



ERC for Precision Microbiome Engineering (PreMiEr)

Duke University (lead institution)

Enabling the bioinformed design of smart and healthy built environments



A National Science Foundation Engineering Research Center since 2022



Partner Institutions:

- North Carolina Agricultural and Technical State University
- North Carolina State University
- University of North Carolina at Chapel Hill
- University of North Carolina at Charlotte

PreMiEr’s vision is to develop an integrated framework for enabling the development of high-impact microbiome technologies that provide innovative solutions to key societal challenges at the interface of human health and the built environment.

People living in urbanized settings spend more than 90% of their lives indoors within human-made structures known collectively as “the built environment.” These include our homes, places of work, vehicles, shopping malls, hospitals, and entertainment venues—but we do not spend this time alone. We share the built environment with diverse communities of microorganisms composed of bacteria, fungi, protozoa, archaea, and—as we learned all too well with the recent pandemic—viruses. This assemblage of potentially millions of microbes in a particular environment is called a “microbiome” and its composition can vary greatly depending upon the specific conditions present. The microbiomes of the myriad spaces that comprise the built environment are just beginning to be explored and we have an incomplete understanding of how many of these organisms there are, what they are doing, and just how they can affect our lives.

Despite a lack of precise knowledge about many of these microbes, there is increasing evidence that the microbiomes surrounding us interact with and impact the composition of the skin, lung, gut, and other microbial communities associated with our own bodies. A number of adverse health outcomes have

been linked to the presence or activities of specific human-associated microbes, including diabetes, asthma, irritable bowel syndrome, cardiovascular disease, and even mental health disorders. As microbes can be transferred from the environment to the human body and vice versa, a more complete understanding of the links between human microbiomes and the microbiomes we most commonly associate with is necessary to predict effects on our health, and to design, build, and operate healthier structures.

The Engineering Research Center for Precision Microbiome Engineering, or PreMiEr, was created to address issues associated with microbial communities within built environments, with the overarching goal of identifying and modifying the microbes and conditions of indoor environments that will ultimately lead to healthier spaces. This will be accomplished not only by attempting to remove, minimize, or inactivate harmful microbes such as the SARS-CoV-2 virus and other pathogens that cause disease, but through active steps to identify and promote the growth of beneficial organisms that actively improve human health. These helpful microorganisms might not only directly impact health through positive interactions with our own human-associated microbiomes, but their mere presence in the built environment might be sufficient to displace organisms that could cause adverse outcomes through competition for scarce resources.

We anticipate that the inventions and methods that arise from PreMiEr research will be impactful beyond the built environment. Microbes exist in abundance nearly everywhere on the planet and the discoveries and methods developed in PreMiEr could have applications for precision engineering of microbes in biotechnology, medicine, agriculture, climate change, or any number of grand challenges in which the power of microorganisms can be leveraged.

RESEARCH

Research in PreMiEr is organized into three research thrusts and two research cores, with a number of associated testbeds modeling or supporting various aspects of the built environment for exploration and experimentation. The research thrusts are clustered around the core concepts of **Measuring** (Research Thrust 1, or RT1), **Modifying** (RT2), and **Modeling** (RT3) the microbes within the built environment. The **Data Analytics** and **Societal & Ethical Implications** cores host their own research projects, while also providing support and guidance to all researchers of the ERC within those specialized domains.

To **measure** the copious amounts of microbial “dark matter,” or communities of microorganisms with unknown identity or function, that comprise built environment microbiomes, PreMiEr RT1 investigators will be developing and refining methods for studying microbial communities in a “multi-omic” fashion targeting whole organisms, genomic or amplified DNA, RNA, and chemical signatures. In association with PreMiEr’s **Data Analytics** core, they will also be

