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Effect of a Microalgae Facade on Design Behaviors: A Pilot Study with Architecture Students

Kathryn Warren, Julie Milovanovic and Kyoung Hee Kim *

School of Architecture, University of North Carolina at Charlotte, Charlotte, NC 28223, USA
* Correspondence: kkim33@uncc.edu

Abstract: The influence of nature on occupant well-being and performance has been proved in office, hospital, and educational settings. There is evidence that plants and green colors affect creative and psychological responses. The microalgae facade in the study integrated spirulina, blue-green microalgae, which were cultivated using natural daylight and room air. While a good body of research explores nature's impact on people, research on microalgae systems has not been linked to creative performance. This pilot study, therefore, focused on how the microalgae facade influences occupant mood and creativity. Forty architecture students were randomly assigned to the control and experimental rooms. The control group was surveyed in a room with a traditional window, whereas the experimental group was surveyed in a room with a biochromic window. Research design for the two conditions remained the same under IEQ-controlled environments except for the inclusion of the microalgae facade. Forty architecture students completed two creativity tasks—alternative use test (AUT) and remote association test (RAT)—and brainstorming for sustainable design in control and experimental settings. Our preliminary findings indicate that the microalgae facade did not affect divergent ideas and convergent thinking during tasks, but participants in the microalgae façade developed more design solutions that included greenery than students in the control space. This research is a preliminary investigation into the human impact of a microalgae façade and represents a new focus for scientific research. More work is needed to better grasp to what extent implementing a microalgae façade will impact human behavior in space.

Keywords: nature positive design and microalgae facade; indoor environment quality; architecture design creativity; health and wellbeing; alternative use test (AUT) and remote association test (RAT)

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1. Introduction

Designing healthy indoor environments is crucial for architects as people today spend the majority of their time indoors. The quality of indoor environments affects humans' physical and mental health (i.e., sick building syndrome). Sick building syndrome can lead to decreases in performance and productivity through symptoms such as difficulty concentrating, muddled thinking, mental fatigue, and drowsiness [1]. Healthy buildings that incorporate sustainable design principles and materials tend to have a positive effect on occupants' well-being, satisfaction, and productivity [2]. To that extent, microalgae facades as a design solution address environmental concerns as well as occupants' health and well-being. Numerous studies have investigated the environmental and technical performance of microalgae facades [3,4]. Microalgae facades can improve indoor and outdoor air quality, which has been documented in previous research [3].

Moreover, microalgae facades provide biophilic design elements by offering a stronger biological connection compared to traditional facades. Biophilic design aims at connecting people and nature within the built environment [5,6]. Previous studies showed accrued cognitive performance and more positive emotions while experiencing biophilic indoor spaces [7–9]. Hence, microalgae facades have the potential to enhance occupants' experience of indoor spaces by improving air quality and providing a stronger connection to

nature. To our knowledge, no studies have yet investigated the impact of this emerging building technology on cognitive performance and emotion. In this paper, we focused on assessing the effects of a microalgae façade on architecture students' cognitive performance and emotions. For architects, performance equates to approaching design through innovation and creativity [10].

Designing for sustainability is critical to provide for future generations [11], and developing sustainable cities and buildings will require creative innovation. A recent study demonstrated that civil engineering students working in a LEED Gold building over a semester developed designs that ranked higher in sustainability (LEED score) compared to students in a non-LEED building [12]. Another study of 108 business students found that students surrounded by plants and exposure to natural views had an increased visual and verbal creativity [13]. Building on previous research, this study focused on the effect of the microalgae facade on architecture students' creative performance and mood during several design tasks. We employed two types of creative design tasks: (1) the Alternate Uses Task [14,15] and Remote Associate Test [16] to assess divergent and convergent thinking in a constrained setting, and (2) a brainstorming task on sustainable design, a more open and naturalistic task. Emotions were tracked using the Brief Mood Introspection [17].

The microalgae facade in this study integrated spirulina (blue-green microalgae) in a network of interlocking modular systems (Figure 1). The spirulina was cultivated using natural daylight and room air, which affected the cell density and growth rate of spirulina. The microalgae façade allows direct access to sunlight and carbon dioxide for photosynthesis. At the same time, the operating system ensures the highest biomass production by controlling optimum cultivation factors such as nutrients, light, and pH. The façade system effectively reduces carbon dioxide and improves indoor air quality due to its superior photosynthetic performance. It showed around 200 ppm CO_2 reduction when comparing CO_2 levels between the intaking air and outtaking air. Ultimately, the system expects to maximize the potential social and environmental benefits through building energy efficiency, improved indoor air quality, carbon sequestration, and biomass production achieved for broad applications in various buildings and site locations.

Figure 1. The microalgae facade in the creativity study is composed of a network of interlocking bioreactors filled with spirulina, blue-green microalgae.

In the following section, we present the context of the study by describing the potential effects of microalgae facades on cognitive performance and emotions. In Section 3, we present the research questions that this paper addresses. Section 4 describes the pilot study and the metrics used to assess participants' creativity and emotions. Section 5 presents the

main findings from this study, while the discussion emphasizes the implications of our findings for future research and potential applications of algae facades.

