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Applicability of Gypsum-Doped Adobe (Adobe with Gypsum Dod) Covered with Paddy Straw in Agricultural Structures and Sustainability: Wall Design Application

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Abstract
The combination of factors such as population growth, industrialization, urbanization, changes in production technologies and consumption patterns; cause climate change and environmental pollution problems. Therefore, the concept of sustainability and the transfer of resources to future generations are of great importance. The aim of this study is to design a wall for use in agricultural buildings where the climate effect, especially the wind and rain effect, is minimized and the paddy straw, which is an organic waste, is evaluated. This design is aimed to be sustainable, more sensitive to the environment, consuming less energy, having economical and at the same time ecological advantages, useful and ergonomic that can provide healthy living conditions. Gypsum-doped adobe (adobe with gypsum dod) was preferred as the material. Rice straw was used as the covering material. In order to make the design aesthetic, the De Stijl art movement was tried to be reflected in this wall design. The study consists of four stages. These stages are design process, projecting process, application process, static analysis. In this study, especially by trying to propose a protective, economical and sustainable solution, by building a wall in two directions with a height of 170 cm, in length of 140 cm was built. As a result, resistant, design alternative that minimizes the negative effects of wind and rain has been created for the implementers who will make construction for agricultural purposes. In this case study, It has been tried to offer a protective, economical and durable and environmentally friendly solution against variable climatic and environmental conditions for those who will construct agricultural buildings.

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1. Introduction

With the increase in the world population, the need for buildings has increased day by day, and this has led to problems such as climate change and environmental pollution. So, the protection of the natural environment, sustainable development and the construction of healthy buildings have been the subject of research in many industrialized countries in recent years. Adobe is a local material, it is a building material that is suitable for human health, environmentally friendly, and consumes less energy in its production and use. About 1/3 of the world's population lives in adobe structures. Many examples of our architectural cultural heritage and 28% of rural buildings in Turkey, are made of adobe (Işık, 2000). According to the report titled “Earthquake Risk Assessment and Retrofit Scenarios for Turkey” published in 2021, a total of 9.889.222 buildings are 546.834 adobe structures (Rao et al., 2021).

In recent years, technological developments have affected the countries of the world and affect more than one sector such as construction, health, education, economy and security. The use of high technology has brought environmental pollution. As a result, practitioners and planners, who prioritize environmental protection, have turned to materials that do not use energy in production or require very little energy and provide the least energy and comfort conditions during use (Özgünler and Gürdal, 2012). While the development of technology creates positive effects in the building material market; it also causes pollution of the environment we live in. The production of modern building materials, which are high-tech products, has a great role in the emergence of environmental problems. The negative effects of these materials on the environment are not only limited to production stages, but also continue in the use and consumption processes in buildings. In this case, in order to leave livable environments to future generations, it is inevitable to take measures to prevent environmental pollution (Acun and Gürdal, 2003).

Buildings that consume little energy at every stage, that are built with little cost and ease during construction, that have minimum transportation costs, that are functional, that benefit from materials that can be recycled back to nature after the end of their life, that minimize operating costs, that make optimum use of environmental data and that have traces of local culture are considered sustainable (Aktaş, 2020).

In the construction process, with the development of technology, the use of modern materials has started to be emphasized by moving away from traditional materials in today's conditions. With this modernization process, the use of environmentally friendly, recyclable and sustainable materials that need less energy has started to come to the agenda. In this context, adobe, which is a traditional material, shows itself as an environmentally sensitive building material with a very low energy requirement starting from the production stage to the consumption and use phase. It is among the comfortable building materials that do not require any facility during their production and provide insulation and balance the humidity (Aktaş, 2020).

With the addition of organic fiber or plant residues into the new generation of adobe, balanced, homogeneous drying is achieved, shrinkage and cracking are reduced, strength increases. In Anatolia, straw has been added since time immemorial to increase the strength of the adobe and to prevent cracking (Leblebicier and Akıncı, 2021). Apart from hay, all kinds of grass, sedge, reed residues, plant stems, wood fiber, saw sawdust can also be used. Thanks to these additives, the moisture on the adobe is absorbed and expelled (Aktaş, 2020). In addition, adobe reinforced with gypsum and lime (gypsum-doped adobe) is preferred in many adobe structures. Until today, although many materials such as straw, grass, tree branches, sand, gravel, stone, etc. have been added to the soil material (adobe), sufficient strength has not been achieved. Although some of them have benefits such as reduction of respiration and homogeneous drying, they also bring harms such as insect production and more water absorption (Işık et al., 1995). Though the adobe structure, whose raw material is soil, has a very old history, it is not capable of meeting all of today's requirements. In order to eliminate the negative aspects of adobe and improve its physical properties, straw and similar fibers, bitumen (petroleum, oil, tar, etc.), various industrial wastes, additives such as lime, cement are added to the soil as binders (Çoşkun, 2005).

