Beyond Green: Growing Algae Façade

As the popularity of glass façades in buildings continue to rise, the environmental impact of using glass façade systems is of increasing concern. Due to their high energy consumption through heat loss and unwanted heat gain, there needs to be a growing effort to promote an environmentally sustainable façade system. As a sustainable facade alternative, an innovative algae façade system was explored in this paper. The primary goal of this research is to demonstrate the design and development of the algae façade system and describe its preliminary structural and thermal performance using a FEA (finite element analysis) software and experimentation. The system details were explored throughout the prototyping of an algae façade panel. The research findings have demonstrated the viable application and improved performance characteristics of the algae façade system compared to a conventional glass façade system. The paper highlights areas of ongoing research activities and challenges associated with the algae façade system.

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INTRODUCTION

The construction and operation of a building significantly contributes to resource depletion and greenhouse gas emissions. A challenge for the building design, construction industries and building owners is to provide healthy indoor environments without depleting non-renewable energy resources and contributing to air pollution and global warming. According to DOE/EIA Annual Energy Outlook, buildings in the residential and commercial sectors in the US consume 40% of total energy, 72% of total electricity, and 40% of raw materials while generating 39% of the country's CO_2 emissions. For the transportation sector, transportation consumes 210 billion gallons per year and produces approximately 2.1 billion tons of CO_2 per year. Biofuels such as starch-based, biomass-based and cellulosic biofuels reduce our dependence on petroleum fuel and emerging technologies lead to the development of advanced biofuels using algae. A considerable amount of research on algae as a biofuel has been conducted and it has been reported that there are several advantages in using algae. First of all, due to their high growth rate, algae require less land and offer a high production rate for biomass and fuel. Further, they absorb CO_2 and do not require the use of fresh water. Figure 1 shows the algae production rate compared to other biofuels and its land use requirement. Corn, for example, requires twice the size of the USA to harvest biofuel of 210B gallons while algae need a state the size of North Carolina (around 50,000 sq. miles) to grow equivalent biofuel.

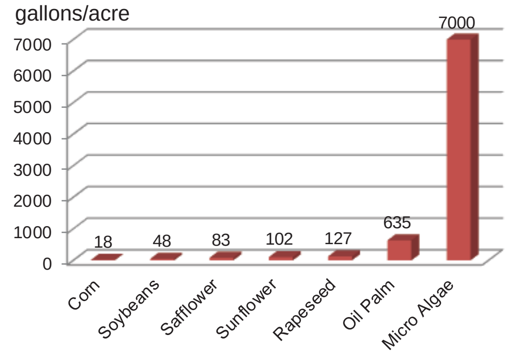

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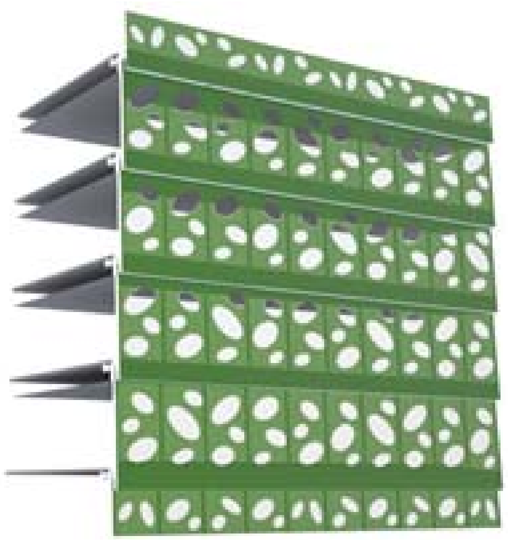
Figure 1: Algae production rate and required land compared to other biofuel alternatives. Image source: (Author 2013). Data source: (DOE, 2012)

A variety of state-of-the-art transparent facade technologies are available: low-e coated IGU, inert gas integrated IGU, and shading device (such as stretched metal, frit, suspended film) integrated IGU. These technologies particularly reduce building energy consumption by improving the heat transmission (U-factor), SHGC (solar heat gain coefficient), and VLT (visible light transmittance). Managing heat flows through building facades alone, however, is not sufficient to give rise to a high performance façade system. Photovoltaic and solar thermal systems are examples of accomplishing both energy management and energy generation currently applied in buildings. As a high performance facade alternative, an innovative algae facade system has been investigated.

The primary objective of this research is therefore to carry out a feasibility study of an algae façade system by exploring its performance attributes, façade system details and fabrication challenges. This paper discusses the preliminary performance assessment in the areas of structural and thermal performance. This effort includes FEA computer simulation and experimentation. More comprehensive study on optimal design configurations for the algae façade system is under development.



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1.0 ALGAE FAÇADE SYSTEM

Environmental concerns and resource depletion are issues that we currently face. Algae integrated building envelopes are not a new concept in the architecture field. Several architects and designers have used algae in their conceptual buildings or art installations. The HOK's first place winning scheme for the 2011 IDEAS competition showed an algae photobioreactor tube attached to the top surface of the opaque building envelopes of the GSA federal building in LA. In addition to this project, their recent concept design of the net energy zero Battery Park project in San Francisco incorporated algae photobioreactor panels to grow algae and reduce CO2. The world's first algae façade integrated building, the BIQ house in Hamburg, Germany is enclosed with an algae panel as a shading device. The algae façade system explored in this paper acts as a building facade system that fulfils various functional requirements such as airtight, watertight, structure, energy, daylighting, occupant's comfort and aesthetic. Further, it creates an optimum environment that maximizes algae growth, thus reducing the amount of atmospheric CO2 and, as an added benefit, produces O2.

