MICROBIOMES OF THE BUILT ENVIRONMENT

A RESEARCH AGENDA FOR INDOOR MICROBIOLOGY, HUMAN HEALTH, AND BUILDINGS

SUMMARY FOR MICROBIAL ECOLOGISTS, MOLECULAR BIOLOGISTS, AND OTHER STAKEHOLDERS IN THE BASIC SCIENCES

Humans spend most of their time in spaces and structures that are designed, built, and managed by other humans. Microorganisms—viruses, bacteria, fungi, and protozoa—can reside in the air that circulates in buildings, in the plumbing systems that supply water and remove waste, as well as on surfaces ranging from kitchen sinks to doorknobs. While some indoor microbial communities are relatively stable over time, new microorganisms and microbial components are also introduced into built environments through pathways such as pets, plants, rodents, an open window, a leaky roof, and dirt tracked indoors on an occupant's shoes.

Indoor environments are important ecosystems that have been the focus of research by microbial ecologists, molecular biologists, and other basic science researchers. Their efforts have resulted in significant contributions to our current understanding of the indoor microbiome, including the characteristics of microorganisms and microbial communities in built environments and how occupant, building, and environmental factors can affect these communities. Despite the progress that has been made in elucidating the characteristics and modifiers of the indoor microbiome, however, significant gaps remain in the knowledge of microbial ecology.

The report proposes a **systematic research agenda with 12 priority areas** to address knowledge gaps and achieve the goals of characterizing built environment interrelationships, assessing effects of exposures on health outcomes, exploring non-health impacts of indoor microbial communities, advancing tools and research infrastructure, and translating research into practice. There are a number of ways in which basic science stakeholders can play a role in the effective pursuit of such a research agenda (see Box on back).

The inter-relationships among microbial communities, buildings, and human health are complex and difficult to study, and translating findings into practical interventions aimed at promoting human health will be equally challenging. Selected knowledge gaps impeding advancement in this field include the need to:

- Define what constitutes "normal" microbial ecology in the built environment, and whether it is the same in different types of buildings and under different environmental conditions.
- Collect better information on sources of microbes in the air, water, and on various surfaces in various built environments.
- Understand what factors control the abundance and diversity of indoor microbial communities.
- Understand how building characteristics and environmental factors allow microbial sources to develop into longstanding microbial reservoirs.
- Clarify how building attributes and conditions are associated with indoor microorganisms that have beneficial or have neutral effects on human health.
- Continue to explore the development of interventions that promote exposure to beneficial indoor microorganisms, and clarify whether, and under what circumstances, these exposures could promote human health.
- Continue to understand how microorganisms affect the integrity of building materials and strategies to minimize negative impacts such as corrosion, degradation, or fouling.
- Develop the research infrastructure and tools that are needed to promote reproducibility and enhance cross-study comparisons in research at the intersection of microbial ecology, built environments, and human health.

In collaboration with building scientists, public health practitioners, and engineers, microbial ecologists and basic science researchers bring critical expertise to the table and will have an important role to play in moving this interdisciplinary field forward. Furthering the proposed research agenda and achieving an improved understanding of the nexus of built environments, their associated microbial communities, and their human occupants can help define and promote healthful indoor environments in the future.

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BASIC SCIENCE COMPONENTS OF THE RESEARCH AGENDA

Microbial ecologists, microbiologists, and other basic scientists can contribute to achieving the research agenda proposed in the report. Examples include:

Characterizing interrelationships among microbial communities and built environment systems of air, water, surfaces, and occupants by studying and understanding these complex interrelationships.

Advancing the tools and research infrastructure for addressing microbiome–built environment questions by improving measurement and data collection tools and advancing the research infrastructure that is used to study complex relationships. Areas for investigation include:

- Refining molecular tools and methodologies for elucidating the identity, abundance, activity, and functions of the microbial communities that are present in built environments, with a focus on enabling more quantitative, sensitive, and reproducible experimental designs.
- Refining building and microbiome sensing and monitoring tools, including those that enable researchers to develop building-specific hypotheses related to microbiomes and that assist in conducting intervention studies.
- Developing guidance on sampling methods and exposure assessment approaches that are suitable for testing microbiome–built environment hypotheses.
- Contributing to development of a "data commons" with data description standards and provisions for data storage, sharing, and knowledge retrieval.
- Developing new empirical, computational, and mechanistic modeling tools to improve understanding, prediction, and management of microbial dynamics and activities in built environments.

This document is based on the report *Microbiomes of the Built Environment: A Research Agenda for Indoor Microbiology, Human Health, and Buildings.* The study was sponsored by the Alfred P. Sloan Foundation, the Gordon and Betty Moore Foundation, the National Aeronautics and Space Administration, the National Institutes of Health, and the U.S. Environmental Protection Agency, with additional support from the National Academy of Sciences Cecil and Ida Green Fund.

Copies of the report are available from the National Academies Press at **http://www.nap.edu.**

For more information, visit: **http://nas-sites.org/builtmicrobiome**

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