Concepts such as sustainability and ecology have gained their place not only in the field of architecture but also in many disciplines. Today, due to the concerns about the future, the increasing tendency to these issues has brought about many studies. As an answer to the question "What is a real ecological building?" during the studies, the process that started with the consideration of village houses, which still constitute a large part of our building stock and carry the traditional culture, has revealed the necessity of a model that can support development in rural areas (Houben and Guillaud, 1994).

In this case study, the wall was constructed with gypsum-doped adobe covered with paddy straw. It has been tried to offer a protective, economical and durable and environmentally friendly solution against variable climatic and environmental conditions for those who will construct agricultural buildings.

2. Materials and Methods

In this study, paddy straw and gypsum filled adobe (Gypsum-Doped Adobe) were used as materials. As a method, the design process, project design process, application process and static analysis steps were followed.

2.1. Materials

2.1.1. Gypsum-doped adobe (gypsum filled adobe)

The mixture obtained by adding gypsum and/or lime to the soil in certain proportions and kneading with water in appropriate granulometry is gypsum-added adobe mud. Gypsum added mud brick is the material obtained from this mud by various casting methods (Tanrıverdi, 1984).

Gypsum-Doped Adobe is a type of adobe with 10-20% gypsum added to suitable adobe soil. Its physical and mechanical qualities have been significantly improved in the direction necessary for the structure compared to the normal adobe. The quick socketing of the plaster joined by the gypsum-doped adobe allows it to gain sufficient strength when it comes out of the mold. In practice, labor and drying space are not required during the drying phase. Thus, time and energy are saved. The rapid setting (solidification) of the plaster prevents the shrinkage that the clay would normally do during drying. At the same time, it prevents cracking and deformation that will occur in the structure when drying is not balanced. These events, cause increased strength and not disperse in water (Acun and Gürdal, 2003). Table 1 shows the participation rates of the material in the construction of gypsum-doped adobe.

Table 1. Participation rates of the material in the construction of gypsum-doped adobe (Aydınay, 2002)

Material	Weight
Soil + Clay (10%) + Shaft + Sand + Pebble (7 cm)	1.000 N
Water	200 N
Gypsum	100 N
Lime	20

2.1.1.1. Mechanical and physical properties of gypsum-doped adobe

The rapid solidification of the plaster prevents the formation changes and cracks that will take place in the structure in cases where the shrinkage and balanced drying cannot be ensured under normal conditions during the use of the clay. The sequence of events in question causes the resistance to increase and prevents it from dispersing in the water. It is seen in the research that the physical and mechanical characteristics of the improved gypsum-doped adobe material have important properties. In case of construction of masonry structures using gypsum-doped adobe, the features in Table 2 should be known in order to reach the necessary comfort and safety conditions (Kafesçioğlu et al., 1980).

Table 2. Mechanical and physical properties of gypsum-doped adobe (Aydınay, 2002)

Mechanical and Physical Properties of Gypsum-Doped Adobe	Value
Unit Weight	1.6-1.7 kg L^{-1}
Shrinkage	1.0-1.5 %
Compressive Strength	2.0-4.0 N mm^{-2}
Shear Strength	0.9-1.3 N mm^{-2}
Water absorption	Very Low
Long-Term Water Effect (Except Surface Impact)	No Erosion
Heat Transition Coefficient	0.4 W mK^{-1}
Heat Storage	1.0 kJ kgK^{-1}

While the compressive strength is 5-10 kgf cm^{-2} in normal adobe, it is 35-60 kgf cm^{-2} in gypsum-doped adobe. The fact that gypsum-doped adobe is more durable indicates that the outer bearing walls can be thinned up to 30 centimeters in regions where heat retention is not important (Kafesçioğlu and Gürdal, 1985). Also, as a result of the fact that the adobe structures manufactured with traditional technique do not have durability, their appearance can change in a short time. Table 3 shows the differences between conventional and gypsum-doped adobe construction technologies are given.

