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A More Bio-Receptive Concrete Façade Design: A Greener Way to Breathe

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Abstract

Cities' expansion has resulted in a decrease in green spaces, contributing to the issue of global warming. Achieving the Sustainable Development Goal (SDG) for zero-carbon, healthy, and clean cities necessitate solutions. One such solution is to examine the idea of Bio receptivity of Concrete, which refers to the ability of concrete surfaces to foster the growth of micro plant species. Although biofouling has a negative connotation, it has the potential to be transformed into an environmental solution. Previous research has devised an effective recipe for Bio Receptive Concrete Façade (BRCF) design. This study aims to adapt this recipe to suit the hot and humid climate of Bangladesh while utilizing locally available Bryophyte species, prioritizing the utilization of readily accessible resources. The study consists of two segments: designing the façade panel shape and observing natural growth under optimal temperature and controlled humidity. After five weeks of observation, it was found that Sphagnum thrives well with our modified mix design recipe on a specific shaped panel. However, further investigation is required to assess the durability of these panels in severe weather conditions, such as extreme heat and cold.

Keywords: *Bio-receptivity; Biofilm; Vertical green; Concrete façade panel; Bryophytes*

1 Introduction

Climate change and global warming cause serious problems that we must address. Our world is rapidly becoming uninhabitable. The book by (Berners-Lee, 2019) says itself, "There is No Planet B". The air we inhale is experiencing a decline in quality. As per report by (UNB Reports, 2023) Sunday (June 11, 2023), the air quality index (AQI) in the capital of Bangladesh, Dhaka (23.8103° N, 90.4125° E) reached a score of 157, indicating an 'unhealthy' air classification. The United Nations Development Programme (UNDP) established Goal 13 of the Sustainable Development Goals (SDG) 2030 to enhance resilience and adaptation ability to climate-related hazards and natural disasters globally (UNDP SDG, n.d.). Today, 55% of the global population resides in urban regions, and it is projected to reach 68% by the year 2050 (UN, 2018). The process of mass urbanization and the centralized economy in Dhaka have a significant impact on its air quality index (BBS, 2015). This situation possesses a threat to other urban areas in the near future. Getting apart from the concrete jungle of urban scape, we must prioritize increasing green spaces.

However, it is challenging to maintain greenery in high-rise buildings. The façade panels of these buildings can be made of Bio Receptive Concrete. This will allow growth of micro level fauna (Guillitte, 1995). If a building surface is treated with a highly bio receptive material, it has the potential to become a green surface. The growths that form on these surfaces are known as biofilms and include algae, fungi, lichen, and Bryophytes. These biofilms can thrive in almost any natural environmental condition, as long as the substrate they are attached to is suitable (Anna A. Gorbushina, 2017). According the LEED 4.1 Certification, it is stated that if any sustainable building material is used in construction which reduces GHG/carbon emissions, delivers cleaner indoor air to improve productivity, focus and reduce respiratory illnesses of its occupants, can be a contributing part of Green Building (*LEED v4.1 | U.S. Green Building Council*, n.d.).

These facades are basically needed at high-rise buildings where buildings are taller than average trees in urban areas. Being the most crowded and polluted city in Bangladesh, Dhaka has the most high-rise structures in the whole of the country. There are currently 71 built, 10 under construction, 9 approved for construction, and 6 proposed high-rise buildings. The City Centre Dhaka, standing at 561 ft, is the current tallest building, but it will be replaced by the under-construction Legacy Tower (1,552 ft) after completion (*List of Tallest Buildings in Bangladesh - Wikipedia*, n.d.). Nevertheless, our aim is to incorporate Bio Receptive Concrete facades into new-generation high-rise buildings, taking advantage of readily available materials to create a greener urban environment in the context of Bangladesh. It has a great potential of making future-ready, sustainable and eco-friendly buildings with bio receptive concrete façades. Studies regarding the feasibility and compatibility of readily available Bryophytes, such as *Marchantia Polymorpha (liverwort), Sphagnum sp. (Moss), Fissidens hadii (Moss) etc* are needed. But the current study was focused on the adaptability of *Sphagnum sp.* with modified bio receptive concrete.