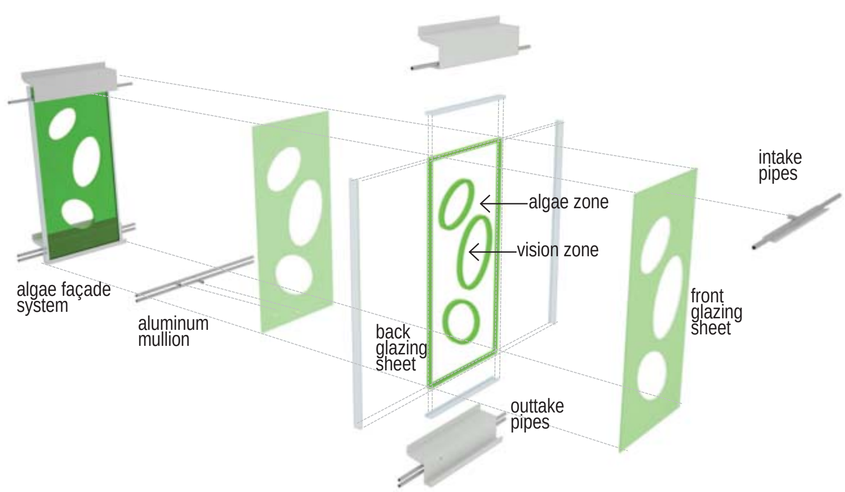

Figure 2: Algae façade application in office building (above) and exploded system details (right). Source: (Author 2013)

The algae façade system consists of an algae panel, aluminum framing and algae growing apparatus. The algae facade system is insulated and thermally broken and is designed to be spanning between slab edges. The algae façade system is sized to be 5ft wide by 12ft tall or taller depending on building conditions and consists of vision zone and algae zone. Unobstructed vision zone in the algae façade system has been introduced for viewing, daylighting and ventilation where necessary. The remaining area called algae zone is assigned for growing algae. The algae façade system is simply supported on four sides of aluminum framings and is mechanically restrained with sufficient clearances for thermal expansion and contraction. A demountable single-piece metal cover is a part of the system to conceal algae growing apparatus. The algae growing apparatus is comprised of intake systems for supplying CO2, and growing algae (e.g. algae, nutrients, medium etc) and discharging systems for emitting O2 and collecting grown algae. Figure 2 illustrates a schematic detail of the algae facade system and its generic application into a building facade.

The short-term research goal is to identify the feasibility of the algae façade system through schematic design and prototyping. The development work of the algae façade system is currently being carried out at the School of Architecture, University of North Carolina Charlotte working with faculties and students across a range of disciplines, under an EPA/NSF funded grant P3 (People, Prosperity and the Planet) project.   A visual mock-up was fabricated to facilitate decisions on fabricability, aesthetics and performance (Figure 3). Acrylic was considered for the algae façade material due to its higher impact resistance, lightweight, optical clarity and ease of fabrication compared to glass. Given that it is important to consider scratch and UV resistance of the acrylic surface, there are coating or surface treatment technologies available that offer good UV and scratch protection.

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(a) (b) (c)

The current research being carried out by the author includes geometrical variations of the vision zone and different surface conditions of the algae zone. One of the performance issues to consider was to block or minimize the green light transmission from the algae zone. As a result, the interior surface of the algae zone was sandblasted or covered with different colors. Figure 3 shows an algae panel with different levels of translucency at the algae zone. These prototyping algae façade panels revealed fabrication challenges associated with making a watertight assembly, especially at the interface between vision and algae zone. The kinds of adhesives and connection method are currently being researched.

Figure 3: Algae façade panels[1] with different surface treatment; transparent (a), 50% sandblast (b) and 100% sand blast (c) at the algae zone. Source: (Author 2013)

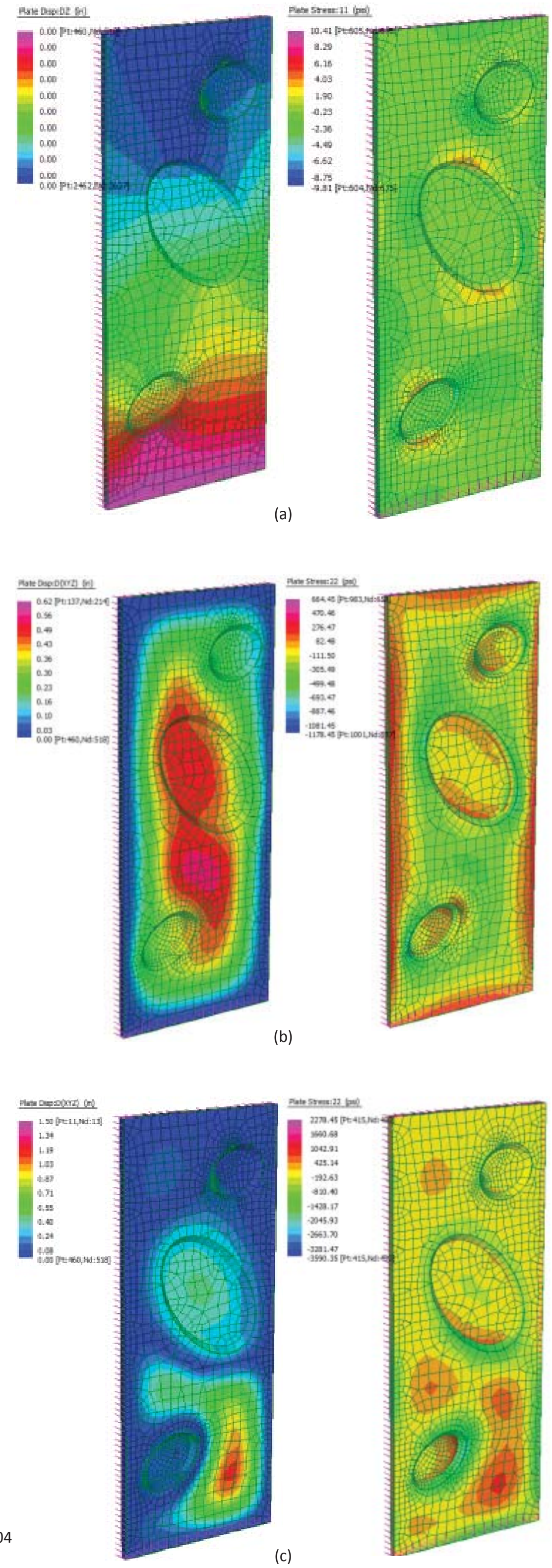

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Figure 4: Preliminary structural analysis results of algae façade; stress (left) and deflection (right) output under self-weight (a), wind load (b) and water pressure (c). Source: (Author 2013)

2.0 PRELIMINARY PERFORMANCE ASSESSMENT

2.1. Preliminary Structural Analysis

One of the primary goals of this research was to understand the general structural behaviors of the algae façade under various loadings. Prior to the lab testing, the stress and stiffness levels of the algae panel were investigated using a FEA software tool, Strand7. The size of the algae panel is 5ft x 12ft x 2in, and the acrylic is 5/16in thick. The algae panel was modeled with plate elements in Strand7, and the mesh was sized to approximately 4in x 4in. The edge supporting conditions were a pin support and a roller support, simulating a typical curtainwall attachment condition and accommodating thermal expansion and contraction. The material properties (E-modulus, density, Poisson's ratio) of the acrylic were obtained from the product data of Acrylite FF provided by Cyro Industries. The shear modulus was calculated using the equation: $G = E/2(1+ v)$. The loading condition applied in this study included self-weight of the algae panel, wind load and water pressure. The weight of the panel is approximately 230lbs without water in the cavity and 650lbs with water. The design wind load for the algae panel is assumed to be 20 psf. It is assumed that the wind load is transferred by the finite volumes of water in the cavity without loss. The water pressure from the water in the cavity is assumed to be a distributed load that is increasing uniformly to the bottom of the algae panel. Additionally the internal temperature of the water in the cavity is assumed to be in the range of 68°F ~ 86°F and any internal cavity pressure from the external isobaric pressure is assumed to be zero. Deflection of a façade system controls the façade design of a curtainwall system.

