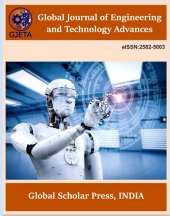
Global Journal of Engineering and Technology Advances

eISSN: 2582-5003

Cross Ref DOI: 10.30574/gjeta

Journal homepage: https://gjeta.com/




(Research Article)

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# Designing architecture with kombucha cellulose, case study: Building envelope

Fermanto Lianto *, Rudy Trisno and Denny Husin

*Department of Architecture, Universitas Tarumanagara, Jakarta, Indonesia.*

Global Journal of Engineering and Technology Advances, 2022, 13(02), 038–045

Publication history: Received on 08 October 2022; revised on 16 November 2022; accepted on 19 November 2022

Article DOI: https://doi.org/10.30574/gjeta.2022.13.2.0192

## Abstract

The green building phenomenon stimulates new green material production to optimize the sustainable design quality goal. While the issue lies in the limited exploration and production of local biomaterials, the acceptance is still problematic in actual practice mainly because of the unfamiliarity. One of the most promising green materials comes from household waste, especially food. Its availability, degradability, and low potential allergy gained popularity as it is user-friendly yet can be directly produced and used at home. Despite the common perception suggesting it is unrelated, odd, or less resilient, global trends have recommended otherwise. It is made from edible materials, and the movement includes kombucha cellulose to be potentially developed as a biomaterial. This research explores the kombucha sheets as a building envelope. The aim is to study its texture which exhibits a specific ambience. The method is customized traditional Indonesian tea fermentation to test sheet in mock-up; the steps are as follows;

- The material production
- Building the envelope
- Capturing spatial experience

The output is a miniature building enclosure using rigid, semi-rigid, and flexible structures; the result is atmospheres generated by translucent textures, natural patterns, and colours of kombucha. The novelty is the spatial experience constructed by the sheet.

**Keywords:** Architecture; Biomaterials; Design; Kombucha; Enclosure

## 1. Introduction

Applying sustainable building materials as a green design strategy has its challenge [1], as the proportion and composition of the material contribute to the overall gesture and performance in architectural design [2]. Indonesia is considered to have less green development, while sustainable building research is still limited [3]. Mainly related to biomaterial, the utilization of building materials is generally considered traditional, with less creativity and innovation in terms of novelty. Developing food waste-based biodegradable building materials is still rare in Indonesia [4]. If any, the product may still be considered alien, odd, unusual, and irrelevant to the general public [5]. However, the tendency to utilize traditional and local materials, especially homemade ones, is still a favourite [6]. Thus, despite the contradiction, developing culture-inspired biomaterial at home potentially contributes more if applied correctly [7], like the one locally trending: kombucha.

One of the most challenging parts of designing with biomaterial is testing the impact of the material on the building design [8]. It is incredibly challenging to convey the space experienced as texture, colour, feel, smell, ambience, nuance, and shadow [9] are hardly presented in a rendered image. Computer simulation may be perfect for virtually transferring

* Corresponding author: Fermanto Lianto
Department of Architecture, Universitas Tarumanagara, Jakarta, Indonesia.

imagination but hardly demonstrating the actual resemblance and true feeling of the space, unlike a diorama or a miniature model [10]. That is why a maquette or a prototype is the most suitable representation of the experiment for testing a specific material. Although it may lack specificity, it shows a difference in scale or even discrepancy in actual finishes. This paper aims to present the character of kombucha sheets as a potential biodegradable material for building design. The output is a collection of photographs that captures the ambience and atmosphere produced by its natural texture. The novelty is a unique spatial experience constructed by the kombucha sheet as the building envelope.

## 2. Material and methods

### 2.1. Theoretical Approach

*2.1.1. The Biomaterial Production*

Design exploration with biomaterials in Indonesia is considered much lower than its global trend [11], especially related to environmental and green building [12]. Most trends and awareness are generally influenced by Western culture or dictated by popular industry [4]. Biocultural development in Indonesia is dominated by agriculture and food technology, with few from the clothing industry, while the rest are supporters of the traditional or home industry. Biodegradable building material has not been developed progressively as it is less popular than others [11]. Despite being rich in biodiversity and cultural products, Indonesia lacks advances in natural product development [13]. The reason is that the general public in Indonesia still believes that traditional products must not be changed because of cultural reasons. Some may assume the development is troublesome, while the rest is sceptical of a new trend [12]. This contributes to general building materials in Indonesia being standard or conventional, exported or stuck on raw, natural, or traditional. If any, implementing natural material focuses on applying few finishes rather than scaling up advanced biomaterial as the prominent element or impactful façade to optimize building performance [14].