2. Background

2.1. Microalgae Facades Increase Indoor Air Quality, Improving Cognitive Performance

Indoor air quality can significantly impact occupant health and comfort. Our measurement data indicate that CO_2 levels in a classroom during lecture hours before the pandemic ranged from 1500 to 2000 ppm, while the outdoor CO_2 level was 400 ppm. The ASHRAE 62.1 standard specifies a minimum air exchange rate depending on room types because excessive CO_2 can cause adverse health effects such as headaches and nausea. Wyon (2004) demonstrated that even improvements in indoor air quality imperceptible to occupants could have measurable effects on their health [18]. An extensive review led by Wang et al. (2021) found that poor indoor air quality is often associated with reduced cognition [19]. In an evaluation of chess players, Künn et al. (2019) found that, although particulate matter in the air had a more significant influence on players' performance than carbon dioxide levels, high CO_2 levels had a negative effect during high-stakes decision-making phases of the game, when players are under considerable stress [20]. Kosonen and Tan (2004) estimate that increasing a building's ventilation rates from 5 L/s per person to 10 l/s per person could provide productivity benefits ten times higher than energy and maintenance costs, although it would increase building energy use by 10% [21]. These studies highlight the influence of indoor quality on well-being and cognitive performance.

Microalgae facades are a state-of-the-art technology in architectural design. Much of the research on microalgae facades indicated that they reduce the carbon footprint of buildings by decreasing buildings' energy demand [4] and have the potential to reduce air pollution in indoor spaces [3]. As microalgae photosynthesize, they effectively remove carbon dioxide from the air and produce oxygen, contributing to improved indoor air quality. As microalgae facades offer a sustainable solution to improve air quality [3] and natural ventilation [4], they could benefit occupants' cognitive performance and emotions in indoor spaces. Microalgae can double their biomass as short as 3.5 h during exponential growth periods [22]. Using the carbon sequestration rate of 1.8 kg of CO_2 removed for 1 kg of dry algal biomass, microalgae facades can be the most promising decarbonating technique due to their superior photosynthesis rate. Enhancing indoor air quality will positively impact cognitive performance, health, and well-being.

2.2. Importance of Biophilic Design to Support Cognitive Performance and Well-Being

Biophilia has become an essential facet of architectural design by implementing nature in the space (nature within the built environment), using nature analogs (e.g., biomorphic forms and natural material), and improving the nature of the space (spatial configuration triggering specific physiological responses) [5,8]. Wilson's (1994) biophilia hypothesis describes the innate desire in living things to understand and connect with other life [6]. Using algae facades in buildings aligns with biophilic design strategies implemented to improve occupants' connection to nature.

Numerous studies have been performed in the last decades to investigate the impact of nature on human well-being [8,23]. Zhong et al. (2022) provide a comprehensive review of how biophilic design can also have positive implications for sustainable architecture and improve one's experience of a space [23]. For example, biophilic design can reduce materials and building costs [24], optimize air quality and thermal comfort [25–27], reduce stress [8], and provide psychological restoration [9,28,29]. Biophilic office spaces tend to reduce stress and improve occupants' satisfaction and cognitive performance [30]. Ulrich (1984) demonstrated that patients who had a nature view out a window recovered more quickly than patients who could only see a brick wall [31]. Access to natural views has also been associated with a higher ability to direct attention [32] and improved mental engagement and attentiveness [33], which can improve performance. Another study from Al Horr et al. (2016) had similar findings: biophilic elements within a building and views

of nature and greenery improved occupants' productivity [34]. In their review, van den Bogerd et al. (2020) were unable to draw firm conclusions about the effects of nature in an academic environment, but found a possible association between green spaces on campus and student quality of life [35].

Aside from cognitive performance, nature in a space, such as the presence of plants in an office, can increase employees' concentration and well-being [36]. In their study, Howell et al. (2011) found that "nature connectedness" positively correlated with psychological and social well-being, although it did not correlate with emotional well-being or mindfulness [37]. In their review of biophilia in the built environment [8], Browning et al. (2014) reference research demonstrating that the presence of water can reduce stress [38] and improve concentration and memory [33].

2.3. The Green Color of Microalgae Facades Can Affect Emotions

With its biophilic property, another element of the microalgae façade that could affect human behavior is its color. Prior research has demonstrated that the color green can increase self-reported participant enjoyment in cycling tasks compared to red and gray [39]. Over a series of four different experiments, granting participants a "brief glimpse" of the color green before completing a creative task enhanced creative performance [40]. The green color of the microalgae facades could potentially improve enjoyment and creative performance during a task. The color green could also impact stress and anxiety. According to Jacobs and Suess (1975), exposure to blue or green light significantly reduces stress levels compared to exposure to red and yellow light [41]. Another study showed that exposure to the color green did not influence perceived anxiety or effort [40], although it can reduce fear of failure [42] compared to exposure to the color red. These findings suggest that the green color of the microalgae façade could help reduce stress and increase enjoyment and performance.

