth/clay) and their mix ratios. His main conclusions were that:

1. Cement based plasters are relatively vapor impermeable,
2. The addition of lime to a cement plaster mix increases permeability. As the proportion of lime is increased, the permeability increases, and
3. Earth plasters are generally more permeable than even lime plasters.

Fire resistance

General perception is that straw bale buildings are inherently weak and susceptible to fire; when designed and built properly, however, straw bale houses can be strong and highly fire-resistant. In general, once a bale wall has been plastered on both faces, the combination of an incombustible surface and an insulating interior that neither burns well nor melts makes an exceptionally fire-resistant assembly [Theis, 2003]. Theis [2003] reviewed five lab tests which all verified the fire resistance of straw bale walls. His report stated that straw bale construction would require little or no additional testing to be readily acceptable for uses such as urban infill, row housing, commercial, retail, and educational buildings. This conclusion was made despite the acknowledgement that fire safety concerns are rising as building and population density increase. The test report also includes straw bale inflammability. Inflammability of straw bales is categorized with a class E as it is stated in certificate Z-23.11-1595 [FASBA, 2014].

Air tightness of straw bale construction

Research on the air tightness of straw bale construction has been limited and has not isolated the various air leakage pathways through the assembly. Air tightness of straw bale buildings is under-researched in the scientific literature, though data on whole building envelope air leakage are available [Racusin et al. 2011].

The experiment results [Brojan et al., 2014] indicate clearly that straw is a poor air flow retarder, and that construction detailing is extremely important to insure appropriate air barrier performance. The results of the study on the whole also indicate the need of future research on the means of assuring air barrier continuity between different elements of straw bale construction. With solid details at joints, better air tightness performance of straw bale buildings can certainly be achieved.

Structural (in)stability

Straw bales are used either as infill in a post-and-beam structure (see Figure 4), or as a load-bearing system where the bales themselves support the above load. The bale walls are commonly wrapped with stucco netting and plastered with mud, clay, lime or cement plaster. In many cases, the netting has been found to be unnecessary, and plaster is applied directly to the bales. In terms of load bearing straw bale walls, the walls can function as load carrying. Research has shown the technique to be an environmentally sustainable practice primarily due to the attributes of the straw bale [Sodagar et al., 2011]. As a result, the method is gaining interest of late from researchers and practitioners who seek ways to counter the negative impact of building on the environment.

It has also been discovered that load bearing straw bale structures are resistant to higher vertical and horizontal loads. King [1996] mentions a few examples of load bearing straw bale buildings that resist high wind loads. He also gives a simple calculation showing resistance of such a building in environments with extreme earthquake hazard (like in California). The ability of such structures to resist high vertical loads can be justified by a few examples of buildings built in Switzerland designed by architect Werner Schmidt [2014].

So far, only a few building codes allow straw bale load bearing construction. One such code is the proposed appendix on straw bale construction in the USA which was approved by the International Code Council (ICC) in October 2013. The appendix will be included in the 2015 International Residential Code (IRC) for one- and two-family dwellings [Hammer, 2014].

Not enough information or experiments

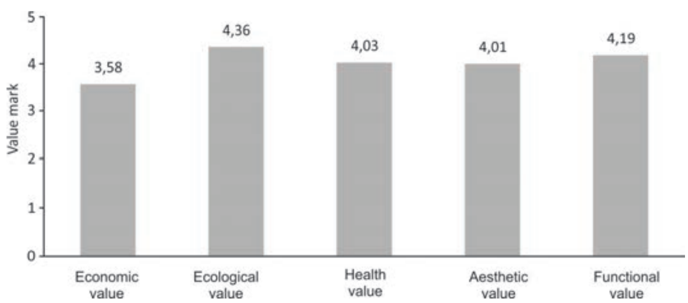
Straw bale building techniques are simple, easy to learn, and require only a few tools to implement. It is a sustainable material with excellent ecological potential. However, straw is still regarded as an alternative building material, marginalized for use in suburban and rural environments where usually the builder is the dedicated owner. Despite its advantages, a general lack of knowledge hinders its use in building and it has yet to be accepted as a universal building material on a global level. In the past few years, however, a few substantial and encouraging straw bale buildings have been erected for commercial use.

User's opinion - survey results

To justify the presented advantages and disadvantages of straw bale building, we created a questionnaire to examine the emphasized straw bale building properties. Over 30 questions were sent to over 500 straw bale building owners. Altogether, 166 responses were received.

Respondents evaluated straw bale building based on five basic attributes of building: economic, ecological, health, aesthetic and functional aspects. In an attempt to put into perspective the relevance and importance of straw bale building, participants of the survey were asked to subjectively compare and contrast and thereby rank the order of importance of these attributes for their building. Each attribute was given grades between 1 (not important) and 5 (extremely important). Within the questionnaire, respondents also had an opportunity to share and

Slika 4: Lesen skelet s polnilom iz bal slame.
Figure 4: Timber frame with straw bale infill.



Slika 5: Povprečne vrednosti ocen.
Figure 5: Average value estimation.

express any comments regarding advantages and disadvantages experienced while living in and using the straw bale building. The results show (n = 166) that investors generally considered all values as very important, but with some differences (see Figure 5): the ecological value had an average mark of 4.36, followed by functional at 4.19, health at 4.03, aesthetic at 4.01 and economic at 3.58. By ranking each value the following order by importance was gained:

1. Ecological value
2. Functional value
3. Health value
4. Aesthetic value
5. Economic value

The ecological value was voted as extremely important by 67 % of people and the average was 4.36. Regarding functional value, 54% of participants considered it to be extremely important. In the case of health, almost a majority of participants consider it to be extremely important (45 %).

Comments regarding advantages experienced while living in and using the straw bale building given by respondents were as follows: the majority of survey participants emphasized a high quality of living environment. Most frequently, a pleasant indoor climate was emphasized in the sense of temperature and relative humidity, low maintenance costs as a reflection of low consumption of heating sources, superior thermal and sound insulation, and a general pleasant feeling inside the straw bale building. Eight percent of respondents did not give an opinion. We have also learn, that 91% survey participants would build again with straw bales.

Considering the disadvantages of straw bale building, the following comments were given by respondents: 30 % of respondents didn't have any negative experience with living in a straw bale house. The biggest disadvantage (20 %) was explained that straw bale building was too labor and time intensive and that it was difficult to find skilled workers to design details that work well in practice, 10 % of respondents mentioned plaster cracks, moisture problems, rodents, difficulties to hang a picture on the wall, and difficulties to get house insurance. In this case, 20 % of respondents did not express an opinion.

Conclusion

Straw is an annually renewable crop, available wherever grain crops are grown. It is indeed a waste product, much of which is currently burned in the field. The thick walls offer superior insulation when appropriately built. And together with natural plaster, straw bale walls "breathe", have excellent sound absorbing and fire resistant qualities providing a quiet, safe, and healthy interior environment. Furthermore, bales are easy to work with, lightweight and require a minimum of tools. Straw bale construction has been shown to be a viable and sustainable building material. However, lack of information and misguided perceptions about the building system currently prevent its widespread adoption. More research is necessary to foster further advances in the technology and more general education efforts on the merits of straw bale building may help elevate it to a mainstream building practice.

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PhD. Larisa Brojan
UL Faculty of Architecture
larisa.brojan@fa.uni-lj.si

Prof. PhD. Peggi L. Clouston
University of Massachusetts
clouston@eco.umass.edu