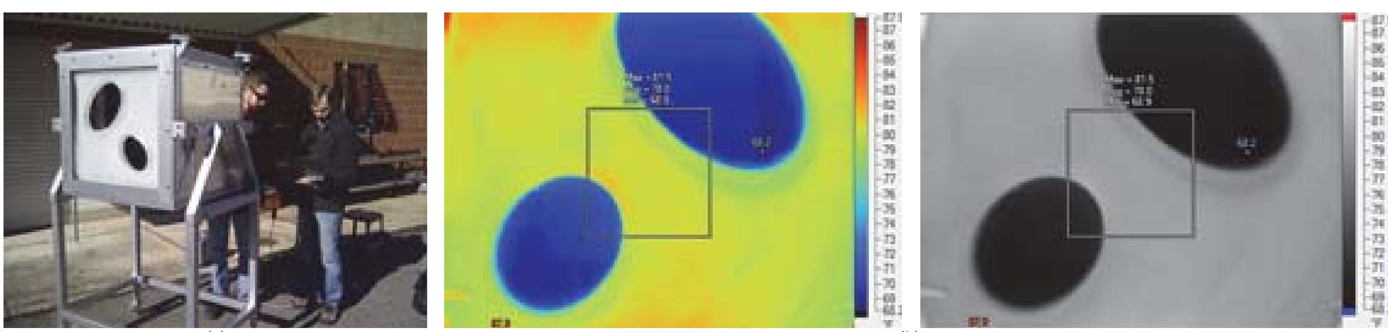
The FEA simulation results showed that the current design deflects 0.62" under wind and 1.5" under water pressure. Deflection of L/90 or 1" is generally regarded as an upper bound on acceptable glass deflection. The current deflection exceeds maximum allowable deflection, which requires design alteration. Deflection can be reduced by increasing the thickness of the acrylic or adding vision zone where the greatest deflection occurs. The maximum principal stress occurs mostly at the panel edges and perimeter of the vision zone. The maximum stress is around 5ksi under combined loading condition. Special attention is required at the adhesion between vision and algae zone. Figure 4 shows the output of Strand7 simulation, indicating deflection and stress levels under self-weight, wind load, and water pressure, respectively. Long-term performance such as creep deformation under water pressure needs to be investigated. The results of a more comprehensive study on both analytical and experimental assessment of the structural performance are expected to be presented at the conference.

2.2. Preliminary Thermal Performance Analysis

In the building industry, thermography technique is often used to detect air infiltrations, cold bridges, moisture creation, and heat loss through windows. An understanding of the surface temperature distribution over a building envelope is important, as the thermal variations affect cooling and heating loads of a building, as well as the occupant's thermal comfort. Ambient temperature and solar radiation are the primary factors affecting the thermal distribution on the exterior building envelope. Infrared cameras convert the thermal energy (i.e. the infrared band of the electromagnetic spectrum) radiated from an object into a visible image where each thermal energy level is represented by a color or grey scale. The thermal energy is dependent on the emissivity of a material surface and a fraction of the thermal energy can be added or absorbed by the atmosphere between the surface and the camera.

In practice, the thermal performance of a facade system is determined in accordance with various standards such as ASTM (American Society of Testing and Materials), NFRC (National Fenestration Rating Council) and AAMA (American Architectural Manufacturing Association). These standards require a specific apparatus and testing procedure and evaluate a final assembly of a building façade system. Since the algae facade system in this paper continues to evolve and develop, the thermography technique proved to be an efficient tool to assess the preliminary thermal performance. The thermography technique is an image based analysis tool that offers a user friendly and time efficient assessment. It allows evaluating preliminary energy performance of a façade system and facilitates design evolutions from the fast performance feedback.

An algae panel was set up to test the thermal distribution of the interior surface temperature. Tests were conducted in a sunny winter noon in outdoor environment using the FLUKE thermography system with its software package. The testing algae panel was 2ft by 2ft and the interior surface of the algae zone was sandblasted with 100% translucency. In order to minimize energy flow between the material and the atmosphere, the interior surface of the testing chamber was covered with black painted plywood. The preliminary thermography data showed that the temperature difference between the vision and algae zone during winter time is approximately 13°F (the vision zone is 69°F while the algae zone is 82°F), indicating that the vision zone is subject to higher heat transmission (U-factor) compared to the algae zone (Figure 5). A simple mouse click of the thermal image shows a surface temperature of the algae panel where dark blue (black in grey scale) represents the minimum temperature and red (light grey in grey scale) represents the maximum temperature.



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In the next step, it is intended to conduct the same experimentation of an insulated glass unit (IGU) in order to understand how much the algae façade outperforms in U-factor relative to an IGU. The temperature data obtained from the thermography testing will be used in a CFD analysis tool to verify interior temperatures of a building enclosed with algae panels. The interior temperature will be used in DesignBuilder to run a whole building energy simulation. By carrying out the whole building energy simulation, energy saving from algae façades can be determined. Since this is an ongoing process, the results of energy performance of algae facades will be presented at the conference.

Figure 5: Preliminary thermal performance of algae façade; test set-up (a) and temperature distribution (b). Source: (Author 2013)

CONCLUSION

This paper shows the development of the algae façade system and its preliminary structural and thermal performance. The research demonstrated that the algae façade system has the future potential for sustainable façade alternatives and energy generation possibilities. The computer simulation on structural behaviors provided alternative design solutions to meet stress and stiffness criteria under various loadings. The IR experiments involved determining the thermal characteristics of the vision and algae zone of the algae façade. The prototyping of an algae façade panel reveals fabrication challenges associated with watertight interfaces between the vision zone and the algae zone. Additional façade system details need to be explored, incorporating algae growing apparatus and artificial lighting to grow algae at night time. The future direction of this research is to investigate long-term performances such as weatherability under outdoor use, durability from periodical maintenance of the algae zone, and creep deformation behaviors under water pressure.