2 Materials and Methods

2.1 Mortar Specimen & Mix

To enhance the bio receptivity by utilizing available local resources, adaptations were made to the method described by (Veeger, Ottelé, et al., 2021). Instead of Crushed Expanded Clay (CEC), which would have made the panel lightweight, coarse aggregate brick chips with a diameter of 12 mm (passed) and 9 mm (retained) ws opted. For the fine aggregate, sand with particle sizes of 2.36 mm (passed) and 1.18 mm (retained) was used. The bone ash was analyzed through a sieve with a mesh size of 150 µm (retained). To maintain a low pH in the concrete, a mixture of food-grade Glacial Acetic Acid (E 260) at 5% concentration and distilled water, commonly known as vinegar was employed.

Table 1: Modified materials composition for mortar mix.

Materials	**Existing Mix** (Veeger, Ottelé, et al., 2021)	**Modified Mix**
Cement	OPC	PCC (300kg/m³)
Coarse Aggregate	Argex AG4/8 (CEC)	Brick chips (578 kg/m³)
Fine Aggregate	Sand (0-4mm)	Sand (762 kg/m³)
Mineral Admixture	Bone ash	Bone ash (30kg/m³)
Water	Water	Water (150kg/m³) (wcf 0.50)
Additives	N/A	Vinegar

2.2 Biofilm & Cultivation

2.2.1 Sphagnum

Bryophytes flourish in abundantly in Bangladesh, a subtropical country with hot, humid summers and mild, dry winters. These plants can be found throughout the country in a wide range of habitats, but they grow year-round in hills and wooded areas. The bryophytes in Bangladesh encompass three classes, 14 orders, 34 families, 92 genera, and approximately 247 species, which include four variations. Among these, mosses are the most widespread (*Bryophyte - Banglapedia*, n.d.). We chose Sphagnum Moss for cultivation. Sphagnum-dominated peatlands store more carbon than all of Earth's forests, playing a large role in the balance of carbon dioxide. Sphagnum moss plays a crucial role in the development of peatland ecosystems and single-handedly accounts for approximately 10% of the global soil carbon storage (Laing et al., 2014). Based on information from the Plant List, (*Sphagnum — The Plant List*, n.d.) there are a total of 382 species within the Sphagnum genus. Sphagnum is an aquatic plant that lacks vascular tissue and is commonly found on the surface of peat bodies. The lifespan of sphagnum moss depends on several factors, including the type of sphagnum moss, the climate and quality of water, and the amount of sunlight exposure[1]. In general, live sphagnum moss doesn't expire and can last forever if these conditions are met[1]. Dried sphagnum moss, on the other hand, can last 2 to 5 years if it's taken care of properly. However, it will eventually lose its absorbency and become less effective over time. It thrives in environments with low nutrient levels, waterlogged conditions, and acidity. It's. leaf has the ability to retain significant amounts of water and withstand drought (McKeon-Bennett & Hodkinson, 2021). Due to these characteristics, sphagnum is an excellent choice for implementing in our Study.

2.2.2 Biofilm Cultivation

The source of the biofilm is collected from a horticulture of Rajshahi (24.3745° N, 88.6042° E), Bangladesh. Subsequently, the collected biofilm was introduced into an Erlenmeyer flask filled with BG11 liquid growth medium under optimal growing conditions (room temperature, ~90% humidity, 12h day/night cycle in a light intensity as well as humidity was maintained by a fume hood at Environment Laboratory, Rajshahi University of Engineering & Technology (RUET).