Table 3. Comparison of conventional and gypsum-doped adobe construction technologies (Aydınay, 2002)

Traditional Adobe Building Technology	Gypsum-Doped Adobe Structure Technology
Preprocess is required.	Preprocessing is not required.
It is necessary to grind.	It is not necessary to grind.
It is necessary to sieve.	It is not necessary to sieve.
Resting is necessary.	Resting is not necessary.
30% clay	10% clay
It gains strength in 15-21 days.	It gains strength in 20 minutes.
Space is required for curing.	Space for curing is not required.
It is necessary to sprinkle water on it.	It is not necessary to sprinkle water on it.
It is necessary to protect from rain.	It is not necessary to protect from rain.

The economic nature of the gypsum-doped adobe structure can be explained by the expenses required by the pre-production, production time and post-production expenses of the gypsum-doped adobe structures. The fact that the main material is soil and can be found more easily than other building materials can be shown as one of the most important reasons why gypsum-doped adobe structures are more economical than other types of buildings. The energy saving it provides during its use and the fact that it does not require much post-production maintenance are other positive features of the gypsum-doped adobe structures in terms of being economical. Reductions in material and labor costs used in production and the fact that it does not require an average stock level reduce the total cost of the adobe structure (Aydınay, 2002).

2.1.2. Paddy straw

Paddy straw is one of the important by-products considering the rice production potential in the world and in our country (Figure 1). Paddy straw has low nutritional value due to its high content of silica and lignin, slow and limited breakdown in the rumen and low protein content (Bölükbaş and Kaya, 2018).

Figure 1. Paddy straw (Anonymous, 2022)

2.2. Methods

The method of this wall construction application consists of two stages. First of all, in order to obtain sufficient information about the material before the application is carried out, the literature review on the subject has been carried out, and articles, text and books have been examined in detail. As the second method, the application stage has been started. The application stages were carried out as the design process, the project design process and the application process, respectively. At the project phase, it was determined how the application would be made and drawing operations were carried out. During the project design phase, the dimensions and construction stages of the concrete blocks and foundations to be used in the wall to be used were realized. In the application phase, which is the final stage, the blocks that have been produced have been placed as determined in the project and the wall has been completed.

2.2.1. Design process

In this wall design, the De Stijl art movement, which emerged in the form of combining the pieces with the idea that it would be better aesthetically for the design to reflect an architectural understanding, was used. In addition, care was taken to ensure that the wall was ergonomic enough to meet the needs of the audience it would address. For this, there were protrusions on the wall where people could sit and put their food and drink, as well as leave tools that might be needed in agricultural structures. In addition, protrusions and small holes were used in the outer part of the wall in order to distribute and reduce the effect of the strong wind. These holes are designed to prevent the wind from completely affecting the wall. The design stages of the wall and the modeling process are shown in Figure 2.

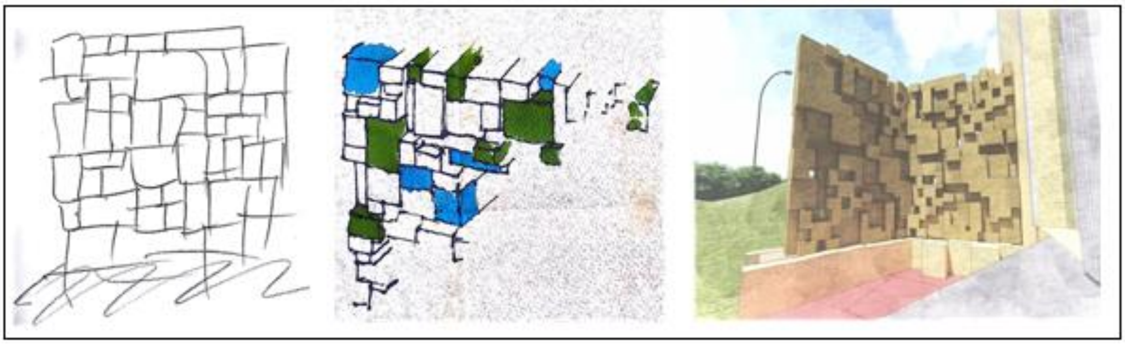


Figure 2. Stages of design of the wall and the modeling process

2.2.2. Project design process

The wall consists of two parts: the foundation and the wall section. Foundation and wall project drawings are included in Figure 3. While designing the wall, it was created from eight different units. The block type, material image, material, number of pieces and material size are shown in Table 4. In addition, produced versions of scratchable modules are shown in Figure 4.

