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Special Issue: Addressing the Great Indoors—
A Transdisciplinary Conversation

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RESEARCH AND THEORY IN HUMAN ECOLOGY

BOOK REVIEW

Research and Theory in Human Ecology

Initiating a Transdisciplinary Conversation to Improve Indoor Ecologies

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Abstract

Indoor spaces have not traditionally been considered the domain of human ecology. They have been the subject of cultural, architectural, and sociological inquiry, and more recently the site at which various pathogenic or toxic encounters may be studied; yet, these concerns have rarely been investigated as part of one unified and codependent ecology. This special issue aims to remedy this dislocation by beginning a conversation between a range of disciplinary perspectives concerned with the indoors. This ambition is not only linked to a desire to articulate and connect multiple interacting variables operative in indoor spaces, but also to address both a number of factors that are increasingly creating indoor environmental conditions that are suboptimal for human habitation, and the broader more-than-human ecosystems in which they are situated. Although certainly not exhaustive in scope, the research presented in this special issue provides an exemplary profile of situated knowledge that must form the basis of future, integrative, transdisciplinary research into indoor ecologies. Spanning design, architecture, social and human ecology, environmental psychology, sociology, mycology, biotechnology, spatial sciences, statistics, engineering, philosophy, and "lay" and experiential knowledge perspectives, this special issue uncovers a number of the challenges and fertile points of overlap across epistemological approaches and areas of concern within the indoors. The goal of this issue is to highlight the points of divergence, and, more crucially, the points of convergence from which a new transdisciplinary approach to indoor research can emerge.

Keywords: great indoors, human ecology, indoor ecology, knowledge integration, transdisciplinary research

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Introduction: The Indoor Biome

The earth is comprised of multiple biomes, habitats that support different forms of life and ecosystems. Today, the most rapidly expanding biome on Earth is the indoor environment. As cities and buildings have expanded to cover the globe in both horizontal and vertical space, they have created new habitats for different species and ecosystems to thrive.

It has been estimated that people in many industrialized regions of the world now spend up to 90% of their lives indoors (Luongo, 2016). As a consequence, it is imperative that an integrated understanding of the composition of indoor environments, what affects them, and how they affect human and ecological health is sought. Yet, very little is known about the indoor ecosystems we inhabit. What is known tends to be confined within disciplinary silos, obfuscating the ways that objects, bodies, structures, and meanings interact and react to create indoor ecologies.

This lack of interaction between different bodies of knowledge is concerning, as research in multiple disciplines is revealing that the confluence of multiple materials in the indoors is central to the creation of suboptimal ecologies. For example, a particular combination of volatile organic compounds emitted from wall paint, antimicrobial chemicals in cleaning products, a dog, and minimal ventilation to ensure temperature control would together produce a very particular indoor biochemical environment that might affect occupants differently if any one of these elements was removed from the system. Consequently, the ways in which indoor environments can cause harm are complex, nonlinear, and relational. As a starting point, one must then recognize that the composition of the indoors depends not only on the entities that reside there, but how they interact and transform over time.

The traditional focus of human ecology has been to tackle complex, "wicked" problems that emerge out of socioecological entanglements (Brown et al., 2010). As Dyball and Newall (2014) proposed, human ecology "has a practical interest in how systems of production, distribution, and consumption might be redesigned, so that the reasonable daily needs of people … might be met without causing harmful impacts" (p. 7). This interest in moving away from the individualization of responsibility for systemic health and environmental sustainability issues to instead focus on how human needs can be met in less harmful ways will be crucial for improving indoor environments. Despite indoor health being central to the inception of human ecology, a focus on the constitution of indoor ecologies has largely been superseded by a focus on the consequences of everyday actions on more macro socioecological issues and planetary health. When Ellen Richards first proposed the concept of human ecology over 100 years ago as a "knowledge of right living," she explicitly addressed the significance of how we live in our indoor environments, and

went on to found Home Economics in the United States (US) (Dyball & Carlsson, 2017). In this special issue we propose a return to the micro and mesoscales of the indoors to ask how we might live well in this expanding biome.

Answering this question in a holistic way requires consideration of a range of perspectives on indoor ecologies, and a transdisciplinary approach to research that seeks to overcome the inherent divide between academic disciplinary knowledge and societal knowledge. While such integrative approaches to research are not mainstream in the academic system and remain an "intellectual, cognitive, communicative, and institutional challenge" (Vilsmaier et al., 2018, p. 170), the call for research that crosses disciplines and links knowledge production to the transformation of complex problems is not new. Influential scholars have addressed the challenge of integrative research over decades (e.g., Freire, 1996; Nicolescu, 2002; Piaget & Wells, 1972) and have provided the grounding for exploring relational thinking on indoor ecologies in this special issue. In particular, the central concern here regards the importance of presenting in-depth case studies and critical reflection on collaboration and collective learning, which often lack in transdisciplinary research (Fam et al., 2018).

Facilitating Transdisciplinary Interaction in this Special Issue

In the interest of initiating a much-needed exchange of knowledge to address suboptimal indoor biomes, this special issue sought to bring together scholars across the natural and social sciences to critically assess and learn from one another's work. Knowledge exchange between disciplines can be critically inhibited not only by exclusive information-sharing platforms, such as journals and conferences, but also by disciplinary conventions for presenting research and measuring the validity of data. Critical reflection on what constitutes "valid data" and whose perspective should be valued is a necessary process in transdisciplinary approaches to inquiry. The very term "data" suggests a positivist epistemology and a politics of evidence associated with "reliability and validity" (Denzin, 2013). A solely positivist perspective rejects intuitive and introspective forms of knowledge, such as interpretations of a comment in an interview, a fragment of a field note, or an anecdote (MacLure, 2013). In relation to transdisciplinary approaches to research into complex problems, Palmer et al. (2018) noted that data have also been attributed with an agency outside of a single methodological approach, standard, or method. This is especially evident in data obtained through interviews, in which the voice of an informant can sometimes speak across and beyond disciplinary theories to which it is assigned. In attempting to draw together a range of perspectives on indoor

ecologies, this special issue includes reference to both qualitative and quantitative data to support the case for transdisciplinarity as a means of improving some of the complex problems emerging in indoor environments.

Transdisciplinary research requires a type of critical reflection in relation to one's own and others' perspectives, values, data, and methodological approaches that inevitably creates challenges. In cases when individuals working within different knowledge systems meet to collectively address an issue, uneven power relations have the potential to emerge. Often, power dynamics come to reflect the dominant modes of knowledge production and marginalization in broader culture; for example, voices of scientists may be elevated above traditional knowledge holders or perspectives based on phenomenological accounts of a situation.

To explicate the transdisciplinary orientation of this special issue, the editors provided authors with detailed guidance for structuring their own contributions and for reviewing alternative disciplinary perspectives. From the outset, the call for papers requested contributions that recognize healthy and sustainable indoor ecosystems as a complex issue. To highlight and begin to transgress disciplinary distinctions, the editors also requested that authors make explicit several elements in their research based on principles of transdisciplinarity. Each author was requested to address the following questions:

- How does your paper offer a contribution to resolving a larger societal problem?
- How is your research participatory or collaborative?
- How does your research transgress disciplinary boundaries?
- How have multiple sources of knowledge from stakeholders and/or disciplinary perspectives sought to be included in your paper?

This protocol was intended to help each author reflect on how their own research might be positioned within knowledge communities beyond their own disciplinary field. In the process, it also provided an opportunity for mutual learning between contributors as well as collaborative research into suboptimal indoor environments. In an attempt to encourage knowledge sharing between contributors, the editors requested lead authors review another manuscript in the special issue from an unfamiliar disciplinary field. This process provided authors with an opportunity to gain insight into alternative perspectives on the problem of indoor ecosystems across fields of inquiry, and ensured that contributions were communicated in language accessible across fields of inquiry. Moreover, this process was instructive in highlighting some of the disciplinary disparities in the framing of indoor environmental health issues, the normative intent of research, the range of methodological approaches adopted, and what constitutes data across fields of inquiry.