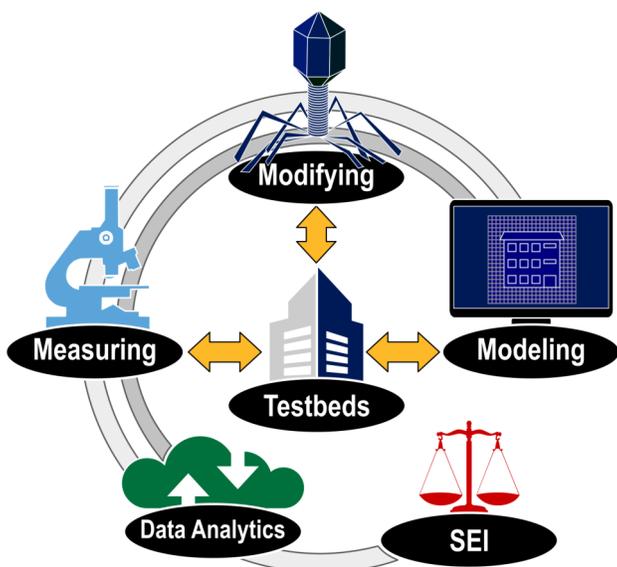
streamlining and standardizing analysis methods across the center, creating open-source, platform-independent, reproducible pipelines for analyzing community structures to be shared with the public. RT1 will also develop sensor technologies for the monitoring and detection of microbes in the built environment.

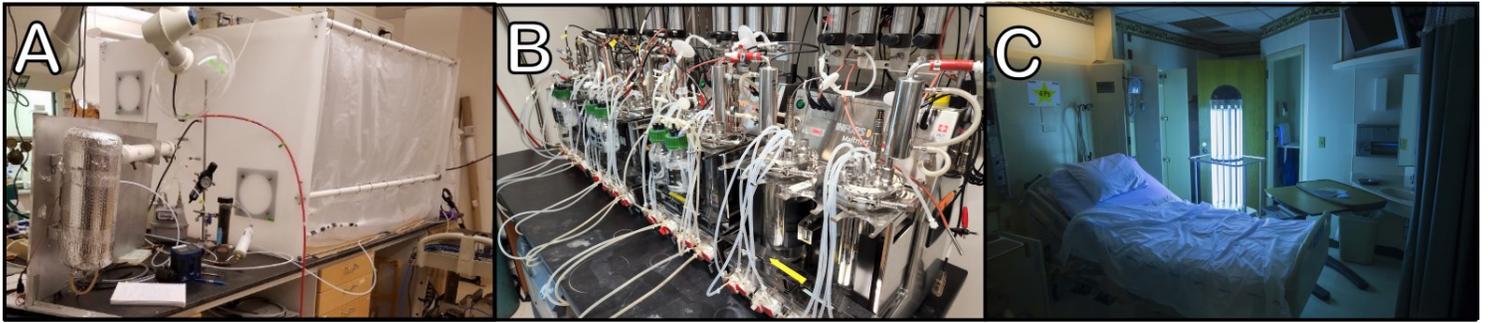
PreMiEr’s RT2 focuses on the **modification** of microbiomes. Building on the knowledge gained from collaborators in RT1, existing and newly developed technologies for neutralizing, removing, or adding microbes to the environment will be used by PreMiEr RT2 researchers to shape the structure of the built environment microbiome to achieve positive outcomes. An integral component of these projects will be collaboration and integration with PreMiEr’s **Societal & Ethical Implications Core** to ensure that all activities arising from this thrust adhere to the highest possible guidelines and standards for such work.

Projects in RT3 will develop predictive **models** that incorporate spatiotemporal methods, generative modeling concepts, and machine learning approaches to analyze built environment microbiomes. RT3 projects will focus on the development of predictive models that identify factors that contribute to microbiome compositional variations, and microbiome signatures that associate with specific health outcomes, which in turn will inform built environment health signature identification.