2.3 Panel Structures & Mold Development

Taking inspiration from the architectural approach of bee hives, we opted for the regular hexagonal honeycomb shape for our panels, with dimensions specified as a side length (L) of 4 inches and an arm thickness (T) of 0.5 inches. For the panel fabrication, we utilized a casting mold made of GI sheet, while white PVC sheets served as the basement formed in different shapes. The surface of the mold comprises of grooved depth of 0.20 in. White PVC sheet being the base, made these shapes possible. This special designed surface is for both aesthetical purpose and for ensuring microclimate. The level of texture present assists in establishing a microenvironment on the surface. It accomplishes this by trapping moisture derived from rain, dew, and the gathering of dust. Additionally, it offers essential shading to counteract the impact of a hostile surrounding (Mustafa et al., 2021). Moreover, the aim of making the surface textured is to make the panel capable of retaining water.

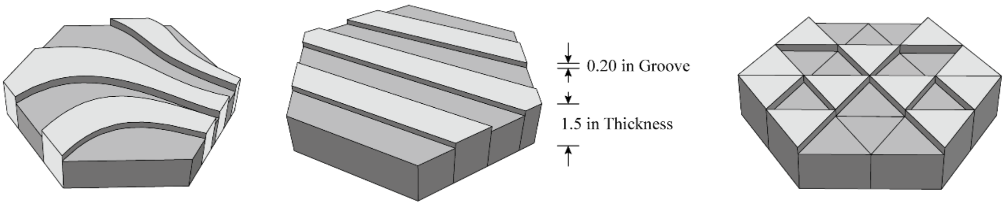


Figure 1. Panel Shapes 3D (Wave, Stripe, Triangle)

2.4 Methodology

Our study comprised of two phased approaches. The first phase involved the preparation of hexagon-shaped concrete panels. We are inspired from honeycomb shaped composition of the panels. We wanted three different panels and to achieve this, we developed three prototypes with distinct surface textures: Wavy, Striped, and Triangular. Designing these panels had a challenge that extended beyond their surface appearance. We needed to ensure that the panels promoted bio receptivity and were porous & textured enough to retain water. To address this, we referred to previous works in this area and utilized modifying the formulation of bio receptive concrete (Veeger, Ottelé, et al., 2021). After casting, the concrete was left undisturbed to set for maturing for 28 days, marking the transition to the second phase of our study.

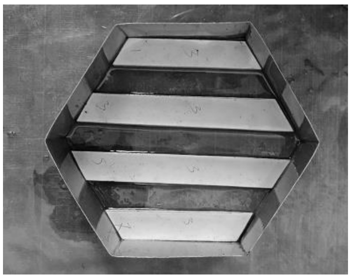


Figure 2. Mold Setup with PVC Base (Stripe)

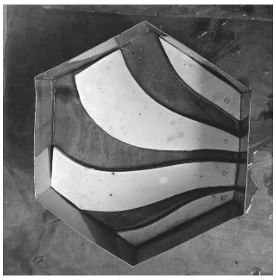


Figure 3. Mold Setup with PVC Base (Wavy)

In our second phase, the panel was inoculated with liquid biofilm previously kept in the incubator of Environment Lab, RUET. A slurry was made with the sample and yogurt and carefully brushed on the rough porous surface of the panels. After inoculation, the prototypes were kept in a distilled water bath, with the water line just below the concrete surface to ensure the proper capillary effect is happening there.

A nutrient solution was prepared by diluting 10mL of liquid NPK fertilizer (1:1 water diluted 7-2-7 NPK fertilizer enriched with trace minerals and humic acid) with 450mL of distilled water. To prevent cell senescence, a practice was implemented during this phase where, every week, 50mL of the previous liquid biofilm was introduced into a fresh solution containing water and liquid fertilizer as per (Veeger, Prieto, et al., 2021). The panels were moistened twice daily during this period to prevent excessive drying of the biofilm. The progression of growth was continuously documented throughout the entire experiment of 28 days of observation.

3 Analysis

3.1. Colorimetric Measurements and Image Analysis

We initially aimed to measure the biomass of the vegetation that grew over the concrete panels. However, due to limitations in our laboratory, we opted to utilize FIJI, an open-source image processing package based on ImageJ2 (Spinedi et al., 2019). We captured the images using a Xiaomi camera with the following EXIF data: f/1.9, 1/33s, ISO367, 6.04mm (equivalent focal length 25mm), no flash, and room lighting setup. Once we collected all 15 images, we imported them into FIJI.

