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Papercrete and *Recipanel* as Wall Material: An Environmental Sustainability Review

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Abstract. This study aims to review the relation between *papercrete* and *recipanel* (wall materials from recycled paper) with indicators of material sustainability in environmental aspects. Recycling paper into wall material is one of the ways to overcome the increasing amount of paper waste in Indonesia. Waste recycling is related to the concept of sustainability, namely the triple bottom line of the concept of sustainability. A literature review of waste management, recycled paper, and recycled paper as wall material were conducted in terms of environmental sustainability. This study was conducted by integrating the theoretical understanding of waste, walls, wall material products from recycled paper and discussion of its impact in terms of the sustainability of recycled paper as alternative wall material. From this study, it was found that the relationship between the characteristics of *papercrete* and walls on the sustainability of recycled paper brought forward four positive values and two negative values. Meanwhile, the relation between *recipanel* and wall characteristics on the sustainability of recycled paper carries four positive values and two negative values. Thus, the recycled paper used as wall material with examples of *papercrete* and *recipanel* products may still be suitable for use as wall material in Indonesia. Suggestions resulted from this study that might be implemented in the future are to increase the durability of materials derived from recycled paper and to conduct studies that discuss wall materials derived from recycled paper from social and economic aspects in terms of sustainability.

Keywords: Recycled Paper, Wall, Sustainability of Recycled Paper as Wall Material

INTRODUCTION

In Indonesia, population growth of around 265 million from 2018 to 2019 has resulted in an increase of the amount of waste by up to 3.4 million tons per year [1, 2]. From the existing various types of waste, paper waste is the one with the largest amount, as much as 9% [2]. In the realm of architecture, there is no rigid definition of the definition of wastepaper. However, when drawn from general definitions, wastepaper is paper discarded as used, superfluous, or not fit to use [3].

To overcome this, waste management is carried out, one of which is the recycling method. In the world of architecture, paper waste can be recycled into wall material, namely *papercrete* and *recipanel*. *Papercrete* is the development of construction materials from paper mixed with cement or clay [4-10]. While *recipanel* is a panel made of recycled paper, polypropylene fiber, and cement [11, 12]. This is done to preserve nature while still supplying the future generations, conforming to the following statement: "Meeting the needs of the present without compromising the abilities of future generations to meet their own needs" [13].

Waste management and material sustainability are closely related [14]. Likewise with paper recycling into wall materials related to sustainability. The challenge in using materials resulting from the waste management process is related to the principle of sustainability. These factors are in the form of a triple bottom line that integrates profit, people, and planet which means economic, social, and environmental [15, 16]. This study discusses the feasibility of *papercrete* and *recipanel* as wall materials in Indonesia. The aim is to review the relationship between *papercrete* and *recipanel* with the indicators of material sustainability in environmental aspects.

METHODOLOGY

Series of literature review about *papercrete* and *recipanel* were conducted to address the relationship between both materials from environmental sustainability perspective. A literature review about turning waste into resource, recycled paper, and recycled paper as wall material was also added to narrow down the theoretical background. The study analysis in this review involved material sustainability indicators.

The experiment of making *papercrete* was carried out by previous studies between 2015-2019 [4, 6, 8]. Those experiments defined series of characteristics of the *papercrete* test results. This study combined their characteristic with other study results for further analysis [5, 7, 9, 10]. Those are structure test, capillarity test, sound test, hardness test, nailing test, cutting and glue test, fire resistance test, thermal test, and density and weight test.

The experiment of making *recipanel* was carried out by a group of researchers in 2012 [12] by making panels used for ceiling and interior walls. The experiment detailed that the characteristics of the *recipanel* test results [11]. Those are dimensional stability test, gravity specification test, flexural strength test, capillarity test, nailing test, fire resistance test, and thermal conductivity test.

Both *papercrete* and *recipanel* were reviewed for their performance based on previous studies. From the results of these initial review, a further study was conducted on the characteristics of the wall to see whether these two products have met the characteristics of the alternative wall materials. Subsequently, the connection with the sustainability of recycled paper were investigated. The study flow of these two products is further explained in Diagram 1 below.