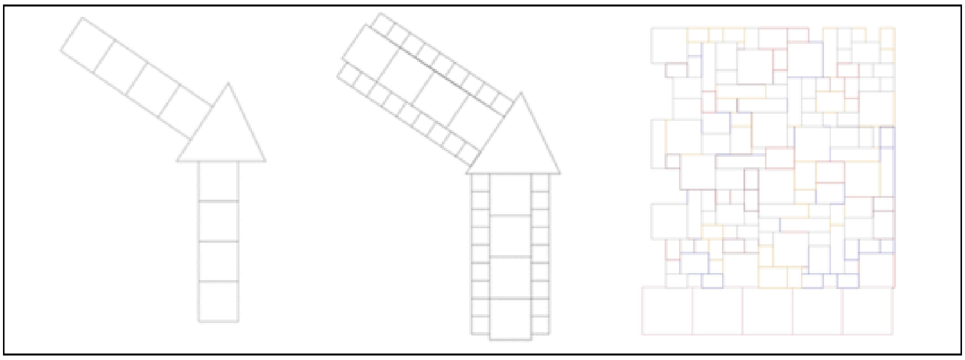


Figure 3. Foundation, foundation joint and wall project

Figure 4. Produced versions of scratchable modules

Table 4. Materials used in wall construction and their properties

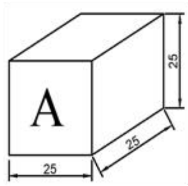
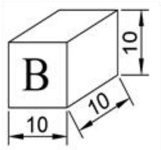
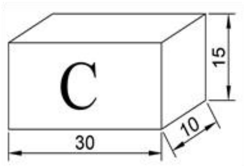
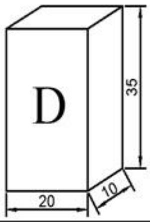
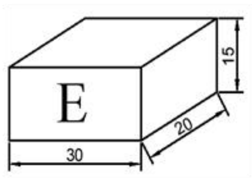
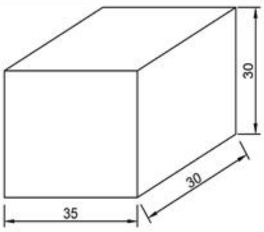
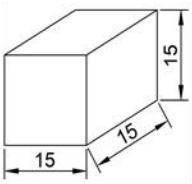
Block Type	Material Shape	Material Image	Material Number of Pieces Material Size
Type A			Gypsum-Doped Adobe 28 Pieces 25cm*25cm*25cm
Type B			Gypsum-Doped Adobe 66 Pieces 10cm*10cm*10cm
Type C			Gypsum-Doped Adobe 100 Pieces 30cm*10cm*15cm
Type D			Gypsum-Doped Adobe 26 Pieces 20cm*10cm*35cm
Type E			Gypsum-Doped Adobe 44 Pieces 30cm*20cm*15cm
Foundation Type			Gypsum-Doped Adobe 8 Pieces 35cm*30cm*30cm
Concrete Blocks			Concrete 72 Pieces 15cm*15cm*15cm

Table 5. Mix calculations

Material	Ratio
Clay Soil	%100
Gypsum	Soil weight is 5%
Lime	Soil weight is 2.5%
Paddy Straw	Soil weight is 1%

Table 6. Prism and cylinder compressive tests results (Aghazadeh, 2011)

Samples	Prism Compressive Strength (MPa)	Cylinder Compressive Strength (MPa)
Pure	1.4	0.91
%10 Plaster	1.7	1.62
% 10 Plaster+% 2.5 Lime	1.0	1.06
% 10 Plaster+% 5 Lime	1.2	0.87

The mixture ratios of the gypsum-doped adobe material we will use in the construction of the wall are given in detail in Table 5 and the mixture calculations are made accordingly. The compressive strength values of the produced gypsum-doped adobe material were taken from Table 6 for prism and cylindrical samples and used in the calculations.