We used RenyiEntropy Auto threshold method for thresholding the green region. Subsequently, we utilized the Analyze Particle command to determine the percentage of green area relative to the entire region of interest. This process provided us with summarized data regarding the percentage of green area. Since processing images in batch mode can be tedious, we created a macro programming script for each panel and executed them accordingly. Analyzing the images, we obtained data for all 15 images, revealing their growth patterns.

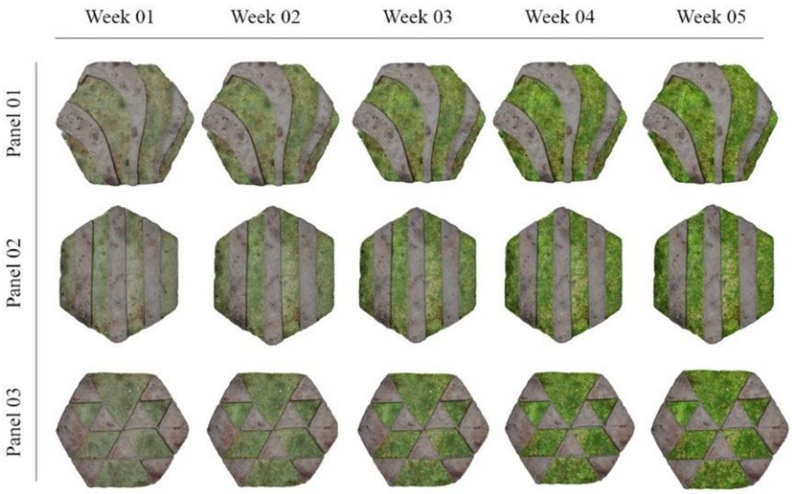
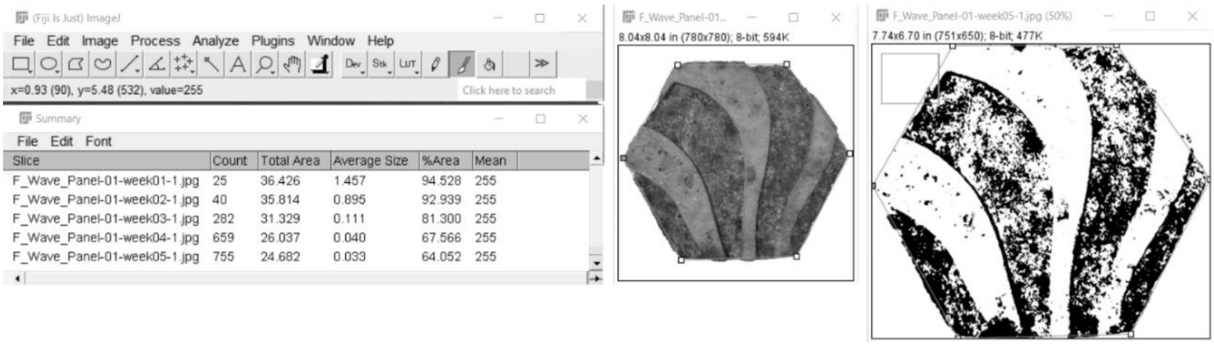


Figure 4. Bryophyte Propagation Observation



x=0.93 (90), y=5.48 (532), value=255

Slice	Count	Total Area	Average Size	%Area	Mean
F_Wave_Panel-01-week01-1.jpg	25	36.426	1.457	94.528	255
F_Wave_Panel-01-week02-1.jpg	40	35.814	0.895	92.939	255
F_Wave_Panel-01-week03-1.jpg	282	31.329	0.111	81.300	255
F_Wave_Panel-01-week04-1.jpg	659	26.037	0.040	67.566	255
F_Wave_Panel-01-week05-1.jpg	755	24.682	0.033	64.052	255