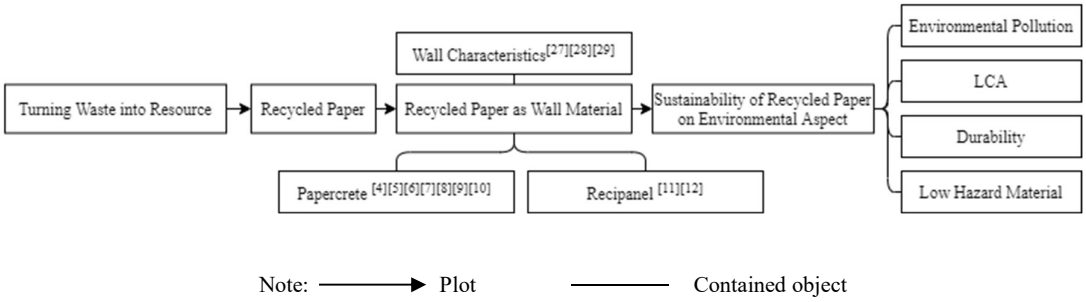

DIAGRAM 1. Analysis Flow

REVIEW AND DISCUSSION

Turning Waste into a Resource

Waste is excess from everyday life that is no longer used [17]. Waste is divided into three types including household waste, and specific waste [17]. Meanwhile, waste can also be categorized based on its shape, source, and impact on the environment [18, 19].

The existence of waste must be reduced by the presence of waste management. Waste management is the collection, transportation, recovery that constitutes of sorting and disposal of waste, including supervision, operation, and maintenance of the disposal site [20]. It aims to improve public health and environmental quality as well as turning waste into a resource [17, 21].

Recycled Paper

Recycling, as one of ways to turn waste into a resource, is the activity of collecting and sorting waste which is carried out to process waste into new products or materials [21]. There is a recycling allocation procedure that differentiates these recycling cases, such as procedures with closed-loop and open-loop [22]. Recycling paper waste into wall material belongs to product recycling that uses an open-loop procedure.

As for recycled paper, it is defined as used paper which is then processed into a new product. In the field of architecture, no fixed definition that can be found by the author regarding the definition of recycled paper [23-25].

Recycled Paper as Wall Material

A wall is a thin vertical structure made of bricks or stone that divides or surrounds something [26]. The wall has a purpose as a barrier structure and function with several characteristics which are further described in Table 1. All these characteristics are obtained from several sources [27- 29][35-37]. In this study, paper recycling is carried out by converting it into wall materials, namely *papercrete* and *recipanel*.

TABLE 1. Wall Characteristics

No.	Characteristics	Explanation	References
1.	Strength and stability of the structure	Withstand vertical and horizontal dead and live loads in buildings and from the environment.	[28, 29]
2.	Weather protection	Maintain internal conditions so that external walls act as a barrier from rain, snow, wind, sun, and pollution.	[27, 28, 29]
3.	Durability	Walls are durable and require minimal maintenance.	[27, 28, 29]
4.	Thermal performance	Heat release and absorption control for comfort inside the building.	[27, 28, 29]
5.	Noise protection	Absorbs sound so it does not disturb comfort.	[27, 28, 29]
6.	Fire resistance	It can reduce the likelihood of fire spreading, avoid collapsing buildings, and facilitate firefighting and escape.	[28, 29]

Sustainability of The Recycled Paper

Sustainability is described as the relationship between nature and humans that pays attention to the welfare of life and the preservation of natural resources for the future (Fig. 1). This is accordingly reinforced by a statement, that sustainability is related to the problem of natural resources, environmental quality, and capital which are then passed on to future generations [15]. Therefore, waste management and material sustainability are interrelated [14]. Similarly, paper recycling into wall materials is related to sustainability. One of the considerations in achieving sustainability is the selection of materials as it has implications on the duration that the material can last [30]. The use of recycled paper is related to the principle of sustainability in environmental aspects.

In the environmental aspect, the life cycle of materials is important. Building materials continue to relate to the environment as the building requires a supply of material from natural resources with a variety of activities from construction, operation, and demolition [31]. A product will usually go through several stages which start with the production, distribution, use, and ends as waste. Each stage has the potential or opportunity to be reused to minimize the potential for the waste.

The Life Cycle Assessment (LCA) is the knowledge needed in the consideration of developing the concept of sustainability so that it will not be limited to the use of natural resources which are ultimately wasted. LCA is made by observing the impact on the environment. That LCA is a compilation and evaluation of inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle [32].