The built environment is exceptionally varied, and no handful of test sites could possibly serve to encompass the structural and operational diversity present amongst indoor spaces around the world. With that in mind, the various PreMiEr **Testbeds** were carefully selected based on the traits of (i) controllability, relevance to “real world” conditions, and (iii) potential pathogen burden, to provide a variety of conditions,

Convergent research in PreMiEr is divided into three Research Thrusts with the general missions of Measuring, Modifying, and Modeling the microbiomes of the built environment, with each making use of diverse testbeds. The Data Analytics Core provides support for each of these thrusts as well as directing their own research projects. Similarly, the Societal and Ethical Implications (SEI) Core performs research and interacts with stakeholders while also contributing recommendations and oversight to the entire Center. (Credit: PreMiEr)





PreMiEr testbeds were selected to represent a wide variety of environments and conditions related to the built environment, with some of them presented here. In environmental chambers (A), researchers can test research hypotheses in the lab under tightly controlled conditions. Artificial-gut bioreactors (B) provide opportunities to test perturbations of environmental microorganisms to model human gut microbiomes. More advanced sampling and testing opportunities occur in PreMiEr’s “real world” testbeds, including hospitals (C). (Credit: PreMiEr)

interactions, and structures in which researchers can test their hypotheses. PreMiEr’s testbeds range from small lab-based environmental chambers and artificial gut bioreactors to working hospitals and residences in both North and South America.

EDUCATION

PreMiEr is committed to the education and training of the next generation of diverse and ethically responsible scientists in microbiome engineering and related disciplines. In addition to training graduate students engaged in convergent research, every PreMiEr-affiliated university will search out ways to engage undergraduates and other students outside of the traditional graduate lab experience. For example, in one university PreMiEr faculty have tasked freshman engineering students to design wearable sensors. All of our PreMiEr-affiliated students, post-docs, and research staff are represented by the Scholars Leadership Council (SLC). Led by elected

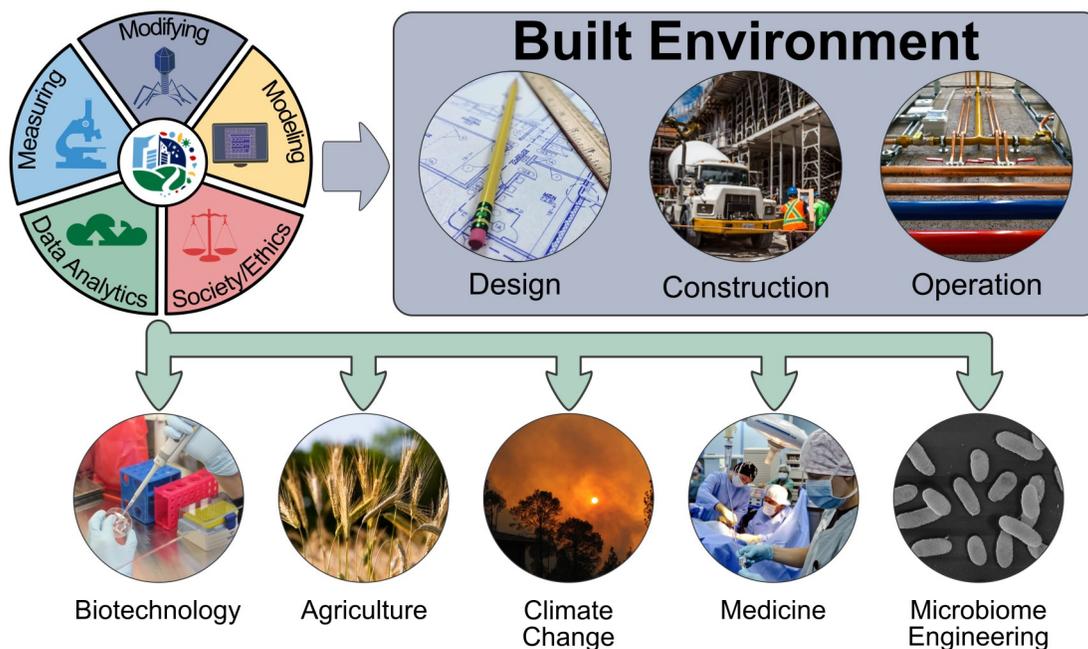
representatives, this internal organization provides opportunities directly to its membership, chances for networking and collaboration, and critical feedback to the Center’s executive leadership through productive two-way discussions.

PreMiEr will also be engaging with undergraduate students, community college students, and K-12 or community college teachers through our REU and RET programs. These annual summer programs will give both groups valuable research experience in Center-affiliated labs at each of our participating institutions. In addition, professional development opportunities will be offered, with REU students gaining skills to help them advance their futures in STEM research, while RET participants will gain experience and knowledge in order to develop and bring back to their home school age-appropriate lesson plans relevant to PreMiEr research goals.

