1. Title of the Area

Transformative Architecture Technology Towards a Carbon Neutral Healthy Built Environment

2. Participating School/Departments

School of Architecture
Department of Biological Sciences
Department of Computer and Electrical Engineering
Department of Psychological Science

3. Research Team Leads

Dr. Kyoung Hee Kim, School of Architecture
Dr. Matt Parrow, Department of Biological Sciences
Dr. Chengde Wu, School of Architecture

4. Target Category for the Submission

Unique Distinction.

Keyword: Net zero carbon buildings, indoor environment quality (IEQ), occupant health and wellbeing, climate responsive regenerable technology, biofuel and solar power production

1. Executive Summary

Low performing building enclosures are responsible for more than half of the commercial building energy consumption in the US.[1] The new administration office plans to retrofit 4 million buildings and weatherize 2 million homes, which calls for innovative research in energy efficient retrofitting. In addition, people spend about 90% of our time indoors[2] and the worldwide pandemic has increased even more time spent indoors. Multiple studies show a correlation between indoor air quality and occupant health and performance.

To address both the environmental and social sustainability of the built environment, a group of faculty and students drawn from the architecture, biological sciences, and electrical and computer engineering departments have been advancing foundational research on transformative architecture technology and acceleration of technology transfer from the UNCC's research lab to the construction market. A team's core research focuses on cost effective high performance technologies that provide multi-functionalities of building energy reduction, occupant health and wellbeing, and on-site clean power production. For example, the novel patent pending microalgae building system offers a decarbonizing, restorative, energy efficient window to retrofit low performing windows to reduce energy cost up to 30% and improve indoor environment quality. Another patent pending building integrated photovoltaic (BIPV) system promotes off-grid buildings with on-site clean energy production and electrification.

The outcomes of the transformative architecture technology research have broad societal, economic, and educational impacts:
<u>Societal:</u> The building energy reduction and clean power production is an important priority as a growing global population and new construction lead to a rise in fossil fuel use and greenhouse gas emissions.
<u>Economic:</u> With energy efficiency and clean power production, the research has the potential to save both upfront and operational cost by reducing cooling, heating, ventilation and lighting load offset by on-site clean energy power.
<u>Educational:</u> Working with students at different levels and disciplines, with a focus on underrepresented populations, the research cultivates scientific talent and hands-on experience on green technology that is adaptable to changing social and professional needs.

The interdisciplinary research has led to recent funding success from the NSF ($425,000 total funded) and resulted in peer reviewed publications, books in contract, invited public presentations, and training opportunities for PhD students and interdisciplinary team-building especially participated by female students, underrepresented minority students, and students of color.

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[1] File, Microdata. "Commercial buildings energy consumption survey (CBECS)." *US Department of Energy: Washington, DC, USA* (2015).
[2] Smith, Joel B., and Dennis A. Tirpak. *The potential effects of global climate change on the United States: Report to Congress*. Vol. 2. US Environmental Protection Agency, Office of Policy, Planning, and Evaluation, Office of Research and Development, 1989.

2. Evidence of Strength and Excellence

Research: Many building projects include architects, engineers, and scientists with integrated backgrounds that span different disciplines. Interdisciplinary collaboration has gained importance in both academia and practice as a result of increasing demand for environmental agendas and global citizenship. The research team has focused on developing cost effective high performance building enclosures for low-performing buildings and new construction applications[3]. In addition to performance innovation, the research has involved multidisciplinary investigation to support net-zero energy net-zero carbon architecture[4]. This collaborative research has led to an academy, industry, and national lab partnership that investigated practical issues and performance verification in real-world scenarios. For example, innovative building material manufactures such as **Corning** and **Kingspan** have provided technical and in-kind materials support for prototyping and performance investigations. **Richter Development**, a leading solar cell developer based in Charlotte, has been working with the team by sharing industry knowledge on commercial innovation of our technology development. The team has been collaborating with Oak Ridge National Laboratory **(ORNL)** and National Renewable Energy Laboratory **(NREL)** on developing dynamic albedos with variable structure colors for energy efficient building retrofitting, which results in other federal funding applications. The team has also begun working with non-profit organizations such as **Clean Air Carolina** and **Breath LA** to improve indoor air quality for K-12 schools located nearby highways.