In terms of sustainability, the fulfillment of the criteria for becoming building materials is related to the triple bottom line in forming a sustainable material assessment [33]. Therefore, in general, several indicators influence the value of the sustainability of recycled paper used as wall material in terms of its relationship with the environment. The existing indicators are slices of several building sustainability assessment tools by looking at their relationship with recycled paper [33-37]. This relationship is seen from the side of its relationship with the environment. For further information, these indicators can be seen in Table 2.

TABLE 2. Summary of Sustainability Indicators for Recycled Paper as Wall Material for Environmental Aspects

Indicators	Keywords	Explanation	References
Ecology	Environmental pollution	Recycled paper as a wall material with a low negative impact on the environment.	[33, 35, 36]
Source and materials	LCA	Seeing the relationship with the environment in its life cycle.	[33, 34, 35, 36, 37]
	Durability	Sustainability in the recycled paper as a wall material for the environment and its subsequent use.	[34, 35]
	Low hazard material	Seeing the chemical content of recycled paper on the environment.	[37]

Note: Indicators and keywords are not entirely listed. Indicators and keywords are adjusted to previous theoretical studies regarding recycled paper and recycled paper as wall materials.

The relationship between recycled paper as wall material and the environment is in the chemical content contained in the paper. In addition, there is a connection between the CO_2 produced from the production of the material to its resources. Additionally, the mercury found in printing inks on paper may be harmful to the environment. This content can pollute the environment in the form of air and water pollution when the levels exceed the limit [38].

This refers to the changes in global temperature caused by the greenhouse effect from the release of CO_2 gas that occurs due to human activities [39]. Paper is recycled to reduce the release of CO_2 in producing new materials. Recycling paper can save energy by up to 40% and reduce air pollution by up to 73% [40]. In addition, recycling one ton of newsprint waste can reduce landfills by three cubic meters, reduce water pollution by 35%, save about seventeen trees, and save 26,000-liters of water uptake [41].

Papercrete

FIGURE 1. Papercrete Form

Papercrete is the development of construction materials from paper mixed with cement or clay (Fig. 3). *Papercrete*-making experiments have been carried out by [4, 6, 8]. At the end of the experiment, the characteristics of the *papercrete* are obtained from the test results along with other sources from [5, 7, 9, 10], such as the structural test, capillary test, sound test, hardness test, nailing test, cutting and glue test, fire resistance test, thermal test, and density and weight test which are further described in the Table 3.

TABLE 3. Papercrete Characteristics

No.	Indicators	Explanation	Characteristics	References
1.	Structural test	Testing on pressure resistance.	Compact, free from defects, elastic, and minor damage on the outside.	[4, 5, 8, 9, 10]
2.	Capillary test	Water-absorbing paper resistance testing.	High capillarity.	[5, 6, 8, 9]
3.	Acoustic test	Testing of the results of the inter-*papercrete* lacing.	The quality of the acoustic material is good.	[4, 5, 8, 9]
4.	Hardness test	Pressure resistance testing during manufacture.	Hard fibrous.	[5, 6, 9]
5.	Nailing test	Testing of load-bearing strength when nailed.	Can hold nails well.	[5, 6]
6.	Cutting and glue test	Inter-*papercrete* binding test.	It fits well together and can be applied to the quick assembly.	[5, 6]
7.	Fire resistance test	Test your fire resistance ability.	Fair resistance to fire.	[5, 6, 7]

8.	Thermal test	Test the ability to store heat.	Excellent compared to concrete.	[6, 4, 10]
9.	Density and weight test	Test weight and density.	Two-thirds lighter than conventional bricks.	[4, 5, 6, 9]

Based on the journal obtained listed in TABLE 1. Wall Characteristics and TABLE 3. Papercrete Characteristics, *papercrete* meets the characteristics of the wall on the strength and stability of the structure, weather protection, durability, noise protection, and fire resistance. More detail can be seen as shown in Diagram 2 below.