2.2.3. Application process

The construction of A, B, C, D, E block types, foundation types, concrete blocks and basic junction stone, which were first designed to be used in foundation and wall application, was completed. The construction of the wall started from the foundation section. It was carried out that the foundation elements formed the foundation with the joining stone and fixed it to the foundation with concrete blocks. Mortar was made to assemble the units. Then the wall-building phase was started. In the walling phase, the wall was raised to 65 cm, 100 cm, 135 cm and 170 cm elevation respectively and the wall length in both directions was 140cm. The construction stages are shown in Figure 5.

2.2.4. Static analysis

The weights and volumes of all materials used in the wall are calculated and shown in Table 7. In addition, the center of gravity of the structure was calculated as 89.4 cm (Figure 6). In Table 7, the total number of used pieces is 345. The total wall volume is calculated as 2.109.638 cm^3. At the same time, the total weight of the wall was calculated as 4.400 kg.

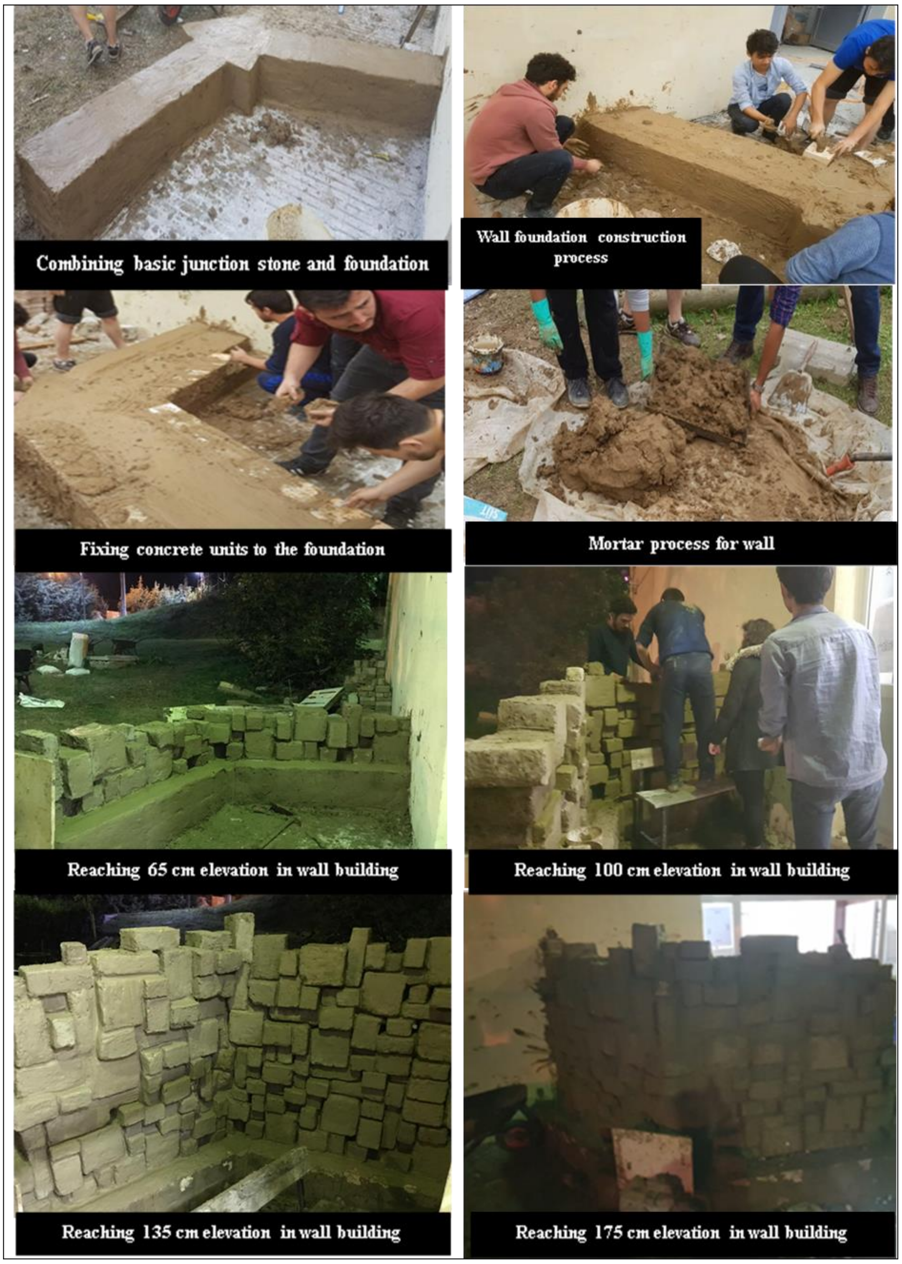


Figure 5. Stages of foundation and wall construction

Table 7. Weights and volumes of materials used in the wall

Block Type	Block Weight (kg)	Block Volume (cm^3)	Number of Pieces	Total Weight (kg)	Total Volume (cm^3)
Type A	31.25	15.625	28	875	437.500
Type B	2.00	1.000	66	132	66.000
Type C	9.00	4.500	100	900	450.000
Type D	14.00	7.000	26	364	182.000
Type E	18.00	9.000	44	792	396.000
Foundation Type	73.50	31.500	8	588	252.000
Concrete Block	8.10	3.375	72	583	243.000
Basic Junction Stone	166.28	83.138	1	166	83.138
Total	-	-	345	4.400	2.109.638

