Microbiome-Inspired Green Infrastructure: a toolkit for landscape researchers and practitioners

J. Harry R. Watkins[1] Jake M. Robinson[1,2,4] Martin F. Breed[3,4] Brenda Parker[5] and Philip Weinstein[4,6]

[1] Department of Landscape, University of Sheffield, Western Bank, Sheffield S10 2TN, UK
[2] *in*VIVO Planetary Health, of the Worldwide Universities Network (WUN), West New York, NJ 10704, USA
[3] College of Science and Engineering, Flinders University, Adelaide, SA 5001, Australia
[4] Healthy Urban Microbiome Initiative (HUMI)
[5] Dept. of Biochemical Engineering, University College London, London, WC1E 6BT, U.K
[6] School of Biological Sciences and the Environment Institute, The University of Adelaide, Adelaide, SA, 5005, Australia

Correspondence: h.watkins@sheffield.ac.uk, jmrobinson3@sheffield.ac.uk, martin.breed@flinders.edu.au, brenda.parker@ucl.ac.uk, and philip.weinstein@adelaide.edu.au

Keywords: Microbiome-Inspired Green Infrastructure; Green Infrastructure; Urban Design; Biodiversity; Urban Microbiome; Microbiome Rewilding

Journal guidelines

Title	8-12 words.
Abstract	Max 50 words.
Keywords	2-6.
Main body	Max 1,500 words excluding text boxes. 2 extra elements (eg diagrams, text boxes or tables) permitted.
Text boxes	Max 200 words.
References	Max 15 references, numbered sequentially.

Introduction

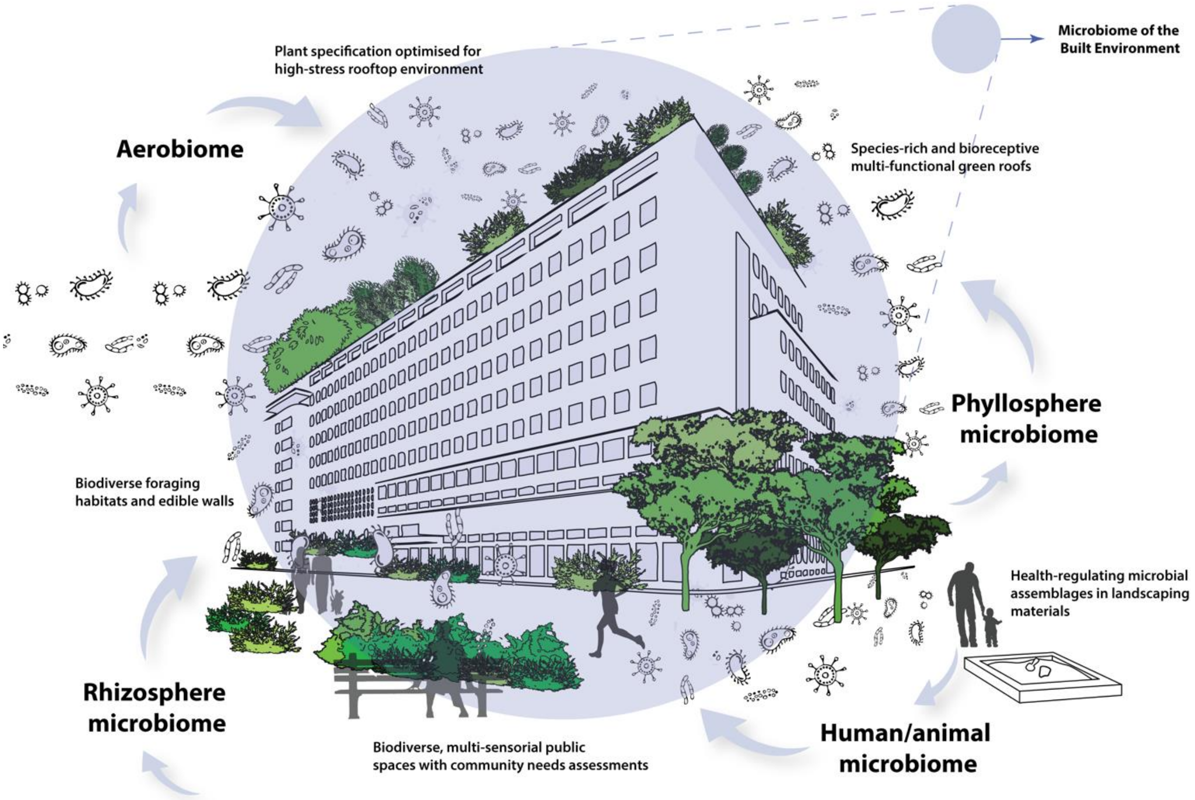
Microbiome-Inspired Green Infrastructure (MIGI) has been proposed as a means of helping to mitigate the negative effects of industrial urbanisation on biodiversity and public health (Box 1) [1]. MIGI includes multifunctional green features, designed and managed to optimise interactions between humans and diverse microbiota, and thus complement other co-benefits of green infrastructure. However, implementing MIGI presents several conceptual, operational and technical challenges to urban designers and managers. This paper presents a testable framework for integrating microbial ecology and public health considerations into design and construction projects using industry-standard project management frameworks, overcoming one of the principal barriers to delivery.