But our goals are not only to reach out to those in the traditional educational environment. PreMiEr is also partnering with community outreach organizations to raise awareness of microbiome issues and the role of the ERC in promoting environmental health, and in turn seeking input from the general community on aspects of the Center that touch their lives. PreMiEr will be working closely with museums, schools, and science centers to provide exhibits and activities based around ERC research and its goals. We will also be partnering with citizen science groups located across the country, such as DIY-labs, in support of their missions engaging with the general public. Through all this, our Societal and Ethical Implications core will be engaging with other stakeholders to connect PreMiEr researchers with those impacted by the Center’s findings and recommendations.



PreMiEr Center Director Dr. Claudia Gunsch works with graduate students in her lab at Duke University. (Credit: PreMiEr)



While primarily focused on improving the health of built environments through precision engineering of their microbiomes, researchers at PreMiEr envision their findings also extending to solving other grand challenges in Biotechnology, Agriculture, Climate, and Medicine. (Credit: PreMiEr)

DIVERSITY AND CULTURE OF INCLUSION (DCI)

Research and innovation are collaborative processes in which significant advancements are strengthened through a respectful sharing of different viewpoints, ideas, and experiences including both those involved and those impacted. At PreMiEr, we strive to recognize those disparate voices and give them a meaningful presence within the ERC. Our primary DCI goal is to develop an inclusive and equitable culture where voices from diverse stakeholders are acknowledged, and all participants are equally treated with respect. To facilitate these goals, all members of the ERC are required to attend regular training sessions on building an equitable community.

PreMiEr's current senior personnel comprises 47% females and 16% from groups historically marginalized in STEM. Those numbers grow to 60% and 20% for our executive leadership team, respectively. But this is only the beginning. We are developing a leadership succession plan that will ensure that individuals from under-represented groups in STEM will continue to move into leadership roles within the ERC as their careers progress. But efforts to increase representation in PreMiEr do not end with the faculty. Another goal of our DCI program is to build a diverse trainee population and broaden participation in STEM.

However, merely recruiting students and faculty is not sufficient to ensure their success. Thus, an important objective of PreMiEr's DCI team is to promote an equitable academic and social environment where scholars belonging to historically marginalized groups in STEM can flourish. We plan to accomplish this through activities such as cross-institutional seed grant opportunities, lab rotations, and mentoring networks with culturally responsive mentor/mentee training that promotes retention and one's sense of belonging. We will provide leadership development for ERC mentors that includes effective communication strategies, and we will incorporate feedback from PreMiEr's advisory boards to foster a thriving, engaging, and inclusive environment.

INNOVATION ECOSYSTEM

PreMiEr's Innovation Ecosystem (IE) envisions significant changes in industries related to livable, healthy indoor environments and will engage a diverse group of researchers, students, and industry partners to develop commercialized products and processes in the realm of built environment engineering and beyond. PreMiEr's IE team will develop a networked consortium of members from industry, government, nonprofit foundations, and investors, nested within a culture of collaboration that drives forward innova-

tion in microbiome sciences. In the near term, PreMiEr's IE will form inclusive connections with researchers, students, communities, and public health managers. In the longer term, those connections will build upward to include national and global contract laboratories, clinical and environmental testing corporations, university technology development offices, and industry partners to directly translate to improvements that enable healthy, indoor environments that promote community and individual health.

PreMiEr will promote diversity and collaboration among stakeholders, including large and small companies, government and nonprofit organizations, investors, and members of the academic community. PreMiEr's IE will also provide the infrastructure to tie the Center's research goals together with the needs of the end users via feedback from industry partners, market assessments, and a lens towards commercialization of products and processes.

Scholars associated with PreMiEr will have ample opportunities to engage with IE through a network involving training, mentorship, and ongoing dialogue with industry partners, faculty, and scholars. Other opportunities will include Entrepreneur Workshops that deliver key knowledge and skills, Mentors-in-Residence that will help guide microbiome engineering startup ventures, and the Founders' Advancement Network to develop and support PreMiEr entrepreneurs. PreMiEr's IE will also rely on industry partners to help guide the evolution of its training portfolio to identify gaps and opportunities, and ensure the knowledge and skills of its trainees, scholars, and faculty align with the market's existing and future workforce needs.