To assist authors in reviewing manuscripts beyond their own disciplinary field and convention, they were provided 12 questions to guide their review. In addition to standard questions around the appropriateness of content and length, questions specific to the overarching goal of the special issue were included:

- Has the author included a description of what interdisciplinarity or transdisciplinarity means in the context of their contribution and how it contributes to theory in practice?
- Have authors sought broad societal outcomes in their contribution to new knowledge?
- Is the language used accessible and engaging to multiple audiences across disciplinary fields?

In reviewing the manuscripts, the editors were also aware of the need to respect disciplinary conventions and avoid elevating any method or format for presenting research above others, provided clarity and accessibility were achieved. As a result, papers appear in the conventional scientific format, with an Introduction, Methods, Results, Discussion, and Conclusion, as well as full provision of data from some contributors, where needed. Additionally, a range of social scientific and design-based conventions were included.

This approach to framing the special issue and guiding authors to contribute reflexive and accessible papers resulted in a rich and diverse array of scholarship. Despite the range of disciplinary foci and epistemological approaches presented, a number of salient shared themes emerged across the papers. An exploration of these themes provides an apt starting point to develop a more integrated and systemic understanding of indoor ecologies and indoor environmental health.

Emerging Themes in Indoor Ecology Research

The breadth of papers in this special issue reveal four distinct but intimately entangled themes: (1) the psychological, social, and biophysical health effects of living in polluted indoor spaces; (2) the adaptation of living practices and environments in response to urban planning; (3) the significance of both affective and molecular qualities of indoor air; and (4) climate change and emerging forms of vulnerability associated with decreasing indoor environmental quality. Although these themes certainly do not account for the complete array of current indoor environmental health issues, they cover a significant breadth and depth of some of the most pressing contemporary indoor environmental challenges.

The diversity of perspectives represented across the themes elevate a range of human and nonhuman actors not encapsulated by any single viewpoint—that is, creating a more complex and nuanced picture of the more-than-human ecology of indoor

spaces (Whatmore, 2006). Through these themes, the articles also highlight the interplay between forces acting at micro, meso and macroscales, and the dynamic and potentially reinforcing linkages between them that are determining the composition of indoor environments.

Living in Polluted Indoor Ecosystems

Indoor environments become polluted through numerous sources both internal and external to the indoor space itself. The types of pollutants that amass indoors vary based on geographical factors; for example, urban indoor spaces generally accumulate more emissions from traffic than rural ones, and the types of fuel used in the home, such as smoke fires, produce high indoor emissions (Luongo, 2016). However, there are a number of concerning trends emerging across industrialized nations associated with the proliferation of certain types of consumer products. Notably, research from North American cities is showing that emission rates of certain air pollutants in personal care products are comparable to that of benzene from motor vehicles throughout the day (Coggon et al., 2018), with similar patterns observed in China (Yang et al., 2018).

Often, sources of indoor pollution are invisible or obscured, and individuals must rely on external authorities and their prescribed forms of measurement and instrumentation to provide knowledge about their living spaces. This dependence on the methods currently employed by authorities to produce and certify the evidence of harm is often problematic, as many emerging indoor air pollutants are either not deemed harmful or not measured until well after they have taken effect, despite affected individuals often noticing their presence (Murphy, 2006; Shapiro, 2015). As a result, scientists and citizens are increasingly calling for greater community involvement in the measurement of pollutants to protect themselves and keep the industries behind the emissions accountable (Pritchard & Gabrys, 2016; Regalado, 2017). Accordingly, a number of papers in this special issue explore some of the physical and psychological effects of the uncertainty and lack of control associated with indoor pollution.

Pollution of indoor environments not only affects people through molecular interactions between bodies and toxicants, but also profoundly affects one's sense of existential security and mode of being in the world. Through their qualitative research with residents living in contaminated urban sites across Australia, Connon et al.'s (this issue) paper provides compelling evidence of the extent to which a contaminated home can affect not only the bodies of individuals, but perceptions of security normally associated with home environments. In these cases, a sense of control over one's future is often replaced with "feelings of isolation, threat, insecurity and a sense of powerlessness." Through their attentiveness to the spatial dynamics

of experiences of contamination, the paper reveals that participants altered their practices in numerous subtle yet significant ways to avoid the risk of contamination, some of which included stopping growing vegetables in their gardens, keeping their windows closed, and either stopping using tap water or boiling it for washing dishes, food preparation, and personal care.

Aligned to Connon et al., Wakefield-Rann et al.'s (this issue) paper also demonstrates how individuals change their practices in response to perceived indoor environmental health hazards to protect themselves and their families. Drawing on theories of social practice, this paper presents findings from a qualitative investigation of parents' attempts to create a safe and hygienic home environment for their children. The practices carried out by Sydney parents with children under the age of five reflects a deep sense of uncertainty about what types of household chemicals and "germs" represent the greatest risk to their families. The burden of responsibility for managing families' chemical "body burdens" (Mackendrick, 2014) and pathogenic exposures is compounded by the demands of other household practices that compete for time and, in most cases, fall to mothers to negotiate expediently.

Both Connon et al.'s and Wakefield-Rann et al.'s papers highlight the uncertainty that permeates the landscape of risk within home environments causes significant anxiety, and adds additional cognitive and psychological burdens to everyday life. Also central to both papers is the erosion of agency and control of those dwelling in particular indoor environments. In the case of Connon et al.'s paper, the indoor environments of residents' homes are subject to a history of land-use practices with toxic legacies, as well as the political and corporate will to remediate land. Similarly, the participants in Wakefield-Rann et al.'s paper are limited to acts of "precautionary consumption" (Mackendrick, 2015) to remove toxicants from their homes in the absence of sufficient precautionary regulation against harmful classes of chemicals.

Although the primary attention in these papers is to issues of disempowerment and the inability to control the environment in which one lives, this is not to say the research participants do not exercise agency and strategically adapt their lifestyle practices around the issues they confront. The ways in which individuals and groups make micro-adaptations in the face of systemic forces over which they have limited control is also central to the following theme of urban planning and adaptation.

Urban Planning and Adaptive Indoor Lifestyle Practices

The influence of broad urban landscape transformations on changes in indoor practices and environmental exposures is central to a number of articles in this special issue. As the global population increases and the middle classes grow, urban areas around the world are rapidly expanding and densifying (Desai & Kharas, 2017). The types of agents, priorities, values, and power dynamics that are guiding urban planning are determining, in large part, the form and constitution of indoor environments.

For example, governments and planners influence indoor environments through decisions about vegetation cover, which consequently influences urban biodiversity, temperatures, perceived requirements for air-conditioning, and the types of allergens in the air (Douglas et al., this issue; Mellick Lopes et al., this issue; Stokols, this issue). They also guide decisions about where certain polluting industries can be situated, and subsequent decisions over whether to build residential dwellings on that land (Connon et al., this issue).

Central to questions of urban planning are considerations of who cities and regions are designed for. The way that different types of knowledge, experience, and data are captured and deemed valid plays a key role in shaping landscapes. Communities whose needs have not been considered in such designs must consequently adapt their lifestyle practices onto the structures they have been provided, often resulting in further marginalization (Dooling & Simon, 2012). Scholars such as Whatmore (2006), Franklin (2017), and Maller (2018) have argued that the framing of healthy urban areas in human-centric terms has had detrimental effects not only on the other organisms that occupy cities, but also the humans that rely on their "ecosystem services," such as cooling and clean water from increased vegetation cover. In turn, they advocate for a conceptualization of healthy urban environments as more-than-human in research and policy, and for the importance of transcending disciplinary boundaries to achieve this. Similarly, the articles in this special issue highlight the often subtle transformations that are occurring to dominant styles of dwelling in the modern world that may have been overlooked, but have a profound effect on everyday lives.