ACKNOWLEDGEMENTS

This research has been supported by UNCC FRG and EPA-P3 grant. The author would like to thank Timothy Blanks, William Mayo and Ben Futrell for help during fabrication and testing.

ENDNOTES

1. Algae façade system© is fully copyrighted and patent pending by Kyoung-Hee Kim in its entirety.

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Climate Change: Sustainability Performance of a Bio-facade for a Retrofitted Building

Climate change has become one of the major problems that the world faces today. The building sector is a larger contributor of generating global warming potentials (GWP). Most of GWPs emissions are associated with electricity consumption from cooling and lighting a building.[1] In order to reduce GWP, bio-facades were used to retrofit an old institution building located in University of North Carolina at Charlotte.

The paper specifically focuses on investigating sustainability performance of a bio-façade as a retrofitting façade material for an old campus building. The study shows that the bio-facades result in substantial reductions to both energy consumption and CO2 emission. The total life cycle energy saving with bio-facades would amount to $110,000 and approximately reduce CO2 production by 200 tons over a 30 year period when the old campus building is retrofitted with bio-facades. Additional benefits from growing microalgae would be CO2 absorption and O2 generation as a result of photosynthesis from microalgae. The preliminary life cycle assessment showed that the bio-facades have the potential for many sustainability merits through enhancement of the energy performance of a building, including future production of bio-fuel and absorption of CO2.

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INTRODUCTION

Climate change has become one of the major problems that the world faces today. The building sector impacts every aspect of the environment, from the physical planet to the people who inhabit it. It should be the responsibility of every architect, engineer, planner and construction professional to improve the sustainability of built environment by promoting the adoption of more universally-sustaining environmentally-successful building systems. As microalgae is shown to have more and more beneficial uses,[2] scientists must have access to creative settings and sources of microalgae to see just how far we can go with this green plant. Building facades play a vital role in reducing energy consumption and pollutant emissions. As an alternative to a sustainable façade system, the bio-façade in this paper incorporates microalgae that offer good insulation, solar heat mitigation, and daylighting performance. It has the potential for many sustainability merits not only through enhancement of the energy performance of a building but also

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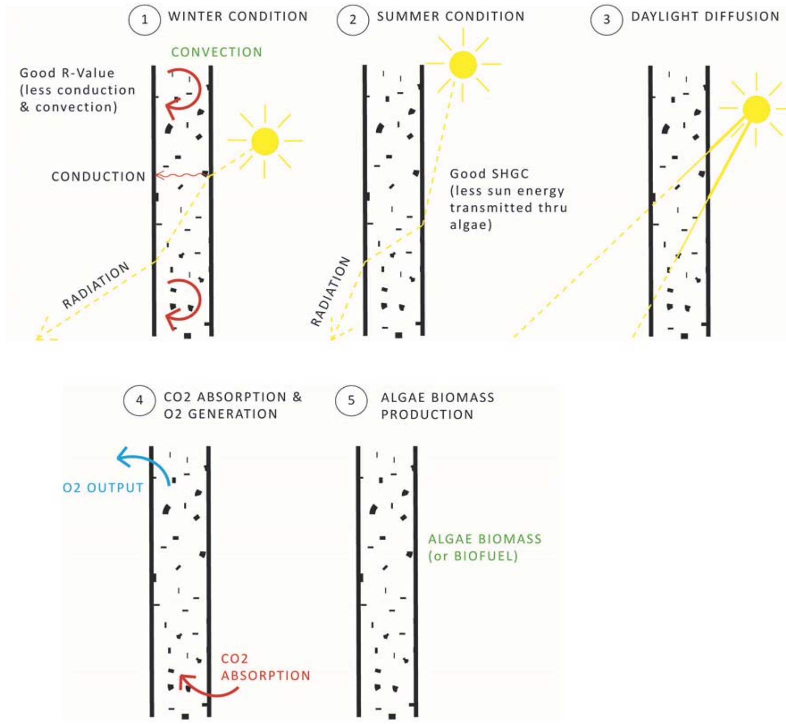

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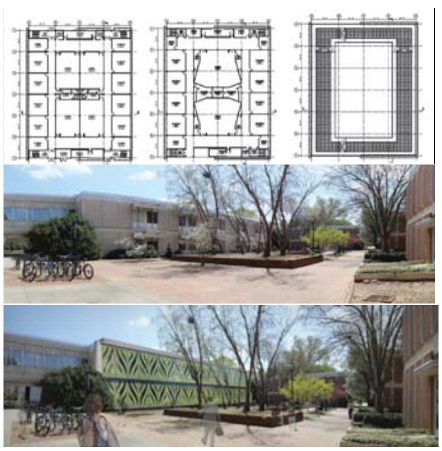


Figure 1: sustainability benefits of a bio-facade

Figure 2: plan of the case study building (a); case study building with existing facades (b) and retrofitted with bio-facades (c)

including future production of bio-fuel and absorption of CO_2. The goal of the study is to evaluate the sustainability performance of a bio-façade as a retrofitting façade material. The life cycle analysis was carried out to quantify the sustainability matrix of the algae facade.