2.4. Effect of the Built Environment on Design Creativity and Sustainable Design

In this study, we explored the cognitive performance of architecture students. Therefore, emphasis was placed on assessing the effect of microalgae facades on creativity and sustainable design. To be competitive, design solutions need to be innovative in how they address design problems. Creativity in ideation is a prerequisite for innovation [43]. As architects, it is essential to understand the impact that built spaces have on occupant health, safety, and happiness [2]. Designing for sustainability requires innovation beyond traditional design approaches [44]. Indeed, creativity is important to develop green innovation practices for a sustainable future [45].

Exposure to sustainable buildings or systems can positively influence students' willingness to implement the sustainable design. For example, Shealy (2016) showed that civil engineering students working on a semester-long design project in a LEED-certified building generated designs that scored higher in the LEED certification metrics than students that developed a similar project in a traditional building [12]. Another study found that green training, related to environmental topics, increased green creativity or the capacity of someone to develop new ideas in sustainable development [46]. Exposing architects and architecture students to sustainable systems such as microalgae facades can have an impact beyond cognitive performance and emotional well-being; it can enhance creative thinking for a sustainable future.

3. Research Questions

Section 2 highlighted elements of a microalgae facade that impact human cognitive performance and emotion in space. Microalgae facades address sustainability principles while reducing indoor air pollution and regulating solar transmission. Moreover, these facades also act as biophilic design elements by augmenting a human connection to nature through their materiality (natural) and aspect (color green). All those factors tend to support better cognitive performance for occupants and tend to favor positive emotions. Nowadays,

performance in architectural design equates to developing innovative sustainable solutions for the built environment. In this research, we explore to what extent a microalgae façade may impact architecture students' emotions, performance in creativity, and sustainable design. The research questions are as follows:

1. What is the effect of a microalgae façade on architecture students' emotions?
2. What is the effect of a microalgae facade on architecture students' creativity?
3. What is the effect of a microalgae façade on architecture students' ability to brainstorm sustainable ideas?

Our hypotheses are that the microalgae façade will have a positive effect on architecture students' self-reported emotions, with students reporting more positive emotions after exposure to the microalgae façade compared to before their exposure to the façade. We hypothesize that students exposed to the microalgae façade will be more creative than those not exposed to the façade and will perform better on different creativity tasks. We expect the microalgae façade to positively impact architecture students' ability to brainstorm sustainable ideas, with students who are exposed to the façade developing more creative ideas than those who are not exposed to the façade.

4. Methodology

To assess to what extent the microalgae facade impacted architecture students' cognitive performance and emotion, we conducted a study where forty students were given two creativity tasks and a design task. Half of the students performed the tasks in an indoor environment without the microalgae façade (control group), while the other half performed the same tasks in an indoor environment with the microalgae façade prototype (experimental group). Results from both groups are compared to assess the effect of the microalgae façade. The research presented is a pilot study to explore the first trends and refine the experiment design to expand this research. It builds on previous research led by the authors' institution on microalgae facades [47].

4.1. Experiment Design

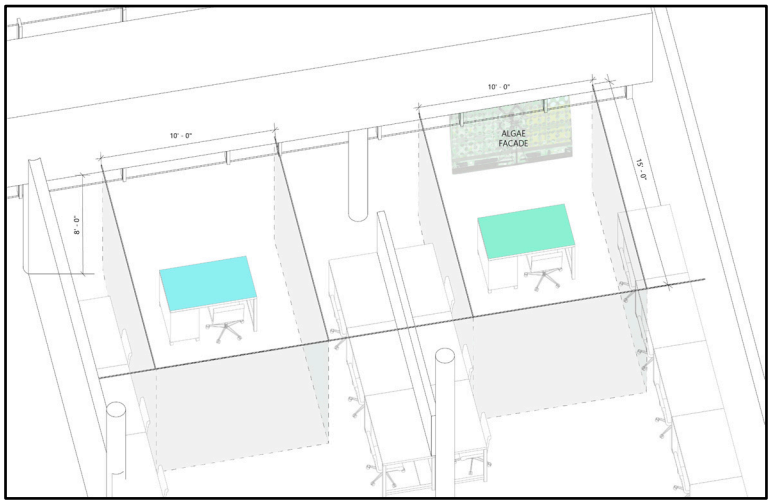
4.1.1. Participants and Setting

We recruited 40 participants from the School of Architecture at the Authors' university via an email campaign and classroom announcements. All participants were architecture majors and were over the age of 18. In total, 19 undergraduate students and 21 graduate students participated in the study. One participant was taken out of the study due to data corruption. The study was conducted over a one-month period from late February to early March 2022. The experiment took place on weekdays between 11 am and 2 pm to ensure a similar sunlit condition as it affects the aspect of the microalgae façade.

Two identical experiment rooms were constructed out of hanging white curtains. Following standard office sizes found in *Architectural Graphic Standards*, the rooms measured 10 ft $\times$ 15 ft [48]. The experiment room faced the microalgae facade prototype (which stands in front of a window), and the control room faced a window with an un-obscured outdoor view (Figure 2). Each room featured a single desk and chair in the middle of the room facing the windows (Figure 3).