Environmental context

Microbiota develop symbiotic relationships with other organisms across all trophic levels. Over evolutionary timescales they have become fundamental to the maintenance of complex physiological processes (e.g. immune regulation) [2]. These relationships scale up to support multiple ecosystem services, bringing considerable health and wellbeing benefits to humans and non-humans alike [3].

The integrity of these relationships and their associated benefits are thought to be threatened by urbanisation [4]. Furthermore, the loss of interactions between humans and the diversity of environmental microbiota is linked to negative health trends, such as non-communicable (chronic, non-infectious) diseases [5]. As a result, there is a potential positive feedback relationship between the biodiversity crisis, climate change, public health impacts and rapid urbanisation [6]. To turn this negative relationship around, there is a pressing need for urban designers, public health experts and microbial ecologists to work across spatial scales to develop new and improved ways of supporting and enhancing human interactions with environmental microbiota in urban areas (Box 1).

Box 1. Microbiome-Inspired Green Infrastructure (MIGI): multifunctional, bioreceptive green features aimed at promoting symbiotic microbial interactions with humans, with several important co-benefits.



Project requirements	MIGI objectives
Social and cultural objectives	• Prepare an ethics statement to ensure that MIGI prioritises socio-ecological inclusivity. • Investigate effects of different GI network configurations and landscape connectivity on environmental microbiota. • Establish MIGI in places where children spend time such as play areas and skate parks, ang integrate MIGI strategies with cultural trends. • Identify which cultural practices (such as foraging and recreational activities) could maximise co-benefits.
Ecosystem services	• Maximise macro-biodiversity, for example using structurally diverse urban meadows instead of amenity grasslands. • Consult microbial ecologists to select plant species and design soil structures. • Assess effects of wind, pollution and land-use at various scales on microbial diversity. • Consider microbiome inoculants in landscape materials, depending on results of ecological assessments. • Create biosecurity management plan at earliest stages.
Project planning	• Overcome commercial pressures and value engineering by consulting nurseries and materials suppliers at early design stages; consider practices such as contract growing to ensure high biosecurity standards and accurate supply of materials. • Anticipate future management regimes and create potential for microbiome rewilding.

Barriers to creating MIGI

Researchers and public health experts have attempted to define the benefits of integrating anthropocentric and microbecentric needs to biodiversity and public health, but whilst in some cases these have led to policy considerations, they have not yet been adopted in practice at a wide scale [7]. There are numerous reasons why this might be, such as the difficulty in providing resources for standard green infrastructure (let alone MIGI) and the challenges of addressing community needs and lifestyle behaviours [8]. There are, however, specific barriers to creating MIGI that need to be overcome, including:

1. Development projects are highly complex and as a result have goal-orientated processes for delivering discrete objectives, whether it is easing traffic congestion through a new motorway, providing education resources through a new school or creating profit through speculative development. In this environment, benefits that do not directly result in goal delivery are not prioritised.
2. The lack of an established evidence base for effective MIGI interventions makes it difficult for designers to know which MIGI interventions are effective, or understand how or why they should try to design them into projects.
3. MIGI objectives have not yet been integrated into industry-accepted project frameworks. As a consequence, design team members are unsure how to structure their scopes of work or how MIGI interventions integrate with other design team members.
4. Many elements of MIGI cross project work-stage boundaries, or require actions at stages when design team members are not typically engaged. As a result, convincing developers to engage a microbial ecologist in the design team will require robust evidence.
5. Project teams lack of awareness of the benefits or the risks of not including MIGI. As commercial pressures increase, this often results in the dilution of aims and objectives throughout a project.

Plans of Work

Green infrastructure design requires multidisciplinary teams to undertake a number of processes, including community consultation, landscape assessment, concept design, detailed design and contract administration. In this process, designers work with specialists and contractors to prepare designs and specifications for interventions that can be built, planted and managed. Green infrastructure design teams typically include planners, ecologists, civil engineers and landscape architects, and as such, work with both ‘hard’ landscape materials (e.g. kerbs, paving, benches, lighting) but also living organisms including people, plants and non-human animals.

Due to the complexity of construction projects, green infrastructure designers often use standardised contracts and frameworks to coordinate objectives with other design professions and client groups. These standardised frameworks are typically published by institutes representing built environment professionals, with examples in the USA, Canada, and Australia. The Plan of Work published by the UK Royal Institute of British Architects (RIBA) is recognised internationally, with clear roles for multiple professional services, providing a 'common language' for the design and development industries [9]. The RIBA Plan of Work has eight key stages, developing incrementally in scale, complexity and detail, enabling design teams to work across scales of space and time. The aim of the Plan of Work is to ensure quality of built work but also that behavioural choices and long-term benefits are considered alongside detailed questions of cost and structure.