Current and pending research grant related to transformative architecture technology:

1. NSF STTR Phase I: 06/2020-05/2021, $225,000, Current, PI-Kim/CoPI- Parrow, Wu;
   High performance microalgae building enclosures for energy efficient retrofitting.
2. NSF STTR Phase II: $1,000,000 team building in progress;
   High performance microalgae building enclosures for energy efficient retrofitting.
3. NSF ICorps: 07/2020-12/2021, $50,000, Current, PI-Kim;
   Regenerative curtainwall for net zero energy architecture.
4. NSF ICorps: 07/2020-01/2022, $50,000, Current, PI-Wu;
   An air purification system for reducing indoor volatile organic compounds.
5. NSF PFI: 08/2021-08/2023, $250,000, Pending, PI-Kim/CoPI- Ebong, Wu;
   Regenerative window for building energy reduction and clean energy production.
6. NSF ES: 10/2021-09/2024, $400,000 Pending, PI-Kim/CoPI- Damakis, Parrow, Wu;
   Innovative microalgae building system as high performance carbon fixer for environmental sustainability.

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[3] Kim, Kyoung-Hee and Im, Ok-Kyun. (2021). Toward Net Zero Energy Retrofitting: Building Integrated Photovoltaic Curtainwalls.
International Journal of High-Rise Buildings Vol10 No1, 1-8

[4] Kim, Kyoung-Hee and Parrow, Matt (2014). Project-based Learning: Interdisciplinary Collaboration of Bio-facades in Urban Environment. Proceedings of 2014 ACSA.

Education: The architecture profession has traditionally been male-dominated despite more women graduating with professional architecture degrees. This gender imbalance is even more obvious in the architecture technology field. The research integrated curriculum has opened up transformative building technologies in validating their feasibility for real world applications, while enriching learning experience for underrepresented students who work directly and indirectly with the team. As an evidence to the impact to the teaching success, works done by students in architecture courses and research projects have received several prestigious national awards, including AIA COTE Top 10 student award, EPA P3 award, first prize of ACSA Sustainability Building Design, first prize of ACSA Steel Design, and first prize of Appalachian Energy Summit. In addition, the team has trained female students, underrepresented minority students, and students of color from BA in Architecture, BS in Biology, MArch, MS in Architecture, and PhD in INES programs, with state-of-the-art advanced experimental and computational techniques. The students directly and indirectly working with the team have contributed to NSF research as well as national and international peer-reviewed publications and conference presentations. Finally, the team has established relationships with research partners and professional organizations such as American Institute of Architects (AIA) and US Green Building Council (USGBC) outside the campus that enable students to foster professional growth and leadership.

Industry Experience: One of our unique research objectives is to ensure rapid translation of fundamental research into practical applications. Team's extensive professional experience in the Architecture Engineering Construction (A/E/C) industry has contributed to advancing practical and commercializable issues. Dr. Kim has worked on a wide range of buildings that received numerous publications and awards for innovative building design and technological advancement, including the HL23 high-rise residential building in NYC that uses a mega facade structure to provide solar reduction, passive heating, structural integrity, an acoustic barrier, and air/water tightness.[5] The Children's Hospital of Philadelphia uses a high-performance curtainwall integrated with an external shading device to reduce the building's energy consumption.[6] With nearly 10 years of professional experience in Santa Fe, Seattle, Boston, Houston, Singapore, and New Orleans, Prof. McCormick has worked on a variety of projects, including several single-family passive houses and LEED-certified commercial buildings and campuses. Dr. Wu also practiced professional design in Beijing and Seoul, primarily focused on high-rise apartment complexes and office buildings.

[5] Kim, Kyoung-Hee (2012). Life Cycle Impact Assessment of a Mega-panel Façade System in the HL23 Condo. 2012 ACSA Fall Conference

[6] Kim, Kyoung-Hee and Han, Seung-Hoon (2016). Urban Glare and Death Ray Potentials from Glass Towers. Proceeding of the 2016 EAAE/ARCC Conference. p.757-763

3. Alignment with Regional and National Priorities

Our research contributes to global citizenship and climate emergency. The building sector plays an important role in resource conservation and pollutant reduction. The demand for energy-efficient and healthy buildings has led to rigorous research on better energy management and healthier indoor environments. The development of clean energy and electrification of buildings is another important priority for both occupants and buildings.

Legislative adoptions are also a driver for energy efficient buildings. The City of Charlotte, for example, aims to meet near zero carbon buildings by 2050.[7] On the West Coast, the California Energy Efficiency Strategic Plan sets goals that 50% of commercial buildings be retrofitted to net zero energy buildings by 2030.[8]

University-industry collaboration is beneficial, as the problems perceived in academia may not always coincide with those of practitioners. Experimenting with innovative green technology in a real-world context elevates awareness of the excitement and social relevance of sustainable technology. Our academy-industry partnerships help close the gap between theory and practice, advancing the acceleration of technology transfer from the UNCC's research lab to the construction market.