In his paper, Stokols presents a broad macropolitical and cultural context currently shaping indoor life in industrialized societies. In doing this, he prompts us to recognize the profound influence of the proliferation of cyber technologies, particularly since the 1980s, on the form and functioning of indoor ecosystems, as well as the urban environments that shape them. He notes that the spatial, temporal, and organizational boundaries associated with residential, educational, occupational, recreational, and commercial settings have become increasingly blurred. In this way, digital communications and virtual communities have since interwoven and coevolved with individuals' place-based environments. With reference to concepts from environmental psychology, Stokols explores how this shift has meant homes are no longer just a refuge from work and a space for family life. Rather, they function as electronic hubs and places where work and a multitude of entertainment options have intruded, or, as Stokols put it, "indoor environments have become increasingly polyfunctional, as their boundaries have been rendered more permeable and fluid by cyber technologies." The changing purposes of indoor environments are exerting pressure on the shape of cities, as cafes and homes become multifunctional offices, and the needs for convenient access to bank branches decreases as more transactions become digital. Similarly, changing use requirements for the indoors alter our

expectations about the level of comfort and other amenities that are provided to enable us to reside inside for prolonged periods of time. Importantly, these additional amenities also often come at a significant cost in terms of the material and energy required to manufacture and run them.

The role of city planning in the ways individuals attempt to create comfortable, protective, and livable home environments is also at the center of Mellick Lopes et al.'s (this issue) paper. The authors note that "[a]s the climate warms, indoor environments facilitated by technical infrastructures of cooling are fast becoming the condition around which urban life is shaped." These factors are compounded by rapidly densifying suburbs, based around a model of urban living that promotes lifestyles carried out in discreet, climate-controlled atmospheres. The promise of air-conditioned indoor spaces has guided city planning and enabled other means of cooling the urban environment, such as increased vegetation cover and free water, to be deprioritized. The negative effects of these decisions are disproportionately experienced by those already economically marginalized, who cannot afford air-conditioning, and do not have the capacity to modify their home environments for cooling due either to poor design or because they do not own their property. These residents adopt practices of "thermal rationing" to balance the competing pressures of comfort and financial sustainability.

A similar set of pressures was felt in the community of the New Ngelepen dome settlement discussed by Yuliar et al. (this issue). Here, people were forcibly displaced by an earthquake near Yogyakarta, Indonesia, and relocated to a purpose-built community of "dome" houses in a style pioneered by the international Domes for the World group. Through their analysis of the settlement grounded in actor–network theory, the authors detail a significant clash between assumptions about interior and exterior lifestyle practices embedded in the building designs and traditional lifestyles, forcing residents to retrofit their domes and adapt their practices.

The analysis presented traces the implications of developing structures that do not respect traditional ways of living and interacting between the indoors and outdoors. The omission of a *tritisan*, an outdoor shelter from sun and rain, and a back doorway from the dome designs meant that important outdoor activities, such as plant cultivation and sheep breeding, which are demarcated and isolated from indoor activates, could not be maintained in a culturally appropriate way. The authors' analysis also reveals that by valuing some actors and uses of space over others in the planning process, many residents' experiences of being in the broader community were diminished. For example, decisions to paint the domes white to reflect sun and keep the indoors cool meant that a large amount of glare was generated, as the close proximity of the buildings and lack of other colors or ornamentations on their white surfaces were not taken into account.

The implications of the values that are embedded in the form of buildings and indoor environments are further borne out in Lee and Wakefield-Rann's (this issue) paper, which examines subtle shifts in how people engage with risk according to archetypal modern apartment lifestyles. With reference to the philosopher Peter Sloterdijk (2016), they examine how from the comfort of an apartment one can achieve daily "resocialization and attainment of worldliness" through a choice of media, and control over the content and dosage of "reality influx" one wishes to absorb. An indoor apartment space allows for content from around the world to enter the apartment cell through various media, while still insulating and providing "immunity," comfort, and distance. As Sloterdijk (2016) argued, this mode of engaging with the world can create a state in which vast quantities of information about potential risks are communicated, which can elicit a type of psychocultural "autoimmune" response. This response may include mental stress that, if not adequately managed, has the potential for adverse effects on individual mental health and the politic as a whole.

In addition to their affective consequences, urban planning decisions also play an important role in the types of pollutants or other health-affecting particulates to which people are exposed indoors. The participants in Connon et al.'s (this issue) study of residents' responses to remediation of the contaminated land on which their homes sit links directly to the ways in which governments and planning authorities have historically restricted or allowed the use and disposal of certain contaminants on land and in water, the way the remediation technologies are selected and residents are engaged in the process (or not), and increasing demand for housing in rapidly densifying urban areas. These combined factors have led to a situation in which residents do not feel safe in their own homes.

Similarly, Wakefield-Rann et al. (this issue) discuss how decisions made by regulators and product manufacturers about the amount and types of chemicals that are allowed in consumer products contribute to both the levels of anxiety that parents feel in relation to their homes, and the actual degree of hazardous material to which they are exposed. Exposure to pollutants in the home is exacerbated by numerous factors that are encouraging people to spend more time indoors. As Stokols suggested, increased digital connectivity and the blurring of work and home spaces are encouraging people in many places to spend more time at home than ever before. Mellick Lopes et al. (this issue) also alerted us to the effects of cities that are designed around infrastructures of cooling that encourage people to spend time in climate-controlled indoor environments, rather than attempting to improve the outdoor thermal amenity.

The geography and design of cities is central to Douglas et al.'s (this issue) paper, which reports on the most comprehensive mapping of the spatial and temporal patterns of aeromycota (airborne fungi) across urban Sydney to date. Their approach of using geographic information system mapping techniques to predict the concentration and

diversity of airborne fungi enables the relationships between building design, urban design, changing climate variables, and fungi exposure levels to be observed. The health effects of inhaled fungal particles can include exacerbation of asthma, allergic rhinitis or sinusitis, hypersensitivity pneumonitis, allergic respiratory ailments, and atopic dermatitis, depending on individual sensitivities and the differing pathogenic properties of the fungi. In drawing out both spatial and other variables that affect the distribution of aeromycota, Douglas et al. demonstrate how the exclusion of certain parameters in city planning can result in certain indoor (and other) health issues being exacerbated. How, and to what extent, indoor air is deemed unhealthy relates to the next theme, which examines more closely how properties of indoor air are defined, understood, and measured.

The Physical and Affective Properties of Indoor Air

Murphy (2006) in her text *Sick Building Syndrome* discussed how the design of office spaces and heating, ventilation, and air-conditioning (HVAC) systems have been informed by definitions of health and harm determined in relation to a narrow set of comfort indicators, such as temperature and humidity, for adult, white, male bodies. These indications and their materialization in office building design have established what she has termed a "regime of perceptibility," which has disabled our capacity to see and measure how different bodies are affected by different elements of the indoor environment, such as chemicals off-gassing from paints and carpets. Murphy and other researchers such as Hoffman (2017) and Wylie et al. (2017) contended that the way we define and measure the properties of air need to be challenged to account for that all potential hazards to all potential bodies.