The Plan of Work is necessarily interdisciplinary, and as such, only sets out high level or succinct descriptions of factors that should be considered at each stage of a project's progress, alongside outputs that should be used to evaluate compliance and principles for timely project planning. As a consequence, 'overlays' are sometimes produced to show how specific considerations might be addressed at given project stages, for example Building Information Modelling, biosecurity [10] or low carbon building. Within the context of green infrastructure, this creates opportunities for different MIGI strategies to be deployed from bioreceptive designs to spatial configurations and community needs, in a framework that is commonly used by design and client teams, thereby increasing the potential for MIGI principles to be embedded at the earliest stages of a project.

Integrating MIGI design principles into established construction workflows

Whereas standard green infrastructure focuses on the design or management of physical objects or organisms, the distinguishing features of MIGI are the recognition of the role that microbial communities have in ecological systems and the strategies to expose users to the environment (Box 1). As such, it is a truly multi-disciplinary strategy that embeds the assessment of community needs and health promotion programs into the design and construction process. In addition to traditional green infrastructure features (e.g. green roofs and walls), there can be several different manifestations of MIGI. These can include biodiverse foraging habitats to replicate communal and 'hands-on' ancestral habits, living barriers to regulate pollution, vegetation communities selected to optimise MIGI dynamics, and other features that are designed with sociobiological and cultural considerations (e.g. augmenting microbial diversity in children's play areas) [11, 12]. It is envisaged that the development of MIGI is guided by microbial ecology, bioreceptive design and public health research. Furthermore, drawing on the social sciences, MIGI should be designed to promote multisensorial experiences and social inclusivity and serve to procure several important co-benefits, such as strengthening community cohesion and enhanced ecological resilience.

We provide an initial indication of how the RIBA Plan of Work structures the many opportunities for microbial ecologists to collaborate with landscape architects and other relevant disciplines (Table 1), pin-pointing opportunities, risks and actions associated with each stage of work. Successful MIGI will require strategic thinking at the planning stages: many features are essential to sustain plant growth or encourage lifestyle or social behaviour and can be difficult to rectify in retrospect. As such, we emphasise the multiple scales that designers work with throughout a project and incrementally build the level of detail with which designers are able to specify materials and actions. A key difference is where most green infrastructure projects do not consider the role or specification of individual organisms until midway through RIBA (i.e. Stage 3), we suggest initial considerations for the framework to include the impacts that microorganisms have at multiple trophic levels from Stage 1. We also provide a set of key considerations for researchers at each stage from the initial design to the in-use and evaluation (operational and monitoring) phases, and strengthen the possibility of developing a joint framework for researchers, practitioners and local communities to contribute towards a population health strategy.

As design teams become familiar with MIGI aims and objectives, there will be opportunities to develop protocols for delivering MIGI features more effectively and contributing to what should be an optimisation model (i.e. other health co-benefits should also be integrated). The research and publication of a MIGI Design and Intervention Guide should be prioritised, ideally supported by interdisciplinary forums and working groups to ensure that MIGI features are socio-ecologically inclusive and address the full range of technological and social opportunities, as well as addressing emerging biosecurity risks [10].

Conclusion

Here, we suggest that an overlay to the existing industry standards for green infrastructure design will be needed in order to create a means for non-scientists to understand the dynamic complexity and embrace the importance of environmental microbiota for public health. We have identified some relevant disciplinary crossover points, and our proposed framework for integrating Microbiome-Inspired Green Infrastructure into standard practice uses an overlay to the UK’s national standard - RIBA Plan of Works - that can be used as a platform for further development in this area. Our suggestions for a joint framework to meet public health demands and initial considerations for the creation of a MIGI design and intervention guide are foundational. With further collaboration and development, these new integrated approaches could help to deliver the needs of a modern urban environment, whilst including fundamental considerations for the life-sustaining microbial constituents of the natural world.

Table 1: The RIBA Plan of Work overlay.

RIBA work stage	Designer's actions	Microbial ecologist's actions
Stage 0 *Strategic definition*	• Horizon scanning • Engage public health experts and microbial ecologists in design team	• Develop MIGI aims and objectives
Stage 1 *Preparation and brief*	• Landscape assessment • Stakeholder consultation • Agree procurement route	• Ecological assessment • Brief development
Stage 2 *Concept design*	• Strategic landscape planning • Site modelling • Supply chain preparation	• Advise designers on plant and growing medium specification
Stage 3 *Developed design*	• Resolve layout design of MIGI features • Carry out detailed specification of plants • Engage nurseries to begin contract growing	• Consider impacts of aspect, hydrology and cultural uses on microbial habitats • Evaluate project development against aims and objectives
Stage 4 *Technical design*	• Complete landscape specification • Prepare landscape management plan	• Create biosecurity plan for construction phase
Stage 5 *Construction*	• Evaluate contractor's sustainability and biosecurity credentials • Weigh value engineering recommendations against whole-life costs	• Ensure contractors understand MIGI objectives • Monitor works at critical stages, e.g. nursery inspection
Stage 6 *Handover and close out*	• Record 'As Built' information to allow future evaluation	
Stage 7 *In use and evaluation*	• Record species establishment and socio-cultural uses of MIGI features	• Ensure spirit of MIGI aims are not lost by providing training to management team • Update MIGI management plan as needed

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