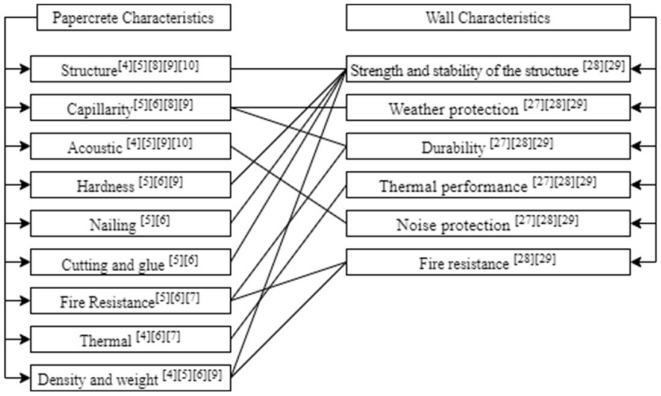

DIAGRAM 1. Relationship between Papercrete Characteristics and Wall Characteristic

The relationship between structure, strength, nailing, cutting and glue, and density and weight of the *papercrete* with the strength and stability of the structure on the wall occurs because of an assessment of the strength of the *papercrete* that can withstand loads well [4, 5, 8-10]. In addition, *papercrete* can hold its shape and does not break when a nail is inserted [5, 6].

The capillarity of *papercrete* is related to the weather resistance and durability of the wall characteristics and this linkage is due to its ability to respond to the environment [27-29]. *Papercrete* must be able to survive to remain in size and shape when exposed to rain. As explained, *papercrete* has a high absorption capacity, which is up to 30% which even exceeds the absorption capacity of a good brick which absorbs no more than 20% of its weight in water [5, 6, 9].

The noise in the *papercrete* is related to the noise shielding of the wall characteristics and this connection is caused by the ability of *papercrete* to absorb sound well [4, 5, 8, 9]. This is intended as when testing which is the impact of the *papercrete* there is a clear and unbroken ringing sound [4-6]. This indicates good sound absorption so that the *papercrete* can absorb sound well from the environment and indoors.

The fire resistance and weight density of *papercrete* are related to the fire resistance of the wall characteristics and this relationship is because the fire resistance of *papercrete* depends on the density of the *papercrete* itself, namely the amount of paper used [42]. In general, *papercrete* is resistant to fire. It is as mentioned in the characteristics of *papercrete* that it is quite resistant to fire. Therefore, this material can be used when used as a wall. This as a wall should reduce the possibility of fire spreading [28].

Later, the review continues to the relation between its sustainability in environmental aspects with ecological and source and material indicators. From the review, it is known that the relation of *papercrete* and wall only linked to the durability and due to the three keywords show their direct impact on the environment. This linkage can be seen further in the Diagram 3.

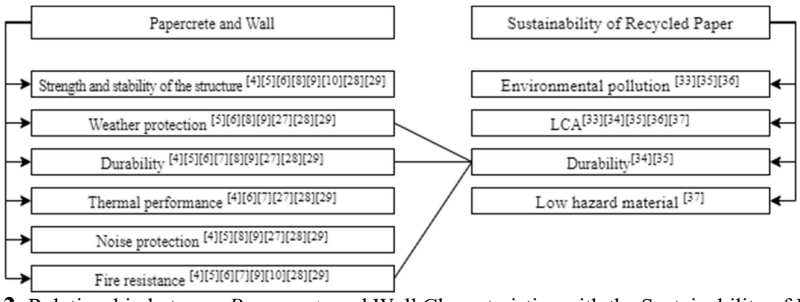

DIAGRAM 2. Relationship between *Papercrete* and Wall Characteristics with the Sustainability of Recycled Paper

Recipanel

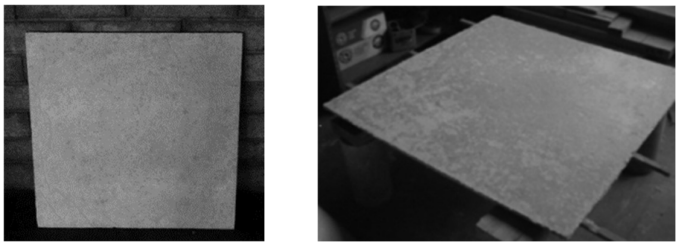

FIGURE 2. Recipanel Form

Recipanel is a panel made of recycled paper, polypropylene fiber, and cement. *Recipanel* manufacturing experiments were carried out by making panels used for ceiling and interior walls (Fig. 4) [12]. At the end of the experiment, the characteristics of the *recipanel* test results were added from other sources [11], namely the dimensional stability test, the gravity specification test, the flexural strength test, the capillary test, the nailing test, the fire resistance test, and the thermal conductivity test which are further described in Table 4 [12].