Mellick Lopes et al. (this issue) remind us that what we now understand as "air-conditioning" refers only to one way of "conditioning" the air based on a particular set of values. They highlight the public health debates in the early twentieth century in which approaches advocating for the circulation of "fresh air" in buildings were pitted against those arguing for the value of climate-control technologies that heated or cooled recirculated air. Like many aspects of home design, the features that are considered essential for human health at particular times directly reflect the way society understands the body, disease and its transmission, and living well, more broadly. For example, as "germ theory" gained cultural traction in Europe, bathrooms and kitchens transformed from being heavily ornamented, multicolored, fabric-adorned spaces, to white, hard, enameled surfaces that could reveal any germ-carrying dirt that may be present (Lupton & Miller, 1996).

Central to twentieth- and twenty-first-century air-conditioning, and design for the indoors more generally, is the emergence of comfort as an important guiding criterion. Shove (2003) argued in her seminal text *Comfort, Cleanliness and Convenience* that like cleanliness, standards of comfort have escalated and become standardized across much of the industrialized world. Mellick Lopes et al. alert

us to the consequences of creating cities in which the indoors is characterized by air-conditioning by emphasizing the implications for energy consumption and on bodies. They contend that air-conditioning is not only further contributing to the warming of the climate, but also creating bodies that are more "sedentary and passive," as they no longer have to work to adjust and acclimatize in a state of air conditioned "thermal monotony" (Mellick Lopes et al., this issue).

Aside from its direct effects on the thermal comfort of occupants, the way indoor air is conditioned also determines what organisms it carries. Douglas et al. (this issue) sensitize us to the crucial relationship between the concentration and composition of indoor bioaerosols (microscopic organisms in the air), and building ventilation types (natural, mechanical, or mixed). The authors note that the interaction between these variables is largely influenced by temporal changes in the inflow of outdoor air, and ventilation requirements associated with thermal conditioning or other indoor environmental quality requirements.

Douglas et al. also highlight that only some aspects of air, such as certain chemical air pollutants and pollens, have been mapped for distribution and diversity in urban settings. Their research into aeromycota mapping adds another layer of insight to our understanding of urban air, which has been largely obscured. By articulating this additional dimension of air through the use of mapping techniques that encapsulate spatial and temporal variables, buildings and their ventilation systems can begin to be designed more appropriately for the requirements of the urban landscape in which they are situated. This addition of aeromycota to air mapping also has potentially significant implications for assisting individuals with self-management of allergies. If provided with readily available information (such as weather data) and an easy way to comprehend their own building ventilation systems, sensitive individuals could limit their exposure.

Aside from the intentional conditioning of indoor air for desirable qualities, such as temperature and freshness, the role of air as a vector of potential hazards was a prominent theme throughout the articles in this issue. Wakefield-Rann et al. (this issue) highlight how the way we are trained to see hazard, or the "regime of perceptibility" we inhabit, determines how we clean our home environments. Normative cleaning regimes were revealed in this paper to be guided by a set of sensory cues and culturally entrained habitual practices that disproportionately sensitize participants to the presence of "germs" over other hazards, such as aerosolized chemicals in cleaning products. The irony of this limiting conception of "clean" and "healthful" indoor atmospheres as germ free is that we add synthetic imitations of cleanliness and freshness in the form of "air fresheners," which are known to contain some of the most hazardous chemicals used in indoor environments (Steinemann et al., 2017).

Lee and Wakefield-Rann's paper provides an important context for the evolution of phenomenological and technoscientific understandings of what air is and how it is experienced in the broadly Western cannon of thought. With reference to Sloterdijk's (2016) contention that air cannot be adequately understood without highlighting the technical changes inflicted on the atmosphere over the course of the last 200 years, readers are provided insight into some of the sociopolitical arrangements that have made certain properties of air culturally and scientifically explicit, and of concern. Sloterdijk (2016) traced developments in "atmospheric terrorism" from the initial uses of gas warfare in World War I, through the industrial-scale extermination camps used in World War II, to gas chambers used sporadically in the US, and radioactive matter atmospherically experienced through nuclear power. These developments, he proposed, have resulted in a "reordering of 'environmental' awareness towards the invisible milieu of waves and rays" (Sloterdijk, 2016, p. 130). Similarly, Sloterdijk (2016) demonstrated how the understanding of air that underpins "atmotechnics" have provided the air-conditioning technology and associated practices that increasingly shape public and private spaces of the twenty-first century. He suggested that various air-conditioning and climate-control technologies have both enabled and testify to the cultural preference for the indoors, in that spaces where identity is constructed and life's activities are carried out—what Sloterdijk (2016) termed "addiction to dwelling" (pp. 169–170)—subsequently extend beyond home to working, shopping, and spectating (i.e., sports and cinema), among other doings.

The negative effects of landscapes shaped according to a preference for comfortable indoor activities are most acutely felt by vulnerable populations. As discussed in the Urban Planning and Adaptive Indoor Lifestyle Practices section above, Mellick Lopes et al. (this issue) detailed how the amplification of "infrastructures of cooling," particularly under a warming climate, have the greatest effect on communities without the means or capacity to access air-conditioning. The following section examines the relationship between climate change, indoor environments, and vulnerability in more detail.

Climate Change and Emerging Forms of Vulnerability

Many of the forms of vulnerability and harm to humans and the environment included in this special issue have been discussed in the literature under the term "slow disaster," as they lack the spectacular, immediate, and explosive qualities that are typically associated with "typical" disasters (Joyner & Orgera, 2013; Morrison, 2017). However, Nixon (2011) and others (O'Lear, 2016) made the persuasive argument that where deliberate actions are taken that have known effects on human health or the environment, such as emitting large quantities of greenhouse gases

or using chemicals that are persistent or bioaccumulative, "violence" is a more appropriate term than "disaster." Note here, Nixon (2011) characterized slow violence as "a violence that occurs gradually and out of sight, a violence of delayed destruction that is dispersed across time and space, an attritional violence that is typically not viewed as violence at all" (p. 2). The papers under this theme in the special issue show how the slow violence of climate change is affecting the evolution of indoor lifestyles in two key ways: first, to maintain comfort and safety in response to new thermal and climatic conditions, and, second, to reduce the effect buildings and lifestyle practices have on the environment.

Douglas et al. (this issue) reported that high average temperatures and high relative humidity favor microbiological growth, therefore, exacerbating urban bioaerosol proliferation, and, consequently, the vulnerability of those who experience allergies. At a far greater scale, Stokols reminds us that nearly half the world's population lives within 150 km (93 mi) of a coast and upwards of 200 million people reside near shorelines, the majority of which will be forced to endure involuntary migration caused by extreme weather events, depriving them of the physical and existential security offered by the indoors. Increased forced migration also raises questions about how people will be resettled and new indoor environments created, according to the physical, cultural, and economic needs of displaced populations.

Although not a climatic event, Yuliar et al.'s (this issue) study of post-earthquake community resettlement in Yogyakarta, Indonesia, provided an instructive example and cautionary tale of the implications of how indoor lifestyle needs and practices are considered in post-disaster resettlement. The particular agents that were engaged to contribute to the design of the new settlement intended to house displaced communities precipitated the creation of indoor and exterior spaces that failed to meet the needs of residents. The discussions between architects, funding bodies, and local government officials highlighted competing design priorities, with the desire for buildings that not only "respond to the physical environment," but also to the cultural needs and aesthetics of the community. The structures that emerged did not meet community needs in several important ways, requiring residents to retrofit, and ultimately abandon, previous aspects of their lifestyles. The politics around how settlements for displaced populations are structured for the perceived physical, cultural, and aesthetic needs of communities has endured in urban studies and geography since at least the 1950s (see Young & Wilmott, 1957; Zukin, 2009). However, this debate will take on new and potentially more urgent dimensions, as forced migration due to extreme climatic events increases. In this context, the tensions between the ways communities value and use indoor spaces, and the preferences of international engineers and architects could become more common. This example also reemphasizes the necessity of transdisciplinary approaches to research and intervention, which does not prioritize technical and scientific ways of knowing over traditional, or place-based, knowledge.