One of the most promising biocultural materials that are currently popular is kombucha. It is presently common for beverage and cosmetic consumption, although it is more well-known traditionally for herbal production [15]. Despite favour, kombucha cellulose is still considered food waste or a starter rather than being developed as a synthetic material [16]. It has great economic value and unique character [17] and can be developed at home, regardless of being stagnant in production and concentrated only on its liquid [1]. This research explores the other benefit of kombucha beyond natural remedies and focuses on testing kombucha sheets as an alternative building material. The paper concentrates on constructing the kombucha sheet as the sample material that contributes significantly to the development of the atmosphere of the space. As dominated by kombucha sheets, the space is mainly shaped by the building envelope, illustrating the gradation of colour, texture, and feel represented in a diorama.

*2.1.2. Building the Envelope*

A building envelope commonly refers to a physical separator between artificial and natural space [8]. This means building envelope creates cavities, a conditioned environment as resistance to unconditioned surroundings [9]. It may be known as an enclosure or a façade, an element that shelters the internal area of the building from the external world [8]. As a shell or a skin, it can control, maintain, and support building performance [18]. However, the most building envelope is constructed with generic industrial material. The common implementation of the envelope focuses on covering or constructing barriers than shaping the overall gesture. Rarely is an enclosure designed for housing a specific experience or exhibiting the unique character of a building [8].

Moreover, less research on building envelopes offers a design point of view of an envelope as the creator of space ambience. The envelope has excellent potential for installing a particular material, detail, craftsmanship, or tectonic to represent a context [19]. That is why it is essential to build the envelope concept not only as a divider or partition but also to contribute to creating internal quality. It represents shelter to construct a different spatial experience, a signature of design in the architecture field [9].

*2.1.3. Capturing Spatial Experience*

Spatial experience is often described as a multi-sensorial and simultaneous experience in the built environment. It enables emotional connection within space as affected by spatial qualities [20]. The elements of a place construct spatial qualities, the relationship between objects around, amid, or within its surrounding [9]. The spatial idea defines the spatial experience relationship between humans, objects, material, and vis-a-vis [5]. Architectural features embody it through material, craftmanship, tectonic, form, and shape that conveys a particular representation [9]. Constructing a meaningful and iconic spatial experience requires a spatial design to manoeuvre the development of the human environment—especially how space creates an interiority that works inside out in a particular context [8]. Spatial experience represents a condensed and complex assessment of atmosphere, ambience, nuance, feeling, and emotion [20], together with specific personal evaluations translated into a judgment concerning the nature and character of the space being experienced [21]. It is often expressed through a specific itinerary, a set of photographs, a material scheme, or details when reported as a journal or portfolio other than a video or documentary of cinematography.

### 2.2. Method of Study

The research method utilizes modified traditional kombucha fermentation to develop cellulose [22] as a building sheet. The method combines fabric manipulation, natural colouring, and material insertion in drying, pressing, and preserving processes to produce a gradation of colour, texture, and depth. Black, green and white tea are used based on home industry standards. The starter is an adapted Symbiotic Culture of Bacteria and Yeast (SCOBY) with a size 7.5 mm diameter and 0.5 cm thickness for 2 litter volume production. SCOBY is a combination of acetobacter *xylinum* and *khamir* [16] with guidelines of 8-14 days of fermentation, temperatures between 20 °C-30 °C, a pH between 4-4.5, and recommended sugar of 214 grams [23]. Fermentation duration is varied between 2-4 weeks, continued by 1-2 weeks of preservation. Instruments: mixing pot, spoon, stove, glass jar, bottle, cheesecloths, rubber gloves, straw, and pipette. The drying method is under direct sunlight, with an average tropical air temperature of 24°C -33°C and supported by an air fryer of 180 °C – 200 °C for better finishing [24]. The targeted final kombucha fresh cellulose is 0.8 cm-1,5 cm in thickness to produce a comparable product of HPL, laminate, wallpaper, shoji screen, or washi paper) when dried. The research scope is limited to producing panel samples for maquettes. They are photographed in a frontal, perpendicular, and orthographical manner to avoid distortion. The aim is to compare 3 different types of structures for constructing kombucha as a building envelope.