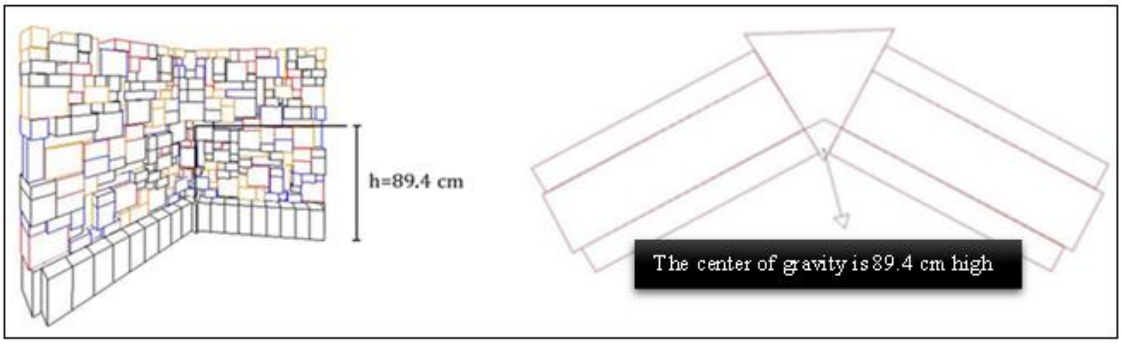


Figure 6. Center of gravity of the wall

3. Results and Discussions

In the study, a wall design application was made to be used in agricultural buildings, in which paddy straw, an organic waste, was evaluated (Figure 7). While performing the wall design, De Stijl art movement was tried to be reflected in order to make the design aesthetic. Therefore, the wall gained an aesthetic appearance. Before starting the wall construction, the design and projecting processes were carried out, then the application process was started and a static evaluation was made. It is aimed for this design to be sustainable, more environmentally friendly, consuming less energy, having economic and ecological advantages, providing healthy living conditions, convenient and ergonomic.

Adobe, stone, brick, panel, gas concrete, briquette, gypsum block, concrete and reinforced concrete, mixed walls…etc. there are many wall types available. These walls differ according to their functions, the stones used in their construction, the place where they will be applied, and the way of use. Each wall applied has advantages and disadvantages according to the purpose and place of use. The selection of materials suitable for the purpose of wall construction should be carried out in the design and projecting processes. Unfortunately, not enough attention is paid to design process, projecting process, application process in our country. Earthquakes are frequently experienced in our country, which is located in the earthquake zone, and economic crises occur in our country and all over the world for various reasons. Therefore, it is very important to decide on the construction method and choose the material.