TABLE 4. Recipanel Characteristics

No.	Indicators	Explanation	Characteristics	References
1.	Dimensional stability test	Testing on material size standards.	Good dimensional stability meets high strength standards.	[11, 12]
2.	Gravity specification test	Testing at the density level on the water content.	Lower than drywall	[12]
3.	Flexural strength test	Testing in supporting loads.	High bending strength.	[11, 12]
4.	Capillary test	Water-absorbing paper resistance test.	High capillarity.	[11, 12]
5.	Nailing test	Testing of load-bearing strength when nailed.	Low weight and high flexibility.	[12]
6.	Fire resistance test	Test the fire resistance ability.	Fair resistance to fire.	[12]
7.	Thermal conductivity test	Its ability to store heat.	Can store heat well.	[12]

Based on the journal obtained listed in TABLE 1. Wall Characteristicsand TABLE 4. Recipanel Characteristics 4, the *recipanel* is related to the strength and stability of the structure, weather protection, durability, and fire resistance in the characteristics of the wall. These two relationships will be further explained in Diagram 4 below.

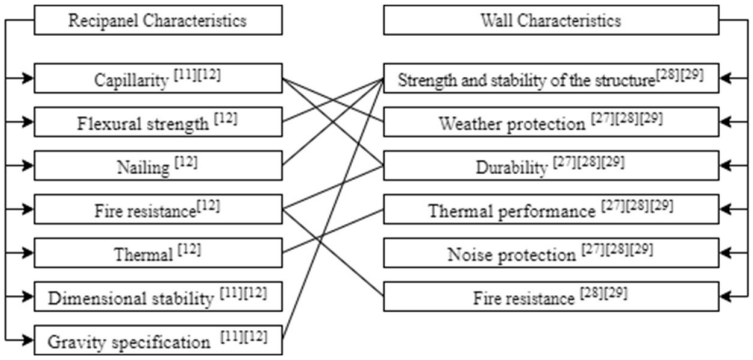

DIAGRAM 3. Relationship between *Recipanel* Characteristics and Wall Characteristics

The capillarity of the *recipanel* is related to the weather protection and durability of the wall characteristics. This relationship is due to its ability to respond to the environment making *recipanel*s must be able to survive in order to remain in size and shape when exposed to water [11, 12]. However, *recipanel* has a high absorption capacity. This indicates that the *recipanel* is not good at responding to the environment.

The relationship between strength and flexibility, nailing, and gravity specifications on the *recipanel* with the strength and stability of the structure on the wall occurs because of an assessment of the strength of the *recipanel* that can withstand loads well [12]. As mentioned in TABLE 4. Recipanel Characteristics, the results of the tests carried out resulted in the characteristics that the *recipanel* was able to maintain its shape and did not break when driven by nails [12].

The fire resistance of *recipanel* is related to the fire resistance and durability of the wall characteristics. This linkage exists due to the high fire resistance of the *recipanel*. As explained in TABLE 4. Recipanel Characteristics that *recipanel* has a fairly good fire resistance. Therefore, this material can be used when used as a wall. This as a wall should reduce the possibility of fire spreading [28].

Next, the review sees how it is related to its sustainability in environmental aspects with ecological and source and material indicators. The indicators of source and material with the keyword durability relate to weather protection, durability, and fire resistance on the relationship between *recipanel* characteristics and wall characteristics due to the three keywords show their direct impact on the environment. This linkage can be seen further in Diagram 5 below.

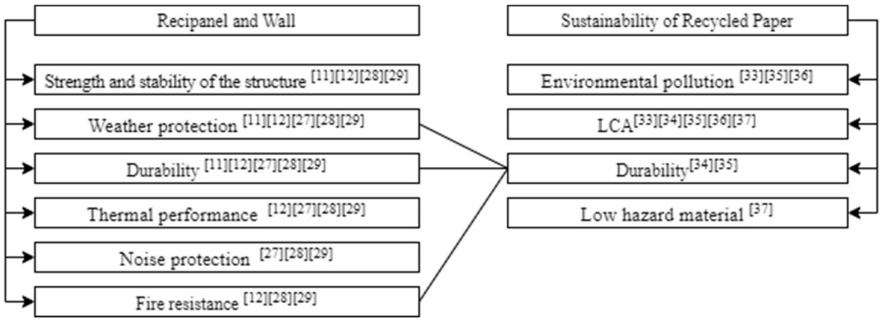

DIAGRAM 4. Relationship between *Recipanel* and Wall Characteristics with the Sustainability of Recycled Paper

In relation to sustainability, ecology with keywords environmental pollution and materials and sources with keywords LCA and low-hazard materials have no relationship with wall and *recipanel* characteristics. This happens because the three keywords show their direct impact on the environment.