Participants first completed a pre-task questionnaire to assess their mood. After entering the experiment rooms, participants had one minute to adapt to the space before performing the design tasks. The order of the design tasks was randomized to distribute the efficiency effect of overall tasks. In total, 20 students engaged in the task in the control room, and 20 in the experimental room with the microalgae façade.

(**a**)



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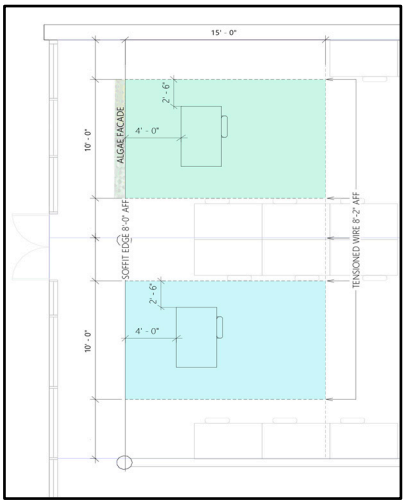
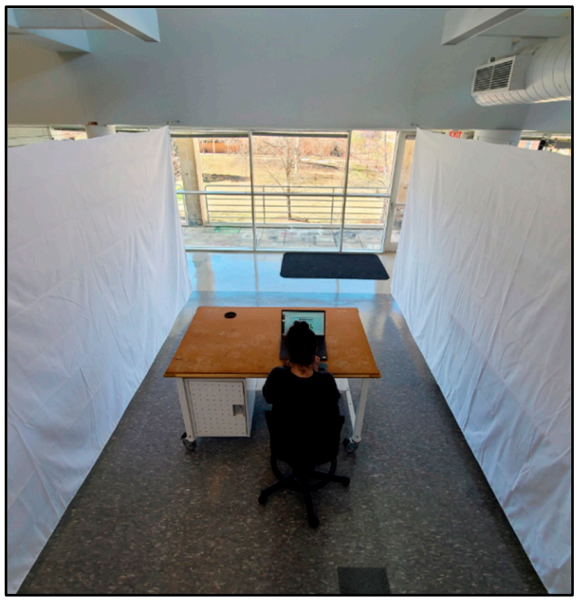


Figure 2. Representation of the experiment room setting: (**a**) axonometric representation and (**b**) plan representation.

(**a**)



(**b**)

Figure 3. Picture of the experiment rooms with a participant: (**a**) without the microalgae façade and (**b**) with the microalgae façade.

4.1.2. Measuring Mood

Before entering the curtained rooms, participants completed the Brief Mood Introspection to determine their baseline mood [17]. This is an open-source questionnaire that asks participants to rank how closely they agree that 16 mood adjectives reflect their current mood (e.g., "happy", "sad", "calm"). The survey can evaluate overall mood based on a 7-point Likert scale (strongly disagree/disagree/somewhat disagree/neutral/somewhat agree/agree/strongly agree). After completing the design tasks, participants repeated the Brief Mood Introspection while still in the experiment room.

4.1.3. Measuring Creativity with AUT, RAT, and Brainstorming for Sustainable Design

We include three types of creativity tasks. The Alternate Uses Task (AUT) is a classic creativity evaluation tool that has been used for decades in psychological studies to measure divergent thinking [14,15]. The Remote Associations Test (RAT) is a similarly established test that evaluates convergent thinking [16]. These two tests are widely used in creativity

studies and provide metrics to measure divergent or convergent thinking. For example, van Dijk et al. (2020) used the AUT to determine the impact of objects in the environment on the children's creativity [49]. Fernández-Abascal and Díaz (2013) used the RAT to assess creativity for happy and sad participants, as influenced by facial positions and exposure to different movie sequences [50].

The AUT consists of having participants think of as many possible uses for a common household item (such as a brick). For example, participants prompted to come up with creative uses for a 'bucket' might list other uses such as "hat" or "stepstool". The assumption is that the higher number of ideas produced by students means higher creative abilities. In this study, participants completed the AUT for three objects ("baseball", "bucket", and "toothpick"), each with a 3-min time limit. Instructions on the screen prompted participants to come up with new, creative uses for the three objects and to enter as many ideas as they liked until they ran out of time. These three prompts were delivered in random order. In this paper, the average number of ideas generated for each concept was used as the AUT score. In the RAT, participants are given 25 concepts and are asked to find a fourth common word. For example, participants are given the words 'aid', 'rubber'. and 'wagon' and should find the word 'band'. Participants spent 5 min completing the RAT to the best of their ability. Here, convergent thinking is measured as the number of correct concepts participants found. It provided a score between 0 and 25 as 25 RAT tasks were prompted to each student.

A limitation of the AUT and RAT tasks is that they do not capture creative thinking in naturalistic tasks. An open-ended brainstorming task was added to the experiment to balance this limitation. The brainstorming activity was used to map onto common thinking processes architecture students implement during their design classes. Since architecture students are used to brainstorming for studio courses, it provides a more naturalistic setting to assess how they perform. This task was more intuitive compared to the other two creativity tasks. Participants completed a 3-min brainstorming activity where they were asked to "come up with original and creative ideas about the cities of the future" and brainstorm what they "imagine sustainable cities might look like in the year 2500". They were audio-recorded during the brainstorming session and were asked to think aloud to capture their thought processes [51].