Figure 7. View of the completed wall

In this study, which was carried out to design a wall to be used in agricultural buildings, gypsum-added adobe was chosen as the material. Because the construction methods and materials used with the developing technology cause more energy consumption, environmental pollution and more carbon emissions. In this case, today, practitioners and planners who prioritize environmental protection and sustainability are turning to ecological materials that do not need energy during their production or show a relatively low energy requirement, and that provide comfort conditions with minimum energy during their use. In this context, adobe, which is a traditional material, shows itself as an environmentally sensitive natural building material with a very low energy requirement starting from the production stage to the consumption and usage stages. It is a comfortable sustainable building material that does not require a facility in its production, provides insulation in addition to it and balances humidity. Among the important advantages of adobe material are that it is economical and healthy, it can be produced easily by using local facilities and simple tools, it does not require energy for its construction and harmful gases are not released into the atmosphere (Aktaş, 2020). As a traditional material, adobe is an environmentally friendly ecological building material with the least energy requirement from the production stage to the use and consumption stage. It is an economical material that can be used as a carrier material and plastering material, the binder of which is clay soil obtained from nature. The use of adobe, which has survived from the earliest times to the present, is indispensable especially for rural areas. At the same time, it is a low-cost material that does not require the establishment of a production facility and has a high thermal insulation value. It provides the most suitable living conditions for the user in the building in all seasons. With this aspect, it provides economy by not leaving the need for a separate heat insulation material (Acun and Gürdal, 2003). Therefore, this study confirms that the choice of gypsum-added adobe was appropriate in the study carried out to design a wall for use in agricultural buildings. In another study, the new generation adobe prepared by adding waste glass dust, pumice, marble dust, gypsum, slaked lime and volcanic tuff in order to increase the quality of adobe while maintaining its cost was found to have high compressive strength, low density and thermal conductivity (Leblebicier and Akıncı, 2021). In addition, with the extra of some fiber additives such as straw, it is possible to reduce the shrinkage problem that may occur due to rapid drying, while increasing the bending strength of the adobe (Acun and Gürdal, 2003). It is one of the cheap and fast ways to solve the sheltering problem. It provides the best level of living comfort. It is the only material with the least cost and whose production does not require the establishment of a facility. It gives the owner the opportunity to evaluate his own possibilities and become a home owner in this way. Mass production is possible and provides great cost reduction. It saves energy in material production, material handling, and fuel savings during the entire use of the building. It saves energy in material production, material handling, and fuel savings during the entire use of the building. It provides the opportunity to benefit from our own resources. The application of adobe structures is easier. Agricultural warehouses, coop, barns... etc. can be done. Agricultural structures are replaced by less sustainable buildings. It is a construction technique known in rural areas. Buildings of sufficient strength can be built. It has important contributions to prevent environmental pollution (Kafesçioğlu et al., 1980). The effect of city construction culture on rural areas is increasing and traditional architecture is being destroyed. Traditional architecture in the countryside is at greater risk every day. However, this architecture, which includes the traditional construction method and culture, needs to be preserved. For this, the traditional material should be made suitable for new construction that will respond to contemporary needs, with low energy input (green restoration) and suitable for traditional architecture. Thus, even if it is a new construction, a sustainable and contemporary architectural opportunity suitable for the rural area can be provided (Özgünler, 2017). It is important for the sustainability of the world to reduce wastes and residues that cause environmental pollution, to recover or reuse wastes, to make production that can be obtained with less parts, to save energy and to distribute the most important production and usage preferences. Therefore, in this study, considering all these aspects, it seems to be suitable for its purpose.

In the study, building safety has been established in such a way that the wall being built will be in balance under the effects of climate, live loads such as snow load, under the influence of its own weight and horizontal wind loads. At the same time, rice straw, which is an organic waste, was also evaluated. The idea of designing a wall to be used in agricultural buildings has been evaluated as a viable and correct idea in line with these studies. As can be seen in Figure 7, a protective, economical, sustainable, statically balanced and durable wall application has been carried out.

4. Conclusions

In this study, a wall was designed to be used in agricultural buildings. In this wall design, paddy straw, which is an organic waste, was used with a traditional material, gypsum-doped adobe. A durable, environmentally friendly, economical wall with a modern appearance, in which sustainability is taken into account, was constructed.

With the development of technology, it has begun to move away from traditional construction methods, especially in rural areas. With the use of high-tech materials in the construction sector, many problems related to the environment and sustainability have begun to emerge. Since agricultural wastes and adobe are natural and sustainable materials, it is necessary to try to evaluate them more. At the same time, while evaluating these materials, it is necessary to put into practice without ignoring the design, projecting and application processes.

It has been concluded that the application of paddy straw, which is an organic waste, together with gypsum-added adobe can be used in load-bearing and partition walls in agricultural buildings in rural areas, and it will also be economical, and that the application of paddy straw together with gypsum-added adobe can be considered as a sustainable material that causes less harm to the environment. With this case study, it has been tried to draw attention to the fact that gypsum-doped adobe is an economical alternative in agricultural structures and in rural areas, together with rice straw.

Declaration of Author Contributions

The authors declare that they have contributed equally to the article. All authors declare that they have seen/read and approved the final version of the article ready for publication.

Declaration of Conflicts of Interest

All authors declare that there is no conflict of interest related to this article.

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