Simultaneously, ways of living indoors are changing in an attempt to reduce the emissions they also produce. Stokols notes that built environments generate a disproportionately high percentage of carbon emissions worldwide. Indoor ecosystems will consequently be challenged to adapt to prevent the exacerbation of climate change by adopting renewable materials and energy, and reducing resource consumption. As Mellick Lopes et al. (this issue) demonstrate, some individuals and communities have more constraints imposed by urban design and economic position to improve their own levels of thermal comfort or retrofit their dwellings to reduce their contribution to greenhouse gas emissions.

In cases when individuals and communities have been empowered to adapt their dwellings to enable low carbon lifestyles, one unforeseen consequence has been the alteration of the chemical and microbial environments within buildings. The sealing of doors and windows to reduce indoor–outdoor airflow and consequent energy loss can have the effect of trapping hazardous chemicals and pollutants indoors, as well as reducing the flow of outdoor microbes indoors; both of which are linked to a range of health conditions (Hamilton et al., 2015; Wakefield-Rann et al., 2018). A narrow framing of the desirable attributes of air around carbon can, therefore, mean that other crucial factors that affect human health and the environment have not only been excluded, but also exacerbated by their omission.

Importantly, the papers in this special issue have highlighted many of the ways that people become vulnerable as a result of the composition of, and forces acting on, indoor environments: Yuliar et al. illustrate how individuals can be forced to change their indoor lifestyle practices in undesirable ways if resettlement housing does not meet their cultural and physical needs, while Connon et al. show us how disempowering the contamination of one's home with hazardous pollutants can be, and how disruptions to supposedly safe and protective home spaces affect one's sense of being and security in the world. Similarly, Wakefield-Rann et al. demonstrate how the uncertainty that surrounds pathogens and toxicants in the home environment causes anxiety in parents and leads to maladaptive practices, which often make individuals more vulnerable to harmful exposures. In all of these cases, the ways in which indoor environmental health has been framed have influenced the actions that have, or have not, been taken. The following section draws on the different ways that papers in this special issue have understood the role of spatial arrangements, and metaphors in constructing indoor environments and certain modes of being within them.

A New Spatial Philosophy for Indoor Ecological Research

One of the most potentially transformative offerings from the papers in this special issue is an indication of how the psychological, cultural, and scientific conceptualizations of the indoor spaces in which we dwell shape both culture and broader ecological systems. Both Stokols, and Lee and Wakefield-Rann offer compelling characterizations of the implications of co-isolated living in modern societies, which are simultaneously hyperconnected and insulated. The metaphorical characterization of these connected yet isolated indoor worlds has been described respectively by Stokols as "cocoons," and by Lee and Wakefield-Rann (through Sloterdijk, 2016) as "foams." The analysis offered in both papers explores how one's relationship to dwelling mediates their relationships with the rest of the world. As Stokols notes, the way that digitized homes permit individuals to conduct all manner of activities from inside—from ordering groceries, to working, banking, studying, receiving news updates, engaging with friends, and consuming entertainment—encourages a form of residential cocooning. Stokols aptly characterizes these spaces as "real–virtual mesosystems," in which connections between a particular physical space, and the virtual places accessed from there, meet. He argues that this restructuring of indoor settings and our increased access to, and control over, the information one receives has altered the very fabric of society and daily life.

Lee and Wakefield-Rann trace a similar set of connections, with reference to Sloterdijk's (2016) analysis of the key advent of the telephone for indoor life, which he proposed offered a two-way channel of connecting the apartment dweller linking the domestic interior with the "real" world outside, putting each into a "state of simultaneity" (p. 555) with the other. Essentially, he argued that modern apartment lifestyles, initially supported by the telephone, represent a significant shift from how communication was conducted within the home in the premodern era, where most interactions related to the immediate locality were generally private and with family, and where the sender of all interesting messages beyond these confines was God.

These insights into the transformation of indoor living experiences through telecommunication and cyber technologies is extended by Connon et al., who demonstrate how this spatial and conceptual alteration of dwelling is also changing our relationship with risk. Connon et al. employ the notion of "lifescape" to explore this intersection between individual psychological, physical, and socioeconomic states with the specific material and social environmental contexts in which they operate. Through their findings, they emphasize how the indoor environment is associated with a sense of personal control, as it provides a secure base for identity construction and freedom from public surveillance. Additionally, they stress the

cultural significance of having a home in particular societies, and the form of existential security and "grounding" this brings, particularly in places with histories of colonialism.

These conceptualizations of space and dwelling, in terms of both what is and ought to be, have implications for how transdisciplinary research is conducted into the future, as the framing of a problem informs the conceptual frameworks and methodological approaches used to understand scientific and societal problems. In this case, framing not only refers to literal descriptions of problems, but also the metaphors we invoke to understand them. For example, Lee and Wakefield-Rann draw on Sloterdijk to demonstrate the power of spatial metaphors by contrasting a conception of our society as a "network" that brings to mind linear connections between nodes in simple geometric space, or as a "foam," which describes the architectural and social situation of simultaneous enclosure and spatial extension. The authors propose Sloterdijk's psychologically and architecturally informed interpretation of human psychosocial space as foam may allow for an account of the complex interweaving of physical and psychic space, which other spatial metaphors may not.

Moving Forward

The rapid growth of the indoor biome is a result of unprecedented material and atmospheric habitat engineering by humans, based on our perceived needs and desires. The papers in this special issue have demonstrated that, in addition to providing shelter and comfort, indoor environments can represent atmospheres permeated by hazard and insecurity for when human needs are miscalculated or inadequately provided for.

This special issue has started a conversation about what is, and ought to be, noticed, measured, and valued in indoor environments from different perspectives, including design, architecture, social ecology, environmental psychology, sociology, mycology, biotechnology, spatial sciences, statistics, engineering, philosophy, and lay or experiential viewpoints. In highlighting these diverse perspectives, values, and ways of knowing, the cases presented in this issue demonstrate how certain forms of action are made possible, or obfuscated, depending on how a problem is defined, and where the surrounding boundaries are drawn. By bringing these diverse perspectives into conversation with one another, such margins of mutual understanding can begin to expand and become adequately nuanced to guide action across multiple social scales.

The exchange across heterogenous and often disparate and disconnected disciplinary fields facilitated by this special issue has also drawn attention to an array of essential nonhuman participants in the construction and experience of the indoors as more-than-human environments. Some important nonhumans that exert agency in indoor

ecologies include the air (as carrier of microbes, fungus, chemical toxicants, and heat, among other qualities), chemical toxicants (in consumer products and contaminated land and air), microbial and fungal life, natural disasters (e.g., earthquakes and climatic events), buildings and urban environments (such as homes, offices, and suburbs), furniture and other indoor products, and contaminated soil and water, among many others.

In addition to articulating some of the diversity of more-than-human indoor worlds, this special issue has provided insights into the challenges and value of transdisciplinary research and collaboration. The articles included represent often profoundly divergent epistemological approaches to research, yet many points of convergence could easily be found when presented together under the overarching theme of indoor environments. In addition, the research in the special issue traverses a range of cultural and geographic contexts across scales, from micro-interactions in the home, to macroclimatic events that affect all organisms and ecosystems.

By elevating the perspectives and experiences of those affected by the decision-making that shapes indoor ecosystems, the articles in this special issue have begun to give voice to some of the humans, and nonhumans, that have previously been excluded from planning, design, and research. This special issue has established a dialogue upon which researchers across disciplines can continue to reflexively build a shared language and shared understandings of the multiple actors, interests, and livelihoods at stake in indoor environments. More importantly, this special issue represents a necessary first step for a transdisciplinary collaboration between researchers, policy-makers, and communities to begin to transform "the great indoors" into a biome that can sustain life into the future.