8.04x8.04 in (780x780); 8-bit; 594K

7.74x6.70 in (751x650); 8-bit; 477K

Figure 5. Data acquisition by FIJI

Table 2: Area and percentage of green area of panels

Week	Area (P01) (in^2)	Area (P01) (%)	Area (P02) (in^2)	Area (P02) (%)	Area (P03) (in^2)	Area (P03) (%)
01	36.426	5.47	35.645	8.29	41.708	6.24
02	35.814	7.06	34.809	10.44	40.733	8.44
03	31.329	18.70	33.336	14.23	27.373	38.47
04	26.037	32.43	28.011	27.93	25.625	42.40
05	24.682	35.95	26.698	31.31	25.608	42.44

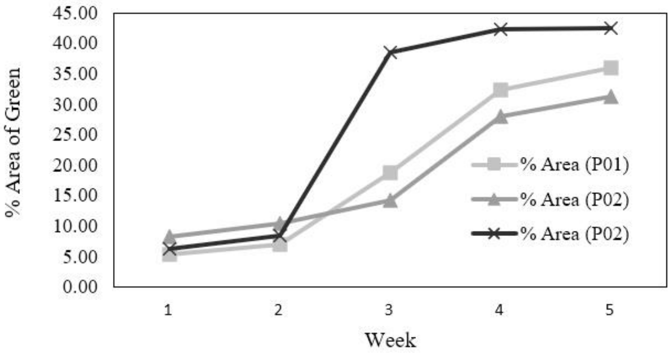


Figure 6. Weekly growth rate on panels in percentage of green

4 Result

Over a span of five weeks, we explored bio-receptive panels' potential for cultivating sphagnum moss as facade material. Panel type P02 emerged as an exceptional substrate, displaying optimal qualities for moss growth and facade integration. Sphagnum moss's intrinsic attributes, including moisture retention and nutrient absorption, align seamlessly with panel P02, making it an ideal choice for exterior applications. This integration not only enhances building aesthetics but also offers ecological advantages such as air purification and sustainable design. Ultimately, our research underscores panel P02's viability as an environmentally friendly solution for moss cultivation and innovative facade design, showcasing its promise for architectural and ecological synergy.

5 Conclusion

The inherent properties of sphagnum moss make it particularly well-suited for implementation on panel P02 as a facade material. Sphagnum moss is known for its high-water retention capacity and efficient nutrient absorption, enabling it to thrive in various climates. This resilience makes it an excellent choice for exterior applications, where it can contribute to thermal insulation and regulate moisture levels on the panel surface.

In summary, our research demonstrates that panel P02, with its stripe-shaped design, serves as an excellent surface for cultivating sphagnum moss. Its unique characteristics, such as moisture retention, water absorption, and visual appeal, make it an attractive option for facade applications. The integration of sphagnum moss on panel P02 not only enhances the aesthetics of buildings but also offers ecological benefits, such as air purification and sustainable design. Overall, our findings support the use of panel P02 as a viable and environmentally friendly solution for moss cultivation and facade design.

6 Discussion

While our research has shed light on the suitability of panels for sphagnum moss cultivation and its potential as a facade material, there are still plenty of aspects that call for additional research.

Future studies might focus on assessing the long-term environmental effects of including moss-covered façade in buildings from a sustainability perspective. Studies on the moss's ability to reduce the effects of urban heat islands (UHI), enhance air quality, and sequester carbon would be significant. Assessing the ecological advantages of moss-covered panels would also benefit by quantifying their contribution to local ecosystem and biodiversity.

To increase the lifespan of moss on panels, further investigation is necessary. Long-term studies are needed to understand the factors that affect moss growth and survival on the panels, such as moisture levels, temperature fluctuations, and exposure to sunlight. Identifying optimal maintenance practices and developing protective coatings or substrates that enhance moss resilience would be beneficial in prolonging its lifespan.

Continued investigation and experimentation will contribute to a more comprehensive understanding of the environmental, economic, and design implications associated with moss-covered panels and pave the way for their wider adoption in sustainable architecture.

5 Acknowledgement

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