SUSTAINABLE ATTRIBUTES OF A BIO-FACADE

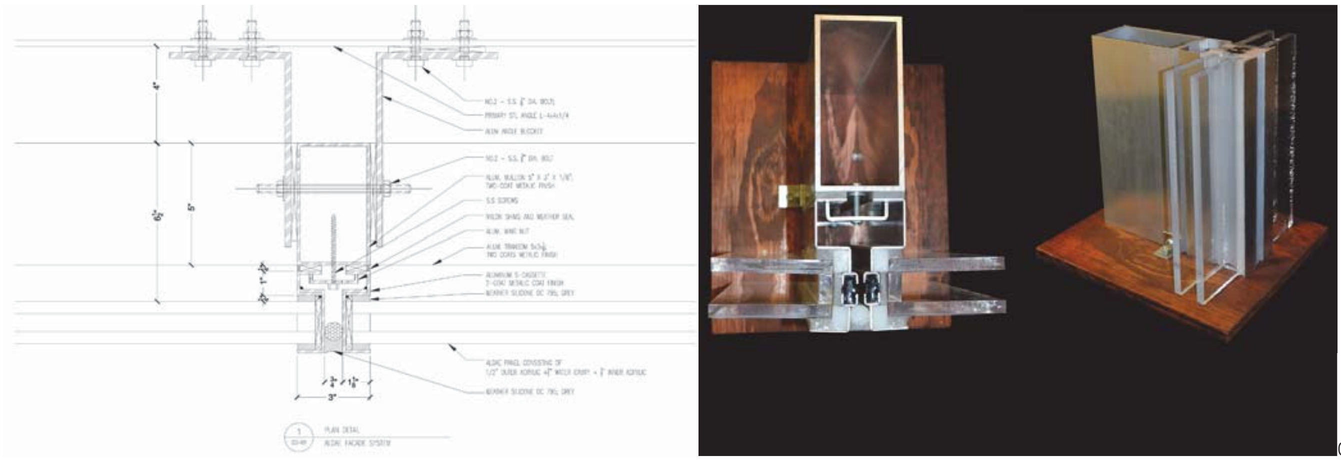
Glazing façade systems affect building energy consumption through three basic mechanisms: heat transmission, solar heat gain, and daylighting. The energy effects of a transparent façade system in general can be minimized by high performance glazing and shading devices. High performance glazing especially with low-e coating can minimize conductive heat loss and reduce solar heat gain. Shading devices even further control solar heat penetration to minimize cooling requirements. In winter time, the shading device can be adjusted to supplement heating through passive solar gain. Daylight can offset lighting requirements while reducing cooling.

The bio-façade improves building energy performance by reducing solar heat gain as well as improving insulation properties. Solar heat is intercepted and absorbed by the bio-façade panel to promote the growth of algae. The bio-facade absorbs CO_2 and generates O_2 during photosynthesis process, thus reducing the amount of atmospheric CO_2 and creating healthier built environment. As a co-product, the bio-façade harvests algae which can turn into either biomass or biofuel as a renewable energy resource. Figure 1 shows sustainability attributes of a bio-façade.

CASE STUDY BUILDING

The Denny building is located on the University of North Carolina at Charlotte's campus. The case-study building has a conditioned floor area of 33,000 ft2 and a volume of 410,000 m3 within two floors. The Denny building was constructed in 1970 whose building facades consist of concrete panels and single pane windows. It is used for classrooms and seminar rooms for various majors and subjects. The building is positioned with its longer sides facing east and west; shorter sides face north and south with bridges connecting to the other buildings.

In order to achieve energy saving, the Denny building was assumed to be retrofitted with bio-facades. The retrofit design only updates the facade of the existing Denny building with interior conditions being unaltered.



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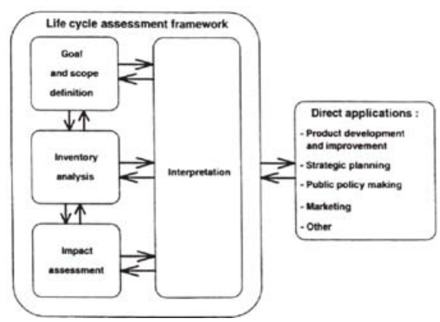
Bio-facade panels were positioned on the facade to align with the existing structural grid. In order to match the structural bay of 24ft, the width of a bio-facade panel was determined to be 4ft wide and 13ft tall. Two mechanical rooms are located on the 1st floor to house mechanical equipment to support growing algae.

A bio-façade panel for retrofitting the case study building is configured to grow microalgae while it meets the requirements of a window wall system specifically in the area of heat transmission, solar heat gain, daylighting, and air tightness. It consists of two sheets of ½" thick acrylic and is divided into two zones – one zone for offering daylight/view out and the other zone for growing microalgae. The bio-façade panel is then framed with a thermally broken aluminum frame that is attached to the primary structure of the building. The top and bottom of a bio-façade panel is equipped with algae growing apparatus such as algae in-take pipe and out-take pipes, CO_2 in-take pipe, and O_2 out-take pipe. At the parapet location of the case study building, a special parapet cap was designed to store the algae growing apparatus. Likewise, at each slab location, a storage space with a 1'x1' sectional profile was designed by overlapping bio-façade panels at the 1st and 2nd floor to conceal the algae growing apparatus.



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BUILDING LIFE CYCLE ANALYSIS

The building life cycle assessment (BLCA) was carried out to understand the environmental and economic benefits of bio-facades. In order to understand the energy conservation potential from bio-facades, an energy performance simulation was carried out both for the case study building enclosed with the existing envelopes and the case building retrofitted with bio-facades.

Figure 3: system details of a bio-facade

Figure 4: LCA procedure in accordance with ISO 14040

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	Energy	Greenhouse Gas Emissions			
	Embodied Energy (MJ)	CO_2 (kg)	CH_4 (kg)	CF_4 (kg)	C_2F_6 (kg)
Electricity (1 MJ)	3.72	2.98E-01	6.49E-03	0.00E+00	0.00E+00
Natural Gas (1 MJ)	1.15	5.58E-02	1.60E-04	0.00E+00	0.00E+00

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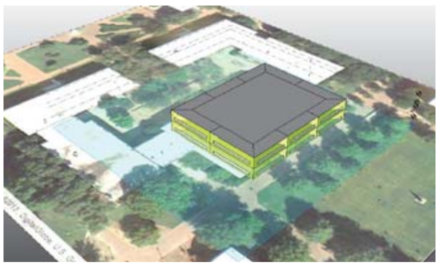

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	Existing envelopes	Bio-facades
Total EUI	99 kBtu/sf/yr	69 kBtu/sf/yr
Life Cycle Energy Cost	$682,200	$571,300
Life Cycle CO_2 equivalent Emissions	457 tons	264 tons net emission

Table 1: inventory data for energy resources

Figure 5: simulation model in Autodesk Vasari

Table 2: summary of life cycle cost and CO2 equivalent

The BLCA utilized parametric building information modeling (BIM) integrated with building energy simulation process. Two software packages – Revit and DesignBuilder (hourly-based building energy simulation tool) was used.

Step 1: Framework of BLCA. A BLCA evaluates the environmental implications of a building during its pre-use, use and post-use phases. In accordance with ISO 14040 series of standards, an LCA procedure starts with the goal and scope definition and continues to inventory analysis, impact assessment, and finally, interpretation of the results. Figure 4 depicts the LCA framework in accordance with the ISO 14040 guidelines.