In the ecological indicator with the keyword environmental pollution and on the source and material indicator with the keyword low hazard material, it is shown that recycled paper is of bad value because it can pollute the environment with mercury in the printing ink on the paper [38]. However, this depends on the level of ink on the paper itself. Therefore, the type of paper that is the basic material is an important thing to pay attention to.

In the source and material indicators with keywords LCA, recycled paper used as wall material saves the environment by showing its response to changes in global temperature and it was explained that less CO_2 is released into nature [39]. When compared to conventional building materials, recycling paper as a wall material produces less CO_2 because wall materials such as concrete, steel, and aluminum generally produce 22% more CO_2 and it helps the environment by not contributing more CO_2 to nature [40]. In addition, that paper recycling saves forests by reducing deforestation.

In the source and material indicators with the keyword durability related to weather protection, durability, and fire resistance on the characteristics of the walls because its ability to be a barrier to the weather. The relationship between the durability of the indicator and weather shield and durability is derived from its ability to be a barrier to the weather. It is said that the capillarity value is high [12]. In addition, the durability of the indicator in terms of fire resistance is related to fire resistance in the characteristics of the walls by showing its relationship to the ability of the material to spread fire and the ability to avoid the collapse of the building [28]. In addition, that durability is related to its ability to deal with the environment, namely paper can be degraded due to thermal, biological, and chemical reasons, such as fire, microorganisms, and acids [6]. Therefore, it requires a special coating to protect against thermal, biological, and chemical disturbances. In addition, building materials should be able to adapt to new and old buildings. However, for this the author did not find a rigid answer.

Concerning sustainability, ecology with the keywords of environmental pollution as well as materials and sources with the keywords of LCA and low-hazard materials have no relationship with the characteristics of walls and *papercrete* or *recipanel*. This has resulted from those three keywords that show their direct impact directly.

The ecological indicator with the keyword of environmental pollution and the source and material indicator with the keyword of low hazard material have shown that recycled paper has bad value as it can pollute the environment with the mercury content in the printing ink on the paper [38]. In the source and

material indicator with the keyword of LCA, the recycled paper used as wall material saves the environment by showing its response to global temperature changes by contributing less CO_2 to the environment. Recycling paper as a wall material produces less CO_2 because wall materials such as concrete, steel, and aluminum generally produce 22% more CO_2 [40]. In addition, paper recycling saves the forests by reducing logging.

Synthesis of The Literature Review

The excess waste is processed into wall material. Walls have six characteristics. *Papercrete* and *recipanel* are proofs that can be recycled into wall materials with their characteristics. After going through the test, *papercrete* appears to have nine characteristics, while the *recipanel* has seven characteristics after passing the test. Recycled paper that is used as an integrated recycled material from waste management and sustainability is connected to the triple bottom line. Ultimately, in the environmental aspect, recycled paper as a wall material has ecological value as well as source and material indicators.

According to this review, it was concluded that the relationship between the characteristics of *papercrete* and walls to the sustainability of recycled paper in environmental aspects and the relationship between *recipanel* and wall characteristics on the sustainability of paper resulted in four positive values and two negative values. From this impact value, it is found that recycled paper may still be used as wall material if it improves its negative values. One of the obstacles is its durability.

Overall, it is still possible to recycle paper waste into wall material. However, recycling paper into wall material is not necessarily better than recycling paper back into paper because of the open-loop form of recycling that turns paper into other materials.

SUGGESTION

Suggestions resulted from this study that can be done in the future included increasing the durability of the material derived from recycled paper by providing a waterproof layer on the material and by increasing the amount of paper used. In addition, a study can be carried out that discusses wall materials derived from recycled paper as seen from social and economic aspects in terms of sustainability. The purpose is to show a balance with the environmental aspects in this study.

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