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The Changing Morphology of Indoor Ecosystems in the Twenty-first Century Driven by Technological, Climatic, and Sociodemographic Forces

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Abstract

The majority of humans reside in urban regions and spend most of their time in indoor environments such as residential, educational, occupational, transportation, and health-care facilities. Interior settings affect occupants' health and behavior through their design, and chemical, microbial, and social features. The initial portion of this paper describes ecological psychologists' conceptions of indoor environments as self-contained and distinctly bounded ecobehavioral systems, with evidence for the behavioral and health effects of homes, workplaces, and other kinds of indoor ecosystems cited. The ensuing sections examine contemporary changes in the structure and functioning of indoor ecosystems propelled by the digitalization of society, global climate change, and sociodemographic shifts toward population aging, income inequality, and anti-immigrant views in many countries. Transdisciplinary action research is needed to understand and manage rapid changes in indoor ecosystems, as evidenced by the increasing permeability of their spatial and temporal boundaries, modifications of their structural features, and shifts in the distribution of certain categories of settings within host communities. Effective collaboration among academic and nonacademic partners spanning diverse fields and multiple environmental scales is likewise essential for developing broad-gauged solutions to enhance the healthfulness and sustainability of indoor ecosystems as they continue to evolve in future years.

Keywords: changing structure prevalence of indoor behavior settings, cybersphere, global climate change, sociodemographic trends, transdisciplinary action research

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Overview

Macrosocietal conceptions of human and social ecology have given relatively little attention to the structure and functioning of indoor ecosystems. One branch of ecological science that has focused on people's transactions with their interior environments is ecological–environmental psychology. Indoor environments are proximal to individuals' everyday behavior and experiences, so it is unsurprising that ecologically oriented psychologists have examined several features of indoor ecosystems in their research. Psychologists Roger Barker (1968) and Urie Bronfenbrenner (1979) have played prominent roles in studying people's transactions with their immediate behavior settings, such as homes, workplaces, schools, and health-care environments. Yet, their conceptions of indoor ecosystems have focused more on the existing characteristics and conditions of settings themselves (e.g., the roles and resources available to current and prospective members of settings) than on their evolutionary structural changes over time.

The Anthropocene epoch of Earth history spanning the twentieth and twenty-first centuries has spawned rapid and substantial changes in the structure and functioning of human environments (Steffen et al., 2015). This paper focuses on the changing morphology of indoor ecosystems during the early twenty-first century as a consequence of powerful technological, climatic, and sociodemographic forces. The proposed conceptualization of indoor ecosystem morphology and change draws on existing empirical evidence for these very forces, which are expected to result in accelerated changes in the structure and prevalence of certain categories of interior space. However, this paper does not present new primary data documenting the changes in those settings projected to occur in the coming decades. Rather, it offers a theoretical and programmatic analysis of important yet previously neglected questions for future study about the changing morphology of indoor ecosystems.

Developing a more complete understanding of how indoor human environments are being reshaped by macrolevel societal forces necessarily requires a multiscale, transdisciplinary analysis that brings together microlevel studies of people's relationships with their everyday local environments; it also considers the diverse array of community, societal, and global forces that are reconfiguring their immediate local surroundings (Stokols, 2018). Transdisciplinarity is a form of scholarly inquiry that integrates concepts and methods from diverse fields to create novel conceptual frameworks and multimethod approaches for understanding scientific and societal problems (cf. Rosenfield, 1992).

Future studies of the changing morphology of indoor ecosystems will require guidance, especially from translational forms of transdisciplinary research—notably, integrative research spanning multiple fields that seeks not only to better understand complex scientific and societal problems, but also to translate empirical findings from

rigorous research into practical strategies (e.g., new environmental design, urban planning, and public policy innovations) to ameliorate and ultimately resolve those problems. Prior writings have referred to this translational form of transdisciplinary scholarship and practice as "transdisciplinary action research" (Stokols, 2006), strongly rooted in Kurt Lewin's (1951) dictum that "there is nothing so practical as a good theory" (p. 169). The proposed analysis of morphological change in indoor ecosystems is intended to serve not only as a framework for future transdisciplinary scholarship, but also a basis for devising evidence-based strategies to better manage environmental change and enhance rather than hinder human behavior, health, and the sustainability of our surroundings. As a case in point, the projected losses of buildings situated near shorelines caused by increasing sea level rise in the coming years call for new environmental planning and public policy solutions that consider anticipated migratory patterns and the needs of growing numbers of climate refugees. Those solutions to complex environmental and societal problems can only be developed through action-oriented collaborations among academic and nonacademic partners bridging multiple disciplines and fields.

What follows is a brief summary of the concepts and methods developed by ecological and environmental psychologists for understanding people's relationships with their everyday local environments. Subsequent sections identify key facets of indoor ecosystem morphology and the technological, environmental, and sociodemographic forces that are altering the structure and prevalence of various kinds of indoor settings. The concluding portion of this article considers promising directions for future transdisciplinary action research on current and projected changes in our indoor surroundings.

Ecological Research on People's Interactions With Their Indoor Environments

Studies of time use in several countries show that people spend the largest portion of their hours each day and over their lifetimes indoors (National Research Council Committee on Indoor Pollutants, 1981; Szalai, 1972). For example, the National Human Activity Pattern Survey of United States (US) residents found that Americans spend on average 87% of their time each day in buildings and 6% in an enclosed vehicle (Klepeis et al., 2001). Worldwide, more people are spending more time in indoor settings, as the rate of urbanization continues to climb from 54.5% of humans living in cities with at least a half million residents in 2016, to 60% by 2030 (United Nations [UN] Department of Economic and Social Affairs, 2016). The substantial number of hours people spend in residential, work, health-care, commercial, and transportation facilities amplifies whatever positive or negative effects those settings may have on their health, behavior, and development. For example, levels of indoor air pollution are often several times greater in enclosed settings than in

outside spaces (Environmental Protection Agency, 2018; Laville, 2018); the longer people are exposed to indoor pollutants, the more negative their effects on behavior and well-being. Further, the microbial profiles of buildings have been found to significantly affect occupants' health (National Academies of Sciences, Engineering, and Medicine, 2017). Also, socially supportive residential and educational settings that are predictable rather than chaotic can have a positive influence on members' developmental outcomes (Evans, 2004; Wachs & Gruen, 1982).

The pervasive impact of both indoor and outdoor environments on health and behavior is a central concern of human ecology (Borden, 2014; Dyball & Newell, 2015; Steiner, 2002; Young, 1983). Yet, many research programs in the fields of human and social ecology have given relatively little attention to people's relationships with their indoor surrounds. Notably, the Chicago School of Human Ecology, which emerged in the 1920s, focused mainly on the spatial distribution of population health and behavioral disorders in urban communities (Hawley, 1950; Park et al., 1925), but failed to address the effects of indoor environments on residents' adaptation to their urban milieu. Similarly, more recent conceptions of human and social ecology emphasize macrolevel analyses of societal relations to nature within regional and national contexts, as they affect global sustainability rather than individuals' transactions with indoor environments themselves. For example, see the conceptual and empirical contributions of the Stockholm, Frankfurt, Vienna, and Vermont schools of social ecology (Becker & Jahn, 2006; Berkes et al., 2003; Bookchin, 2005; Haberl et al., 2016; Hummel et al., 2017).

Conversely, ecological analyses of individuals' and groups' experiences with their everyday proximal environments (rather than society–nature relations viewed at more molar levels) have explicitly examined the influence of indoor settings on occupants. In Roger Barker's (1968) conceptualization of ecological psychology, the principal unit of analysis is the behavior setting—an ecobehavioral system comprised of a physical location, or "milieu," and recurring patterns of individual and organizational behavior that comprise the "behavioral program" of that setting. Behavior settings have both spatial and temporal boundaries, which are located in specific places where recurring activities take place predictably over specified periods. For example, a college course taught in a university lecture hall is a behavior setting that occurs reliably on certain days and at designated times during an academic term. Similarly, the members of a church congregation may attend services every Sunday morning at their place of worship.