Step 2: Goal and Scope Definition. The first phase of the LCA framework under ISO 14040 is to define the scope of work with respect to the functional unit, study boundaries, assumptions and limitations of the study. The goal of the BLCA in this paper is to understand the environmental benefits of a retrofitted campus building with bio-facades. The functional unit of the bio-façade is to cover 4ft wide by 13ft tall for a service period of 30 years. The study boundary is the use phase of the campus building not including the pre-use and post-use phase of the building.

Step 3: Life Cycle Inventory Analysis. The second phase of the LCA framework under ISO 14040 is the life cycle inventory analysis, which quantifies material use, energy input and pollutant emissions during a specified life cycle phase. The inventory data typically rely on companies engaged in product fabrication and processing activities as well as published databases. The BLCA in this paper was using a database provided by SimaPro 7. Material use and primary energy consumption are calculated as a form of kg/functional unit and MJ/functional unit respectively, and pollutant emissions are expressed in terms of kg/functional unit. Table 1 shows inventory data for electricity and natural gas.

Step 4: Life Cycle Impact Assessment. The third phase of the LCA framework is the life cycle impact assessment. ISO 14040 defines the impact assessment phase consisting of classification, characterization, and weighting. Classification assigns inventory results to impact categories while the characterization process involves defining characterization factors to convert each pollutant emission into equivalent potentials represented by a reference substance (e.g., CO2 equivalent). The weighting process combines the impact categories into a single score (e.g., ecopoint, SimaPro eco indicator method). In this paper, the impact assessment focuses on global warming potential specific caused by four major pollutants such as CO2, CH4, CF4 and C2F6.

Step 5: Life Cycle Result Interpretation. The last phase of an LCA is interpretation of the results. The findings from the inventory analysis and the impact assessment are combined in order to reach conclusions and make recommendations. A sensitivity analysis (what-if analysis) helps to understand how input variables change LCA results or how critical uncertain parameters reduce environmental impacts.

RESULTS

Two energy models were constructed and analyzed. The simulation models included the existing façade and bio-facades. The models were analyzed in Autodesk Vasari. The energy analysis for each situation was performed for a 30 year period at a unit rate of $0.08/kWh for electricity and $0.93/Therm for fuel. Figure 5 shows the simulation models in Vasari.

The life cycle impact assessment indicates that the 30-year life cycle energy cost for the existing building was estimated to be $682,000 and $571,300 for the retrofitted building with bio-facades, based on the unit energy cost of $0.08/kWh and $0.93/Therm in Charlotte NC. The existing building produces approximately 457 tons of life cycle CO2 equivalent emissions during a 30-year operational period while the retrofitted building with bio-facades would generate 414 tons of CO2 equivalent emissions. There is additional CO2 reduction from microalgae as a result of photosynthesis process. From the published data for the CO2 intake rate for C. vulgaris for example is 1.83kg CO2 per 1kg dry algae biomass (Edberg, 2010). Assuming that one bio-façade panel is able to harvest 1kg of dry algae in two weeks, the additional CO2 reduction from algae is estimated to be around 5 tons per year, leading to a life cycle CO2 reduction of 150 tons. As a result, the life cycle net CO2 equivalent emission from bio-facades would be 264 tons over a 30-year period, 40% less than the building with the existing building envelope.

The energy simulation results clearly showed that it is possible to significantly reduce a building's energy consumption and environmental impact by upgrading the old façade of the case study building with bio-facades.

CONCLUSIONS

The whole-building energy simulation shows that the bio-facades results in substantial reductions to both energy consumption and CO2 emission. The building retrofitted with bio-facades reduced the energy consumption by 30% compared to the existing building due to its improved thermal and daylighting performance. The retrofitted façade also cuts down the life cycle costs by $110,000 and lowers the life cycle by approximately 200 tons. Further, additional O2 generation as a result of photosynthesis from the biofacades is estimated to be 150 ton over the 30 year life cycle.

ACKNOWLEDGEMENT

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Project-based Learning: Interdisciplinary Collaboration of Bio-facades in Urban Environment

Interdisciplinary collaboration has gained more importance in both academia and practice as a result of increasing demand on environmental agenda and building energy efficiency. Many building projects show the need for architects, engineers and building scientists with integrated backgrounds that span different disciplines. This integrated and collaborative design approach will prepare students to think critically in emerging design situations and real world problems. While it is clear that we do not currently integrate the important subjects of design, engineering, materials science, and fabrication/construction in architectural design, the advantage of doing so is apparent.

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INTRODUCTION

The paper was developed based on an interdisciplinary class offered in the School of Architecture at the University of North Carolina at Charlotte in 2013 Spring term. Representing three colleges and four departments at UNC Charlotte, all 24 students (17 architects, 2 biologists, 2 mechanical engineers, and 3 construction managers) came together to work on a P3 project to develop an algae-integrated façade system - Bio-facades. P3 stands for People, Prosperity and the Planet, and Environmental Protection Agency (EPA) sponsored a P3 research grant to develop a sustainable façade project at UNCC, which can enhance the sustainability of built environment and "benefit people, promote prosperity and protect the planet".

The course deliverables were structured to produce the final project to meet course requirements and to participate in Expo and competition for the Phase 2 Award in Washington D.C. (Figure 1). The students worked in teams representing their main departmental discipline under faculty guidance from the participating departments and were given specific tasks to investigate in the context of the overall project. Students worked within a set framework of pedagogical strategies and expected outcomes, and their progress, including work production and pedagogical goals, was monitored through weekly meetings, workshops, lab sessions, and design reviews.

PROJECT DESCRIPTION: BIO-FAÇADE SYSTEM:

The construction and operation of buildings significantly contributes to resource depletion and greenhouse gas emissions. A challenge for the building design and construction industries and building owners is to meet sustainability goals in reducing energy consumption and pollutant emissions while providing healthier indoor and outdoor environments. The University of North Carolina at Charlotte participated in the P3 competition in 2013 and adopted an interdisciplinary teamwork as a pedagogical method to teach sustainable building practice. The P3 Award is a national college competition sponsored by EPA and focuses on designing solutions for a sustainable future in five categories - water, energy, agriculture, built environment, and materials and chemicals. We proposed a bio-facade system as an innovative facade material to enhance building sustainability and carried out a feasibility study and the system development in collaboration with four departments – ARCH, BIO, CM, and ME. The bio-facade project was an entry project to compete the P3 Award aiming to benefit people, prosperity and the planet by improving sustainability and air quality in the built environment.