4.2. Data Analysis

Answers to the Brief Mood Introspection and Intrinsic Motivation Inventory were collected on a 7-point Likert scale (strongly disagree/disagree/somewhat disagree/neutral/somewhat agree/agree/strongly agree) in alignment with precedents [40,52,53]. Responses to the brainstorming question were transcribed using Microsoft Office, and a researcher corrected transcription errors. Responses were then analyzed using the online SemDis tool developed by a team of researcher from Washington, Lee University, and Penn State University [53]. Responses to the AUT were also analyzed using SemDis. Semantic Distance is a powerful automated tool that can evaluate creativity rather than relying on subjective human or labor-intensive traditional methods [53].

5. Results

5.1. Effect of the Microalgae Facade on Mood

Participant mood was measured before entering the experiment room and after completing the tasks. The comparison between before and after exposure to the microalgae facades show little changes in participants' emotions (Figure 4). The most significant change in emotion is related to the perception of an 'active' mood. Participants feeling of 'active' decreased after being exposed to the microalgae façade.

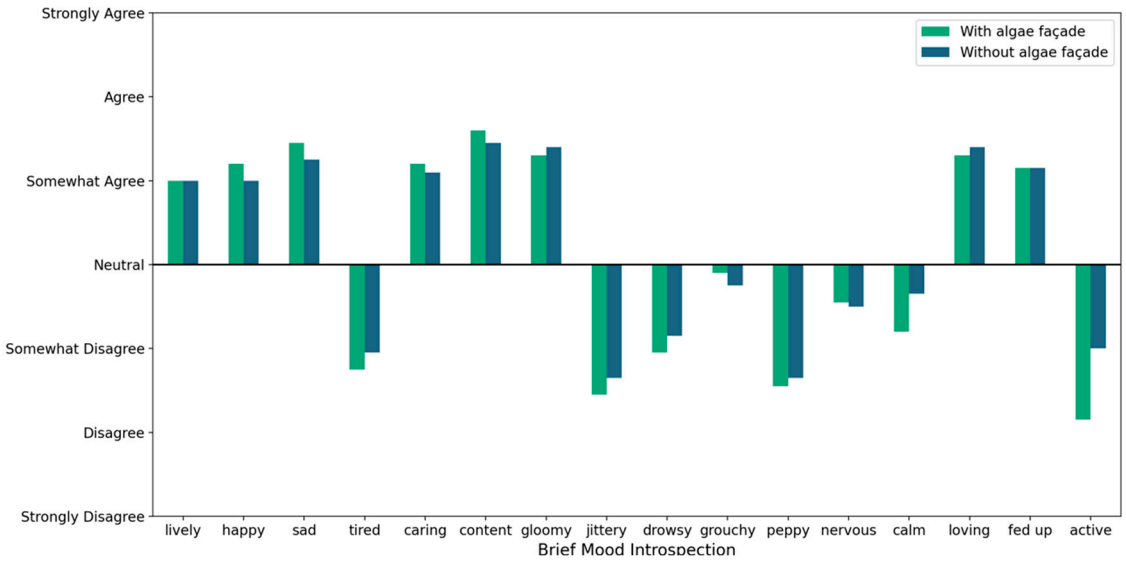


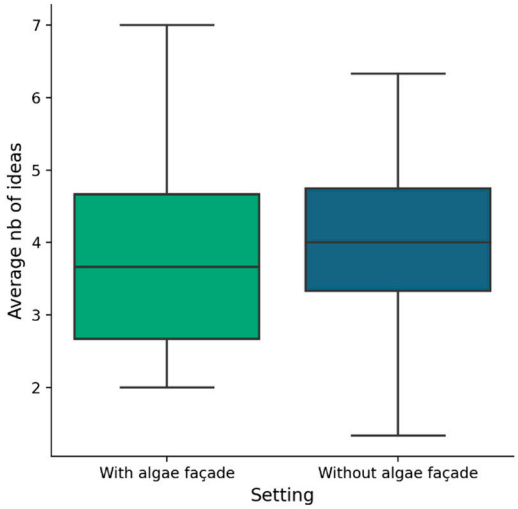
Figure 4. Effect of the algae facade on the Brief Mood Introspection after design tasks completion. Average across participants in each group on a 7-point likert scale (strongly disagree to strongly agree). Participants agreed that they felt lively, happy, caring, loving, and less nervous in the controlled room.

Figure 4 illustrates the average effect of performing the design tasks with and without the microalgae facade. The result shows that the microalgae façade did not specifically affect student mood. A difference appears in the feeling of being active. The microalgae façade tends to make the participant feel less active than without.

5.2. Effect of the Microalgae Facade on Divergent Thinking

Divergent thinking was measured with the AUT. On average, participants generated 3.7 ideas (SD = 1.4) for the AUT while in the room with the microalgae facade. Participants in the control group generated 4.0 ideas (SD = 1.3) for the same task. The results suggest that the algae facade did not affect the number of ideas participants thought of during this task (Figure 5a). SemDis also highlights similarities regarding the creativity and novelty of ideas generated (Figure 5b).