A core assumption of ecological psychology is that the physical milieu and behavioral program of a setting are in a dynamic, equilibrium-seeking relationship with each other. Barker (1968) found that understaffed settings, which have fewer members than the number ideally needed to maintain the activities therein, are less selective about whom they admit and from whom they evoke higher levels of commitment. Examples of understaffed settings are events in churches with

small congregations or sports events at small high schools that have relatively few participants (e.g., a basketball game in which a school's team has five to six rather than ten or more players). In Barker and Gump's (1964) study of high schools in Kansas, smaller schools whose extracurricular settings (such as the editorial office of a school newspaper, or the orchestra, cheerleading and sports teams) were chronically understaffed exerted stronger pressures on students to participate in after-school activities and take on more leadership roles compared to larger schools. These understaffed settings can have long-term effects on the development of students' personalities and leadership skills. In another study of church congregations, the members of small churches on average donated more money at Sunday worship services than those belonging to larger congregations (Wicker, 1969), hence, reflecting higher levels of commitment among the members of understaffed settings.

Unlike understaffed or adequately staffed settings, overstaffed behavior settings have more members and new applicants than are ideally needed to maintain its core functions. The larger the number of applicants seeking membership in a setting (e.g., joining an orchestra, being hired by a new company, or enrolling in a college course), the more stringent the eligibility requirements to join (Wicker et al., 1972). For example, college courses that are highly sought after by students typically manage excess enrollment demand by placing some individuals on a waiting list to ensure the number of class members does not exceed the maximum occupancy of a lecture hall and available instructional resources.

From the vantage point of ecological psychology, behavior settings are the "building blocks" of communities situated within larger geographic regions. Mapping the number and diversity of settings in a city or town affords insights about the social roles available to the members of a population, and the pressures they are under to participate actively in community organizations. Barker and Schoggen (1973) developed methods for surveying the total stock of public behavior settings in a community based on Barker's (1968) "K-21" scales for identifying individual settings in terms of their distinct spatial–temporal boundaries, membership rosters, and core functions (Wicker, 1979). By mapping the distribution of various categories of behavior settings in a region (e.g., recreational settings for adolescent and elderly residents), important features of a community as a whole can be discerned, such as how well it supports the needs and activities of particular subgroups in a population.

Urie Bronfenbrenner's (1979) ecological model of human development also emphasizes the substantial influence of individuals' daily activity settings on their social, psychological, and physical well-being. Homes, classrooms, day-care facilities, and workplaces, which often contain multiple behavior settings, are referred to as "microsystems" in Bronfenbrenner's terminology. His model focuses on both the separate and combined influence of multiple, interconnected microsystems on individuals' social and intellectual development, wherein the connections between distinct microsystems (e.g., a child's home and school settings) constitute

a person's "mesosystems" and "exosystems." In Bronfenbrenner's (1979) model, mesosystems are composed of "two or more settings in which the developing person actively participates (such as for a child, the connections between home, school, and neighborhood peer group; for an adult, among family, work and social life)" (p. 25), whereas exosystems incorporate "one or more settings that do not involve the developing person as an active participant, but in which events occur that affect, or are affected by, what happens in the setting containing the developing person" (p. 25). Examples of exosystems in the case of a young child are his or her parent's place of work and network of friends. Bronfenbrenner (1979) further posited that a person's micro, meso, and exosystems are embedded within the broader community context of the "macrosystem," which encompasses cultural belief systems, and both economic and political circumstances that are pervasive in a society and influence its smaller scale settings. He also introduced the term "chronosystem" to refer to the cumulative developmental influence of a person's micro, meso, exo, and macrosystems over a particular life stage or historical period (Bronfenbrenner, 1994).

Together, Barker's and Bronfenbrenner's ecological models address the influence of people's micro, meso, and macroscale surroundings on behavior and well-being. Their analyses provide both a conceptual bridge between microscale studies of individuals' reactions to local stimuli and environmental conditions—for example, research in environmental psychology on the health effects of exposure to residential crowding, school noise, information overload at work, and indoor or outdoor nature (Cohen et al., 1986; Gifford, 2014; Misra & Stokols, 2012; Wells & Evans, 2003)—and broader-gauged theories of human and social ecology that focus on the interrelations between populations, societies, and the biosphere. Barker's and Bronfenbrenner's ecological models give more explicit attention to the behavioral and health influence of micro and mesoscale ecosystems, relative to macrosocietal theories of human and social ecology. Moreover, many of the settings examined in Barker's and Bronfenbrenner's studies are grounded in indoor environments such as homes, classrooms, and occupational and health-care facilities. Any effort to trace the separate and combined effects of these indoor ecobehavioral systems on members' routine activities and well-being requires that the spatial and temporal coordinates of particular settings be clearly specified.

Dimensions of Change in Contemporary Indoor Environments

When Barker and Bronfenbrenner were writing in the second half of the twentieth century, the boundaries and structure of people's everyday environments were largely presumed to be stable and distinct. Accordingly, Barker devised on his K-21 assessment criteria to demarcate the unique spatial, temporal, and organizational

boundaries of nonoverlapping behavior settings. However, in the early twenty-first century, rapid technological, environmental, and sociodemographic shifts began to challenge and blur the previously distinct boundaries surrounding people's indoor ecosystems. These dramatic contemporary changes include the digital revolution and emergence of the cybersphere from the 1980s onward, climate change and the substantial threats it poses to global sustainability, and sociodemographic shifts including population aging, unabated ethnic and international conflict, and the rise of nativism, nationalism, and extreme socioeconomic inequality in many parts of the world.

The ensuing discussion traces some of the recent and anticipated effects of cyber technologies, climate change, and sociodemographic forces on the morphology of indoor ecosystems. Three types of change in environmental morphology are considered: the blurring of spatial, temporal, and organizational boundaries demarcating particular indoor settings; modification of the physical features and social functions of indoor environments; and shifts in the prevalence and distribution of certain categories of indoor settings in host communities, which are likely to continue and accelerate in the coming years. The concluding section examines the broader implications of these structural changes in indoor environments for personal and collective well-being, societal cohesion, and long-term sustainability of the global ecosystem. Looking ahead, broad-gauged transdisciplinary action-research strategies will be essential for better understanding and managing complex changes in indoor ecosystems, and their pervasive effects on personal, societal, and global well-being.

Effects of Cyber Technologies on the Form and Functioning of Indoor Ecosystems

The discovery and rapid deployment of digital information and communications technologies (ICTs) from the late twentieth century onward have substantially changed how people interact with their indoor built environments. The communication links between separate computers through the Internet (pioneered in the 1970s) and the advanced ICTs that followed during the 1980s and 1990s (including Wi-Fi-enabled smartphones and computers, web browsers and search engines, social media, GPS navigation, augmented and virtual reality [AR, VR], artificial intelligence [AI], robotics, the sharing economy, cryptocurrencies, and the Internet of Things) are all part of today's vibrant and multifaceted cybersphere (Stokols, 2018). The digital communications and virtual communities encompassed by the cybersphere (e.g., email and text messaging, online classrooms, bookstores, social media and gaming sites, and scientific collaboratories) are now interwoven with individuals' place-based environments and exert as profound an influence on a person's day-to-day activities, social behavior, and well-being as one's physical (non-virtual) surroundings.