## 3. Results and discussion

The kombucha production begins with the starter. It is usually initiated by a small batch to test the productivity and results in a thin layer of cellulose. Adaptation requires around 1-2 months (2-4 batches) until the starter reaches a steady production. As kombucha depends on a specific environment, the producer recommends green tea in this research to be used in the adaptation process. At least 2 batches are required for producing cellulose with a thickness of 0.5 mm, yet another 2 batches to produce beyond the minimum thickness. The intermediate process is commenced with a tea, sugar proportion, and jar size variation in testing possible alternatives. Green, black and white tea are tested with 150-350-gram sugar variation in a 1-3 litter jar or aquarium. The experiment achieves stability after 2 months with a combination of the same proportion between the three. The last batch was tested using a 30x30x10 cm, 45x60x10 cm flat aquarium and obtained a stable output after 2 months. While the initiation poses a problem in adaptation and productivity, intermediate concerns with the stability as the batch has been transferred to a flatter container. The uneven surface challenges the final batch as cellulose grows sporadically. It occurs because of a larger coverage area, including a higher risk of moulding. The drying and preservation problems lie in climate change and high humidity. As cellulose is difficult to achieve total dryness in a tropical climate, an air fryer aids the process in this experiment. Once kombucha has been stabilized, the production relies on replication and modification of the same techniques, as shown in Table 1.

**Table 1** Kombucha Sheet Production Process Sample

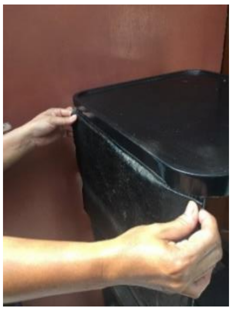
| Level and Activity | Initiation (July 2021) | Intermediate (August 2021) | Final (September 2021) |
|---|---|---|---|
| Preparation |  |  |  |
| | 7/07/21 | 10/08/21 | 24/09/21 |

| Level and Activity | Initiation (July 2021) | Intermediate (August 2021) | Final (September 2021) |
|---|---|---|---|
| Fermentation |  |  |  |
| | 11/07/21 | 22/08/21 | 15/10/21 |
| End Product |  |  |  |
| | 30/08/21 | 05/09/21 | 22/10/21 |

*Organic material demonstrates a variety of growth and maturity; the date may illustrate progress but should not be taken as the best momentum of representation.

Building a kombucha sheet as an envelope means giving structure for the sheet to stretch. The elasticity and plasticity of kombucha cellulose require a structure that holds. In the initiation, the sheet is tested on an ordinary object like a cupboard, door, or partition; a sample is illustrated in Table 2. At the same time, this also addresses the common problem of uneven tone in general flat organic material. Structure, in this sense, supports the envelope to demonstrate depth and fluid nuances. By providing a simple or complex construction, the sheet displays the whole stretch of the surface. The sheet may exhibit colour, intensity, texture, and shading if appropriately supported by the light. A module structure represents a piece of kombucha sheet, while a joint module creates a relationship between frames, bonding the connection between them, whether to create a bigger screen or form a shape. As a result, a compilation of structures constructs a spatial form, consisting of a spatial experience while building a gesture to the surrounding environment. In other words, a spatial experience consists of various frames that represent the scene; suggests a set of specific sequences, exhibiting perspectives experienced by an observer.

**Table 2** Kombucha Sheet Prototype Concept Testing

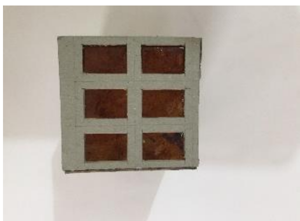
| Product Information | Furniture | Building Element | Envelope Component |
|---|---|---|---|
| Process |  |  |  |

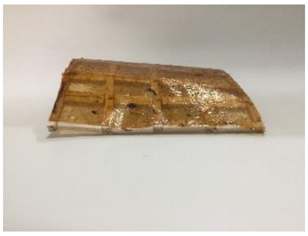
| Product Information | Furniture | Building Element | Envelope Component |
|---|---|---|---|
| Detail |  |  |  |
| Presentation |   |   |   |

*Photo may have been altered to emphasize the concept or to highlight particular detail for specific purposes.

Although spatial experience may be considered personal, capturing it relies on documentation sequentially demonstrating a set of scenes. The problem of documentation when presenting spatial experience falls to segregation and division of images or merely an artistic representation. Consequently, one may not be able to understand the continuation yet be distracted by a certain angle. Even though the case is simple and only focuses on the material, suggesting a sequential itinerary from the point of departure to the end is essential to offer an alternative method for presenting spatial experience. The kombucha sheet demonstrates a fluidity of a texture that may not be the same throughout the envelope. Although kombucha may contrast with the standard industrial product, this experiment recommends the idea of nonuniformity in building design. Its texture is unpredicted and surprising, showing fluidity that highlights a unique spatial experience. A similar character may be possessed by other fermented material but frequently distinct from regular traditional material that is already popular, like shoji paper. Although different, the kombucha may have negative side effects such as smell and slimy texture, which some may consider harmful, whereas latent potency.