PreMiEr's IE team will work with PreMiEr's researchers to engage stakeholders to identify gaps in foundational knowledge and current technologies to generate research endeavors that address market needs. With a catalytic accelerator model framework, industry partners and practitioners, government representatives and policy makers, and community citizens will advance PreMiEr's strategic plan and guide revisions to research questions, designs, and processes, and identify new partners to maximize the Center's societal impact.

FACILITIES

PreMiEr is headquartered at Duke University in Durham, North Carolina and has partnered with other top-tier research and teaching universities across the state. North Carolina Agricultural and Technical State University (NCA&T) in Greensboro, NC is a leader among HBCUs in successfully training graduates with STEM degrees. The University of North Carolina at Chapel Hill is the flagship institution of The University of North Carolina system and supports a variety of PreMiEr research labs on the main campus, as well as the Institute for Marine Sciences in Morehead City, NC. North Carolina State University boasts a strong history of engineering and is the home of the Genetic Engineering and Society Center (GES), a key component in maintaining the social and ethical compass of PreMiEr. The University of North Carolina at Charlotte brings to the center both world-class researchers and extensive computing capabilities.

Duke University: ERC administrative and support space, Duke Microbiome Center, Shared Materials Instrument Facility, Duke Human Vaccine Institute, Duke Center for Genomic and Computational Biology, Duke Innovation & Entrepreneurship, Duke Molecular Physiology Institute, Duke University Hospitals.

North Carolina Agricultural and Technical State University: Office of Intellectual Property Development and Commercialization, Center of Excellence in Entrepreneurship and Innovation, Visualization and Computation Advancing Research Center, Center for the Advancement of STEM Leadership, Center of Excellence in Product Design and Advanced Manufacturing, Waste Management Institute, Department of Computational Data Science and Engineering—3D Visualization Lab.

North Carolina State University: Bioinformatics Resource Center, Genetics and Genomics Academy, Gnotobiotic Animal Core, Molecular Education, Technology, and Research Innovation Center (METRIC), Genetic Engineering and Society Center, NCSU Bioinformatics Cluster, Genomic Sciences Laboratory.

University of North Carolina at Chapel Hill: High-Throughput Sequencing Facility, Center for Bioinformatics, Microbiome Core Facility, Biomarker Mass Spectrometry Facility, Metabolomics and Metabolic Molecular Phenotyping Core, Center for Bioethics,

BeAM Design Center, ITS Research Computing, Renaissance Computing Institute (RENCI), Odum Institute for Research in Social Sciences, Morehead Planetarium and Science Center.

University of North Carolina at Charlotte: University Research Computing Orion and GPU Clusters, Bioinformatics and Genomics Sequencing and Advanced Molecular Detection Facility, Wastewater and Translational Environmental Research Infrastructure, Civil Engineering High Volume Filtration and Environmental Sampling Equipment.

CENTER CONFIGURATION, LEADERSHIP, TEAM STRUCTURE

PreMiEr's Executive Committee is led by the Center Director with the assistance of the Deputy Director and includes three Associate Directors who together represent each of the five participating universities. Supporting the Executive Committee are an Administrative Director, Assistant Administrative Director, Financial Director, and Director for Evaluation and Assessment. DCI efforts are directed by two individuals on different campuses, while IE is led by a Director and supported by two Directors for Strategic Partnership and Innovation. PreMiEr's EWD leadership comprises three Directors for Education and two for Outreach. Each convergent research thrust or core is led by two to three faculty from across the universities. The Center's varied testbeds are overseen by four faculty members. The Scholars Leadership Council (SLC) elects leaders from among their membership who directly interact with leadership in each of the foundations of the ERC. We believe that a deep leadership team for nearly all aspects of the Center provides not only redundancy in responsibility, but also provides multiple viewpoints in accordance with our goals of building an equitable community.

CENTER HEADQUARTERS

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