Promoting green technology will help attract a more diverse population. The team has been facilitating team-building and disciplinary diversity, advancing the participation of underrepresented minority students and students of color, and establishing a culture of respect, a variety of perspectives, and open communication. This collaborative research also supports interdisciplinary mission to be more active in research-oriented curriculum and brings innovative technologies to a wider cross-section of UNC Charlotte students.

[7] City of Charlotte, "Action Area 7: Near Zero Carbon Non-Municipal Buildings By 2050", Accessed on Feb 20, 2021, https://charlottenc.gov/sustainability/seap/Pages/climate/NearZeroCarbon.aspx

[8] Energy Upgrade California, "California's Energy Goals", Accessed on Feb 20, 2021, https://www.energyupgradeca.org/californias-energy-goals/

4. Project Team

This uniquely qualified team, with multi-disciplinary expertise (Table 1) has collaborated on innovative architecture technology research.

Dr. Kyoung-Hee Kim is Director of the Integrated Design Research Lab (IDRL) and an Associate Professor of Architecture. She is an expert in advanced facade design and engineering with broad knowledge and expertise in sustainable building systems integration. As a licensed practicing architect, she has extensive experience in the design, analysis, and full-scale execution and implementation of high performance buildings, with more than 15 years in architecture profession. Dr. Kim has been involved in all milestone activities of the research projects and led funded projects.

Dr. George Demakis is a Professor of Psychology and Health Psychology at UNC Charlotte. He is a licensed psychologist and board-certified clinical neuropsychologist. Dr. Demakis' research interests are civil competency, financial decision-making, and various clinical conditions such as Attention-Deficit/Hyperactivity Disorder, Mild Cognitive Impairment, and Alzheimer's disease. He will plan, coordinate, and supervise all cognitive and psychological evaluations.

Dr. Abasifreke Ebong is a Professor in the Department of Electrical and Computer Engineering at UNC Charlotte. His current research includes 1) low-cost contact to lowly doped emitters for high-efficiency Si solar cells, 2) an alternative to Ag paste for lowly doped emitter for high-efficiency Si solar cells, and 3) understanding the impact of conducting glass layer at the Si/gridline interface. His expertise will guide the team with design, modeling, fabrication, characterization, and analysis of solar cells that are low-cost and high-efficiency for greater commercialization potential.

Prof. Liz McCormick is an Assistant Professor of Architecture. With a sizeable portion of the globe occupying hot-humid climate zones, her research strives to enhance architectural innovation and construction technologies in rapidly developing tropical regions. She is an architect, educator, and researcher whose work explores climatically sensitive and contextually appropriate building enclosure designs that connect the occupant to the outdoors and reduce the dependence on energy-intensive mechanical conditioning.

Dr. Matthew Parrow is Director of the Microbial Ecophysiology and Evolution Laboratory in the Department of Biological Sciences. He is an expert in the field of microalgal growth, culturing, and physiology. Dr. Parrow has engaged in the microalgae window research since 2011 and will continue support on the integration of nature into sustainable building material by cultivating microalgae cultures and biomass growth monitoring from the microalgae enclosures.

Dr. Chengde Wu is a Research Fellow and Lecturer of Architecture. He has expertise in full-scale prototyping, performance evaluations, and sensing/physical modeling. He leads digital technologies to facilitate sustainable technology development utilizing building information modeling (BIM), performance simulations, and digital fabrications. This digital technology is crucial to rapid prototyping, performance verifications, and physical mock-ups.

Table 1 Interdisciplinary Research Team for Transformative Architecture Technology

Name	Title	Contribution/Expertise
Dr. Kyoung Hee Kim	Director of Integrated Design Research Lab, Associate Professor of Architecture	Performance-based design; sustainable technology integration; performance assessment
Dr. George Damakis	Professor of Psychological Science	Civil competency, financial decision-making, and various clinical conditions such as Attention-Deficit/Hyperactivity Disorder, Mild Cognitive Impairment
Dr. Abasifreke Ebong	Professor of Electrical & Computer Engineering	Optoelectronic devices' contact interface characterization - solar cells design, analyses, modeling and fabrication
Prof. Liz McCormick	Assistant Professor of Architecture	Energy consumption of commercial buildings in developing hot-humid climates
Dr. Matthew Parrow	Director of the Microbial Ecophysiology and Evolution Lab; Associate Professor of Biological Sciences	Microalgal ecology and physiology, biofuels, applications of algae in biotechnology
Dr. Chengde Wu	Research Fellow and Lecturer of Architecture	Building performance simulation and optimization; sensing/ physical computing; digital modeling and fabrication