A sustainable building with bio-façades require a high interdisciplinary approach consisting of architecture, engineering, urban planning, biology, material science to maximize the integration of environmental resources surrounding a building and minimize environmental impacts associated with operating a building. The results of our feasibility study and design development showed great sustainability potential from the bio-facade system. Preliminary data showed that this bio-facade system can provide a cost-effective, environmentally-friendly, sustainable, and aesthetically pleasing alternative to glass facades. Advantages of the bio-façade system include good thermal performance, improved daylight transmission, and impact resistant. Further, the algae-growing area of bio-facades modulates solar gains over the entire year and has thermal mass potential for passive heating in winter months. Bio-façades are expected to reduce greenhouse gas emissions as a result of photosynthesis and even has future potential for producing a renewable energy fuel stock in the form of biofuel or biomass.

Specifically in line with the P3 goals (People, Prosperity and the Planet), further bio-facades are expected to benefit people and the planet by reducing concentrations of CO2 in outdoor and indoor environments and promote prosperity by developing local economies through its manufacturing and fabrication. Because algae can grow in different climates and locations, bio-facade has the potential to create a wide variety of jobs, from research to engineering, construction to farming, and manufacturing to marketing. In addition, bio-facades will produce renewable energy fuel stock and, consequently, protect the planet by lessening the need to extract and combust non-renewable energy resources. Algae can grow in different climates and locations and has the potential to create a wide variety of jobs, from research to engineering, construction to farming, and manufacturing to marketing.

Three industrial partners (i.e., Reynolds Polymer Technology Inc. in Grand Junction, CO; Optima Engineering in Charlotte, NC; and Front Inc. in NYC) were involved on this P3 project, providing in-kind consultation to the student groups on system development, fabrication, and operation of a bio-facade system. Optima Engineering particularly assisted students with specifying distribution systems, controller and pumps for air and water.

Figure 1 UNCC interdisciplinary team[1] for 2013 P3 competition in Washington DC

INTERDISCIPLINARY COLLABORATION THROUGH ARCH, BIO, CM, and ME FIELDS

This paper tests the promise that interdisciplinary teamwork produces more comprehensive outcomes for a sustainable building project. This research project observed the Spring 2013 offering of this three credit course. The class consisted of four departments with various backgrounds - ARCH, BIO, ME, and CM. Participating students were part of a senior capstone courses that bridge biology and engineering which collaborated with senior and Master students from the Architecture department. The course offered lectures on how to design and develop an bio-façade system while estimating performances in the areas of structure, environment, and sustainable energy potential. The course focused on teaching sustainable façade practices through lectures, lab work and a semester-long team project. The semester-long project was served as a P3 competition project to be presented in Washington DC and to compete for the P3 2 Award.

The teaching plan to offer a course in preparation of the P3 competition seek to develop and extend curriculums in the area of the Building Technology at the undergraduate and graduate levels, focusing on innovative facade system characterization, performance assessment, and its real world applications. With the vital and growing role played by building façades in building sustainability, it is imperative to conduct an interdisciplinary collaboration to complete the P3 project. Architecture students were divided into three groups and given primary role in sustainable building practice and façade design. They took a leadership role in developing an bio-façade system while coordinating information with BIO, ME, and CM students. The biology students had closely worked with ARCH and ME students to select appropriate algae strain, cultivate selected algae and carried out laboratory work in measuring cell counts and estimating biofuel and CO2 absorption rate. The ME students had cross collaboration with ARCH and CM to specify bio-façade operation systems and mechanical equipment. The CM team coordinated case-study building information and energy performance measures of the algae façade with ARCH and ME students and carried out whole building energy simulation and building life cycle cost analysis. We held weekly meetings and milestone presentations with each team to discuss group work, monitor progress, and appreciate individual roles and contributions to the P3 project. Each team was given specific tasks to investigate in the context of the entire project, including the following:

I o Architectural applications
o Performance assessment of thermal, daylighting and structural integrity
o Life cycle assessment & cost analysis
o Assembly development and prototyping
o Algae strain selection and algae growing environment optimization
o Lab work to check growth rate, O2 generation, and CO2 reduction.

Figure 2 shows interdisciplinary teams consisting of four departments at UNCC and explains the relationship between each department. The Architecture students played a major role in coordinating project information with BIO, ME, and CM. Each ARCH, BIO, ME, and CM teams compiled own data, exchanged knowlege and produced a progress report as part of course deliverables.

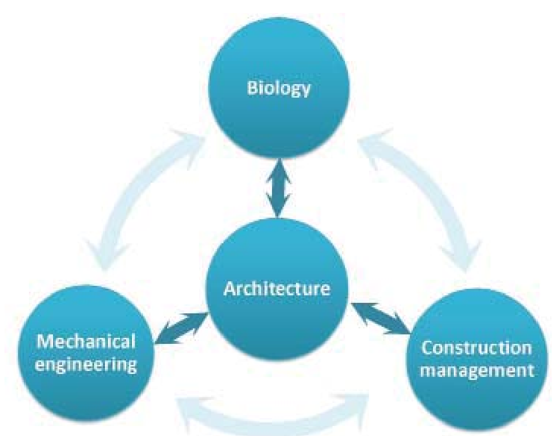

Figure 2: Interdiciplinary collaboration, *twenty-four students and seven faculties drawn from four departments involved in the bio-facade research during 2012-2013*