**Table 3** Kombucha Sheet Maquette Experimentation

| Information | Rigid Structure | Semi-Rigid Structure | Flexible Structure |
|---|---|---|---|
| Top View |  |  |  |

| Information | Rigid Structure | Semi-Rigid Structure | Flexible Structure |
|---|---|---|---|
| Front View |  |  |  |
| Side View |  |  |  |
| Aerial Perspective |  |  |  |
| Exterior Perspective |  |  |  |
| Interior Perspective |  |  |  |

The research tested 3 types of structures to erect kombucha sheets, namely rigid, semi-rigid, and flexible structures, to produce the ambience of spatial experience by using a maquette, as shown in Table 3. To avoid miss-perception regarding orientation and direction, the division of photographs is categorized under common architectural drawing and perspective representation: top, front, side, aerial, exterior, and interior perspectives. It begins with the top and ends with the interior perspective. Different sides and standard perspectives are used to crosscheck the characteristic of the sheet when applied to the model. The exact position and orientation are compared side-by-side, featuring the essential side to the most complex volume.

The top position suggests that the rigid and flexible structure shows a stiff and seamless sheet, as the sheet has been stretched maximally, while the semi-rigid structure exhibits a wavy texture. Front and side positions show rigid has smooth, tidy, and impeccable texture, semi-rigid has variation, while flexible suggests a slight gradation. Three sides influence the overall perspective of the maquette, illustrated by aerial and exterior perspectives. While the rigid structure shows a kombucha sheet feature almost like translucent glass, the semi-rigid structure demonstrates undulating, curly, and crinkly sheets, yet the flexible structure illustrates a slightly bumpy texture but is hardly seen at a distance. The characteristics can be confirmed when investigating the internal area of the maquette. While rigid and flexible structures display relatively flat and almost shiny stretch, the semi-rigid structure exhibits wrinkles as they are not adequately stretched, developing a 3-dimensional texture. Thus, these three variations of texture generate at least three types of spatial experience as follows;

- The rigid structure supports the creation of a modern, sleek, and geometric tendency
- The semi-rigid structure potentially generates a sculptural, carved, and quasi-relief façade
- The flexible structure presents the most natural feature with the elastic, plastic and uneven texture of a kombucha sheet when applied to a similar characteristic structure.

## 4. Conclusion

This research output is a kombucha sheet as an alternative building biomaterial. It is presented as a prototype sample for the building envelope. The exploration focuses on demonstrating the texture strength of sheet design. The finding shows that the sheet displays a certain fluidity and organicity, reflected in uneven texture, earthy colour, and certain elasticity or unusual plasticity in contrast to other traditional sheet materials. As a novelty, kombucha possesses a transitional feature between paper, skin, and rubber while exhibiting abiotic characteristics. With translucent, natural, and stretchy features, this material may easily modify by layering, inserting, and shaping processes into different products other than architecture, yet presenting a match. The material displays a specific characteristic that may be best for proposing an organic or fluid building style. According to the research, the experiment suggests that a rigid structure is the best preference for providing a smooth and seamless texture of kombucha; the semi-rigid structure may produce an undulating sheet, potentially displaying landscape-like texture if managed correctly.

In contrast, a flexible structure demonstrates plastic, elastic, and slightly bumpy texture, the strength of natural kombucha characteristics if installed correctly. The overall feature of the kombucha sheet supports the development of soft-space material, like textile, tensile, and fabric, although it may not be best for presenting uniformity. It has a certain degree of biodegradability that needs to be treated for longer. However, it must be produced, constructed, and treated sterile to control. Yet the most challenging process is to elevate a specific aroma and manipulate the finishing touch as it is now at the border, whether some perceive it as a problem or others as a strength.

## Compliance with ethical standards

### *Acknowledgements*

The authors would like to thank RISTEK-BRIN (Kementerian Riset dan Teknologi/Badan Riset dan Inovasi Nasional) Indonesia, who funded this research; LPPM (Lembaga Penelitian dan Pengabdian Kepada Masyarakat) Universitas Tarumanagara, and also the editor, and reviewers for their valuable suggestions.

### *Disclosure of conflict of interest*

The Authors confirm that the content of this manuscript has no conflict of interest.

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