(**a**)



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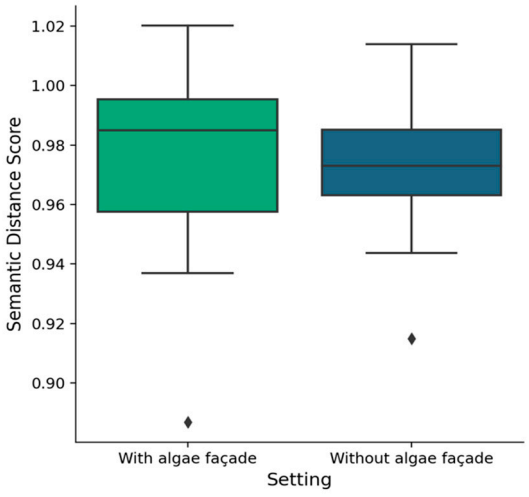


Figure 5. Effect of the microalgae facade on the number of ideas participants formulate (average across participants) (**a**) and their average semantic distance (score range from 0 to 2) (**b**); the microalgae façade did not have a greater impact on divergent thinking than the controlled group.

5.3. Effect of the Algae Facade on Convergent Thinking

To measure convergent thinking, participants took a RAT with 25 objects representing different levels of difficulty. The test was designed to be longer than would be possible to complete in the given time. Overall, participants did not perform well on this test. Participants in the room with the microalgae facade identified on average 5.3 concepts (SD = 4.2) in the RAT task. Participants in the control group identified, on average, 6.0 concepts (SD = 6.8). The difference is insignificant, implying that the microalgae facade did not impact divergent thinking during this task (Figure 6).

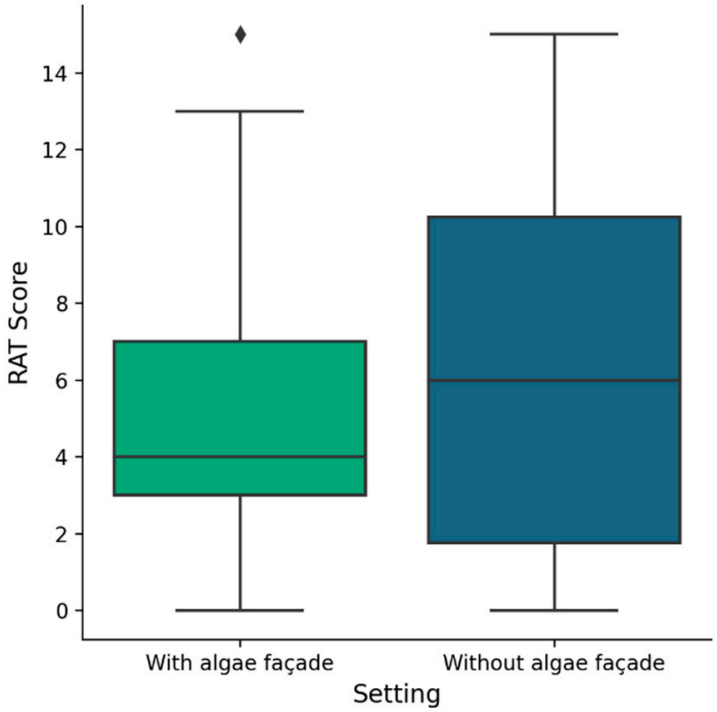


Figure 6. Effect of the algae facade on the RAT score; the microalgae façade did not have a greater impact on convergent thinking than the controlled group.

5.4. Effect of the Microalgae Facade on Concepts Included in a Design Solution for a Sustainable City

The last task of the experiment was for students to brainstorm ideas for a future sustainable city. This task offers a more naturalistic setting for a creative design task. Architecture students that conducted the task in the environment with the microalgae facade put more focus on environmental sustainability than students in the control environment. From the transcripts, the frequency of concepts was analyzed (see Figure 7). Results show that the concept 'plant' occurred almost twice as many times during the brainstorming task within the environment with the microalgae façade (Figure 7). For participants in the control environment, the design solution focused relatively more on space and transportation (Figure 7). For both conditions, the prevailing concepts were buildings and people.

We produced word clouds to provide a qualitative representation of important topics in architecture students' solutions for a sustainable city in the future (Figure 8). For participants that brainstormed in the microalgae environment (Figure 8a), their concept centered on buildings, people, plants, and cars. On the other hand, recurring topics for architecture students that performed the brainstorming in the control environment are building, people, transportation, and space (Figure 8b).