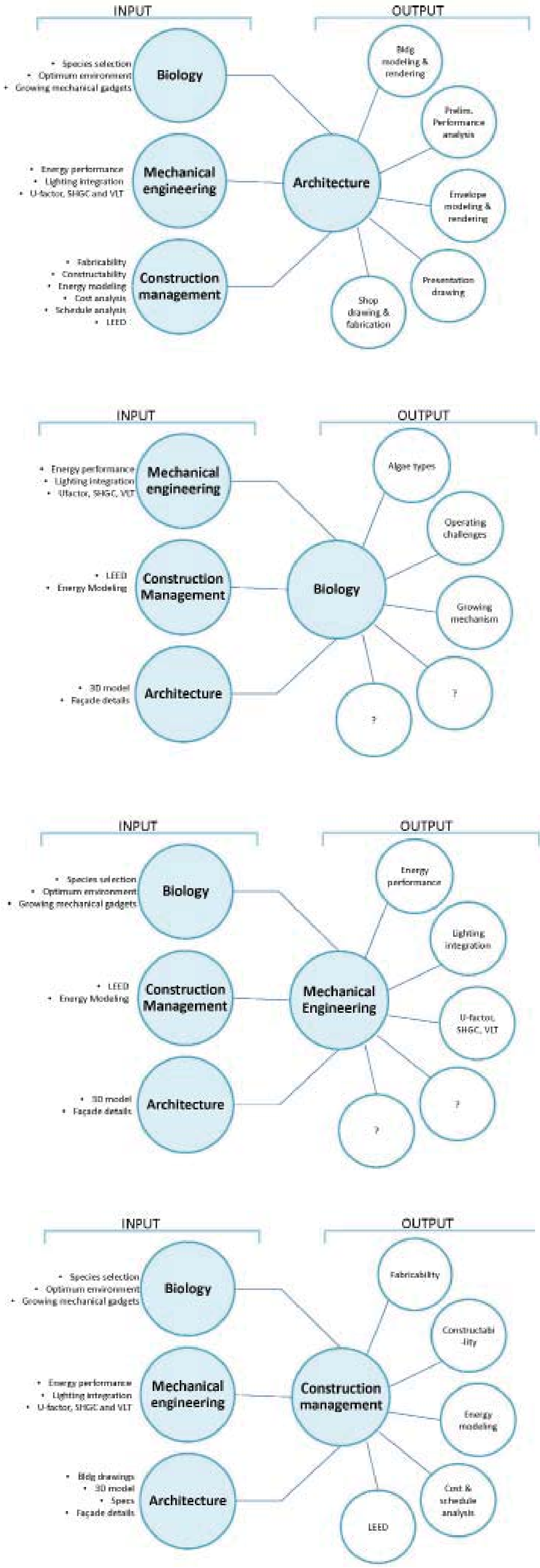

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Figure 3: Interdisciplinary collaboration, *deliverables and action items from each department - ARCH, BIO, ME, CM from top to bottom image*

PEDAGOGICAL OUTCOMES

The P3 project linked two significant future directions for building technology; innovative building material and sustainable systems engineering. It further proved that investigation on innovative facade materials and sustainable systems engineering thinking infused into traditional architecture studies to invigorate and carry the profession forward. Through the P3 project, not only are links developed within architecture department such as building design, structural calculation, and environmental performance, but also facilitated between architecture department and other fields. The students from four departments experienced the excitement of the link between research in an advanced building system and real-world needs for contemporary sustainable buildings. Team members who had previous experience on a group project or interdisciplinary collaboration with other classes, showed more proactive project communication than team members with no previous experience. A higher level of project communication resulted in strong trust and knowledge sharing between team members, leading to better process and final presentation.

Student learning outcomes was primarily assessed with observation and reviews during the semester and the final project presentation. Because non-architecture students had a time conflict with architecture students on regular class schedule, there were several group meetings outside the class to keep track of information exchange with other groups and reliance they placed on other group members. The faculty advisors also tracked the communication density between group members in terms of its nature and scope of information. During the final presentation, the student and team performance were assessed by the depth of central research inquiry, interdisciplinary exploration and the quality of final project presentation.

The architecture students primarily focused on delivering bio-façade system details, carrying out preliminary performance analysis, fabricating visual and performance mock-ups and producing analytical renderings that demonstrate different applications of bio-facades in built environment. The primary deliverables from the biology students consisted of a scientific report and laboratory measurements. The scientific report contained literature review on suitable algae strain selection and state-of-the art technology in algae-based biodiesel production as well as opportunities and challenges associated with energy generation potential and CO2 reduction and O2 supply from bio-facades in the built environment. The lab measurement included algae cell count in order to estimate algae growth rate in bio-facade invironment. The CM students used the P3 project as their senior capstone course in Sustainable Systems Engineering, produced data of energy conservation and renewable energy potential from bio-facades along with life cycle cost analysis using literature review and a whole energy building simulation. The students from Mechanical Engineering focused on executing a bio-facade operation system including distribution pipes, controller and pump equipment.

The P3 project carried out at UNCC was pedagogically successful in that we addressed our project goals and research inquires during the project schedule and received encouraging outcomes and results. From the very beginning of the project, we knew that the involvement of the campus community, including faculty, staff, and students from different disciplines, was essential to the success of our P3 project, and we have been pleased to see this enthusiasm across all sectors.

Our students have been very excited to participate in this P3 project, and as a result, the quality of the work has been highly rated by the teaching faculty and co-advisors. Our industry partners were very supportive through sharing their professional expertise and in-kind consultation with the class.

CONCLUSIONS

While it is clear that we do not currently link well the important subjects of sustainable design, building technology, bio-technology, applied mechanics, materials science and manufacturing, interdisciplinary education is imperative, and the various paths to be taken in the future remain to be discovered. In order to achieve an optimal linkage between these subjects in the training of undergraduate and graduate students, our collaborative P3 project involved faculty and students from disciplines including architecture, biology, and mechanical and civil engineering. Representing three colleges and four departments at UNC Charlotte, all 24 students (17 architects, 2 biologists, 2 mechanical engineers, and 3 construction managers) came together to work on a P3 project to develop a bio-facade system, focusing on innovative facade system and sustainable performance assessment. Our overarching pedagogical goal was to give students a multidisciplinary experience in problem solving on a research project through integrating innovative technology into a broad spectrum of solutions.

The P3 project was an exciting opportunity to direct our coursework towards sustainable design pedagogy within the collaborating departments of Architecture, Biology, Mechanical Engineering, and Construction Management. Students from each of the above four departments successfuly delivered fundamental research in environmentally responsible design and developed a bio-façade system for real world application. This project was highly relevant since it encompassed all the mentioned disciplines as well as others that became involved as the project unfolds, in relation to its technical, environmental, materials, fabrication, cost, and building life cycle assessment. In addition, as part of our initiative to engage with the departments of Mechanical Engineering and Construction Management, integrating interdisciplinary studio-based learning into engineering, we foresee this P3 project becoming the bedrock for how we proceed with future initiates in architectural education and sustainable built environment.

08_ENDNOTES TITLE

1. The 2013 UNCC P3 was supported by EPA Grant Number: SU835322. The title of the project was “Beyond Green: Bio-reactor Integrated Building Envelope (BIBE) in Urban Environment”. The Project abstract can be downloaded from http://www.epa.gov/ncer/p3/project_websites/2013/su835322.html.