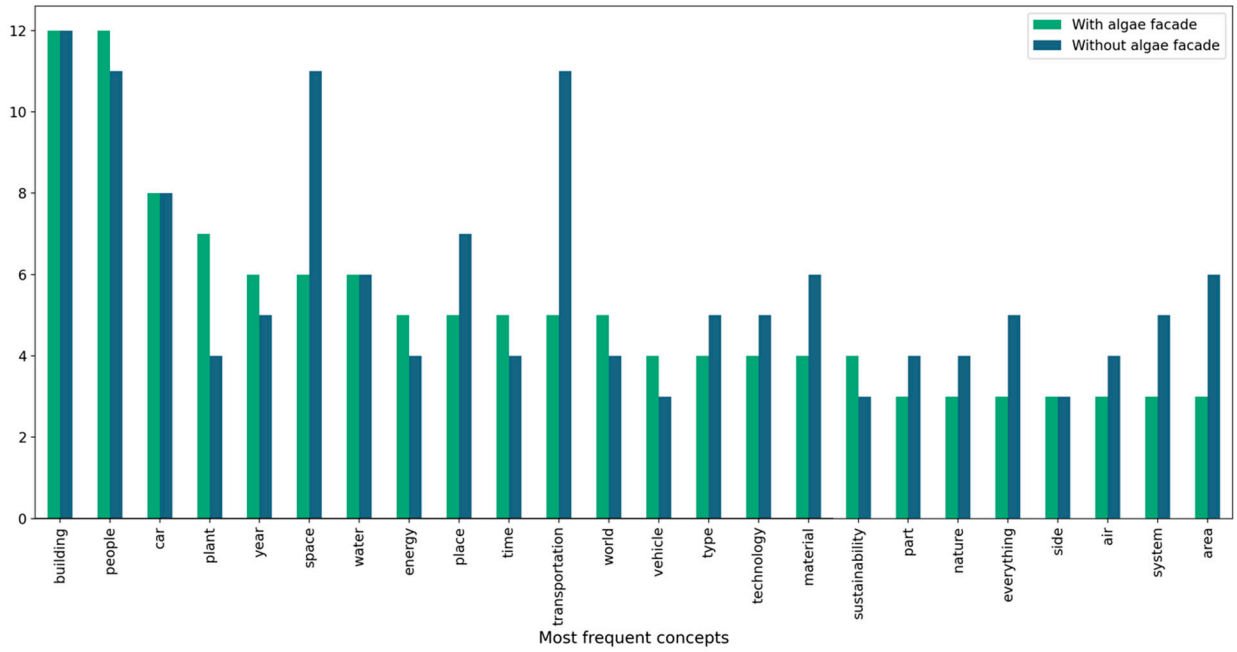
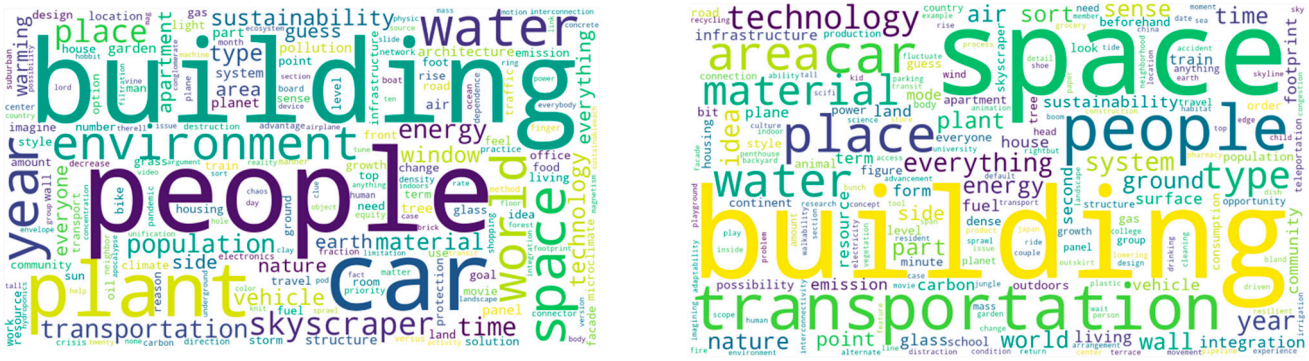


Figure 7. Frequency of concepts for the brainstorming tasks in a room with an algae facade and without an algae façade.



(**a**) (**b**)

Figure 8. Word Cloud illustrating the frequency of concepts for the brainstorming tasks in a room with an algae facade (**a**) and without an algae facade (**b**).

6. Discussion

The aim of this study was to evaluate the impact of a microalgae façade on cognitive performance in design and emotion of architecture students. This research is relevant as microalgae facades have significant environmental and sustainable implications. Still, little is known about the impact microalgae facades may have on occupants of the spaces where they are installed. We investigated the impact of the microalgae facade on architecture students' emotions, creativity, and ability to brainstorm sustainable ideas.

Our pilot study indicated that the microalgae façade did not have an impact on architecture students' moods. Previous research on biophilia and exposure to the color green suggests that a microalgae façade could impact emotion by augmenting human connection to nature through its materiality (natural) and aspect (color green). For example, biophilic office space tends to reduce stress and improve occupants' satisfaction and cognitive performance [31]. Another study suggests an association between green spaces on campus and student quality of life [35]. The research highlighted that biophilic design could reduce stress [8] and provide psychological restoration [9,29,30]. In other studies, exposure to the

color green increased self-reported participant enjoyment in cyclists [39], reduced fear of failure [42], and did not increase stress levels [41]. Our findings do not align with previous research on the effect of biophilic design and the color green on emotions.

The analysis of the results for the two creativity tests, AUT and RAT, suggests that the microalgae façade did not have an impact on creative performance. The color green has been demonstrated to enhance creative performance [40], and biophilic design can reduce stress and improve occupants' satisfaction and cognitive performance [31] as well as productivity, concentration, and memory [8,35]. Our findings do not align with previous results that studied the impact of biophilic design and the color green on cognitive performance. Overall, the weak biophilic value of the microalgae façade can be attributed to the limitations of our research design, such as small sample sizes, short interaction durations with the microalgae façade, and the presence of the view window in the room setting.

On the other hand, the microalgae façade had a qualitative impact on students' ability to brainstorm sustainable solutions. Designing for sustainability requires innovation and creativity to go beyond traditional approaches [44,45]. Exposure to sustainable buildings or systems can positively influence students' willingness to implement the sustainable design [12]. Our result showed that participants who brainstormed solutions for a sustainable city mentioned 'plant' almost twice as many times than participants in the control environment. It suggests that being immersed in an environment with microalgae nudged participants to include plants as part of their design solution for a sustainable city.

In summary, our experimental results do not align with previous work regarding the effect of biophilic design or the color green on emotion or creative performance. Several explanations are plausible to interpret these results. First, we made the assumption that the microalgae façade is a biophilic design element. The extent to which a microalgae façade may have a biophilic impact on occupants is unknown. It is unclear whether algae-filled tubes can evoke a similar biophilia response as leafy foliage. However, the brainstorming task highlights that seeing the microalgae façade prototype evoked 'plant' when generating solutions for a sustainable city, suggesting that occupants might perceive the façade as a biophilic element. Second, participants in the control group had a window view outside greenery. Views on greenery positively affect emotion, well-being, and cognitive performance [54]. The control room setting possibly had a positive effect on participants' emotions and tasks, which can explain that no differences were found between the two settings. This suggests that despite reducing natural light in the room, the microalgae façade had a similar effect on participant emotion and cognitive performance compared to views on greenery.

Limitations of the Study and Future Work

One limitation of the study is that the control and experiment spaces had similar biophilic elements from view windows. Setting the experiment, we intended to provide a naturalistic environment and provide the exact same space with and without the algae prototype. In future work, we will add a third setting adding a curtain on the window to cut the view on the outside. Future research will compare performance with the microalgae façade against a control group with a non-nature view.

The microalgae façade prototype houses algae that grow and multiply. Hence, the color of the facade mock-up became a much deeper/denser green over the course of the study. Although it is beyond the scope of this study, future research might investigate whether algae density can impact mood or creativity. The increase in color density in our study parallels how a full-scale facade would behave after it was installed on a building. The color gradually changes over time as algae populations grow, are removed, and regrow. In future studies, we intend to investigate the impact of the changing color of the microalgae façade on emotion and creative performance.

Our control and test groups were in the same large space and were separated by hanging curtains. Thus, the impact of the algae facade on occupants was only visual. This study did not investigate the microalgae facade impact on participants through improving

indoor air quality. To assess the impact of indoor air quality on occupants, our future research will perform similar tests with fully separated control and experiment spaces.

7. Conclusions

Microalgae facades are a significant emerging technology with implications for carbon sequestration and ecological sustainability. In addition to evaluating their technical performance, it is important to understand their impact on humans occupying these spaces. Indoor spaces have a significant influence on our psychology and experiences [2]. Implementing novel sustainable architectural elements, such as microalgae facades, is a way to move forward and improve our living spaces. This study is the first step toward evaluating a microalgae façade's impact on human mood and creative performance. These metrics are important for productivity, well-being, and the ability of designers to design a sustainable future.

The microalgae façade did not have a direct impact on convergent or divergent creativity or mood compared to a glazed façade with views on greenery. Participants in those environments performed similarly to generate ideas (AUT task average score with the algae façade was 3.7 ideas [SD = 1.4]; average control group score was 4.0 ideas [SD = 1.3] for the same task.) and to synthesize concepts (RAT task average score with the microalgae facade was 5.3 concepts [SD = 4.2]; average control group score was 6.0 concepts [SD = 6.8]). There were qualitative differences between the control and test groups when participants were asked to brainstorm their ideas for a sustainable future. Participants in the space with the microalgae façade developed more design solutions that included greenery than students in the control space. It suggests that biophilic design can nudge designers to include biophilic elements in their designs. This research is a preliminary investigation into the human impact of a microalgae façade and represents a new focus for scientific research. The results suggest that this microalgae façade will not have any detrimental impact on building occupants. More work is needed to better grasp to what extent implementing a microalgae façade will impact human behavior in space. There are numerous ways that microalgae facades might impact occupants, including by improving indoor air quality, increasing exposure to plant life and the color green, and increasing occupant awareness of sustainability efforts. Our future work will have a more holistic approach to explore relationships between microalgae facades, indoor quality, and human behaviors.

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