Individuals' electronic communications with others and their participation in virtual settings always occur within a particular place-based or "real" environment. These real–virtual environment linkages constitute "R–V mesosystems" in which a physical place is digitally connected to one or more virtual settings. Whereas Bronfenbrenner's original concept of the mesosystem denoted the links between two or more "real" environments (e.g., a child's home and school), R–V mesosytems are defined by the connections between a particular physical (or real) place, and the virtual transactions and settings that are accessed electronically by occupants located therein (Stokols, 2018). The digital links between real and virtual settings can be *complementary*—as when a professor shares online resources with students in a classroom to reinforce key points covered in lecture—or they can be *conflicted*, such as when the behavioral programs of the real and virtual settings contradict each other (e.g., employees checking social media at a workplace are reprimanded by their supervisor for wasting time rather than concentrating on work assignments).

The proliferation of cyber technologies from the 1980s to now has wrought tremendous changes in the form and functioning of people's indoor ecosystems. First, the spatial, temporal, and organizational boundaries associated with residential, educational, occupational, recreational, and commercial settings have become more fluid and less distinct. For example, college courses and work environments are no longer restricted by rigid geographic and temporal boundaries. With the emergence of massive open online courses (MOOCs), thousands of students from around the world can enroll in online seminars, participate in digital discussion groups, and complete course requirements at their own pace without having to attend lectures at specified times in classrooms on a particular campus. Also, the members of work teams and organizations located in different places and time zones can collaborate with each other in real time using online meeting tools such as "GoToMeeting." Individuals can even find friends and romantic partners online through social media (e.g., Facebook, Tinder, and Instagram, among others) without having to meet each other first in a shared physical location such as a restaurant, nightclub, or lounge.

In addition to blurring the spatial, temporal, and organizational boundaries of indoor ecosystems such as educational, work, and recreational settings, the emergence of the cybersphere has increased the polyfunctionality of place-based behavior settings (Stokols et al., 2009). Homes are no longer simply a refuge from work and other non-domestic activities, but now function as electronic hubs for accessing information and entertainment, and performing parental and work-related roles. Employees can telecommute to their corporate offices through computers, and avoid rush-hour traffic to and from work while carrying out their domestic and occupational activities at home. Likewise, many workplaces now incorporate restorative and home-like features, such as child-care facilities, showers, exercise facilities, and meditation rooms for employees. Other cyber technologies such as VR make it possible to enfold a highly immersive virtual environment into one's

immediate physical setting where such simulations are viewed (cf. Stokols, 2018). Across many different realms of everyday life, indoor environments have become increasingly polyfunctional, as their boundaries have been rendered more permeable and fluid by cyber technologies.

The incorporation of ICTs into our built environments has also altered the form and distribution of indoor ecosystems in communities. Today's residential, educational, commercial, health-care, and work environments must be equipped with Ethernet or Wi-Fi connections to the Internet. Many cafés and restaurants now install computer-friendly work areas enabling customers to go online and complete digital tasks while having a meal or ordering beverages. Automated teller machines (ATMs) and online retailers such as Amazon, Netflix, and eBay have also replaced or necessitated smaller brick-and-mortar banking facilities, movie theaters, and department stores in many cities. Similarly, the proliferation of online news sources such as BuzzFeed, Huffington Post, and many others has led to the constriction and, in some cases, the demise of print newspapers and editorial offices.

Effects of Global Climate Change and Sustainability Threats on Indoor Ecosystems

Global climate change has been driven by society's excessive reliance on fossil fuels and concurrent spikes in atmospheric greenhouse gas (GHG) emissions triggered by the Industrial Revolution in the eighteenth and nineteenth centuries, and magnified by the Great Acceleration of economic and urban development following World War II (Steffen et al., 2015). The dramatic elevations of carbon dioxide (CO_2) concentrations in terrestrial and marine ecosystems observed since 1950 are unprecedented in over 800,000 years, based on stratigraphic analyses of CO_2 bubbles trapped in polar ice core samples (Intergovernmental Panel on Climate Change, 2015). The steady accumulation of atmospheric GHGs has warmed the planet and unleashed multiple threats to global sustainability. This includes glacial melting, rising sea levels, ocean acidification, biodiversity loss, extreme weather events, as well as regional and international conflicts over increasingly scarce water and food supplies (DiMento & Doughman, 2014; Sachs, 2015).

The sustainability challenges spawned by the Anthropocene epoch (marked by widespread human-caused planetary change) are imposing stringent constraints on the location, physical features, and social organization of indoor ecosystems. For example, built environments situated in areas most vulnerable to the near-term effects of climate change (e.g., residences located along shorelines, on low-lying islands, in estuaries, and arid regions) will disappear by the end of this century due to sea level rise, flooding, and desertification. Today, nearly half the world's population lives within 150 km (93 mi) of a coast, and upwards of 200 million people reside near shorelines (Woods Hole Oceanographic Institution, 2018). Most

will be forced to endure involuntary migration caused by extreme weather events and rising tides. Impoverished groups living in climate-sensitive regions will be affected most severely by these calamitous events, and will have no choice but to flee their homes, joining the growing ranks of climate refugees worldwide (Biermann & Boas, 2010). These events can be expected to intensify cross-national conflicts about which countries are able and willing to accommodate growing numbers of displaced individuals and asylum seekers (cf. DiMento & Doughman, 2014).

Indoor ecosystems less immediately threatened by the ravages of climate change will be challenged to become more sustainable and self-sufficient by adopting renewable (e.g., solar) energy technologies and resource conservation strategies (such as participation in community recycling programs). Homes and workplaces will come to rely more heavily on local decentralized technologies such as urban farming, water capture, and solar energy units that can operate "off-grid," independent of large-scale agricultural, water distribution, and electrical power systems (Despommier, 2010; Tomlinson et al., 2015). However, greater independence of indoor ecosystems from centralized civil infrastructures can help fortify community resilience, especially during times of regional resource shortages and intermittencies.

Currently, built environments generate a substantial portion of carbon emissions worldwide, accounting for nearly 40% of CO_2 produced in the US alone (Gardner & Stern, 2008). As such, the owners and occupants of indoor settings will face increasing pressures to reduce their carbon footprints through ecological design strategies (Van der Ryn & Cowan, 2007), while urban dwellings will become more compact and densely concentrated to improve energy efficiency. One example of an ecological accounting system that encourages "green design" (e.g., through the use of local, nontoxic construction materials, recycling and waste reduction, improved indoor environmental quality, and management) is the US Green Building Council's (2018) Leadership in Energy and Environmental Design (LEED) Program. Such evaluations of buildings have proven to be effective in curtailing adverse environmental effects of public and corporate facilities. LEED-certified buildings have 34% lower CO_2 emissions, and consume 25% less energy and 11% less water than comparable non-LEED facilities (US Green Building Council, 2017). Improvements in the design of indoor ecosystems will continue to be at the forefront of future efforts to enhance global sustainability.

Influence of Sociodemographic Forces on the Form and Prevalence of Indoor Ecosystems

In conjunction with global trends toward digitalization and planetary warming, sociodemographic forces also are reshaping the form and distribution of many built environments. Population aging in several countries is prompting greater investment in and prevalence of assisted living environments for the elderly, as well as inpatient and outpatient health-care settings. Further, to enable older persons to remain in

their own dwellings for as long as possible before transitioning to assisted living arrangements, there will be a growing need to retrofit existing stocks of residential settings with universal design features as people age. Future environmental design and planning strategies to support older adults' desire to live independently and "age in place" in the comfort of their own dwellings can benefit by adopting an ecosystem approach that combines indoor universal design features with outdoor affordances, such as proximity to neighborhood transit lines and retail services. Achieving these ecologically grounded solutions to better accommodate the housing needs of an aging population calls for transdisciplinary action research strategies to sustain close collaboration among environmental designers, urban planners, gerontologists, elected officials, and community stakeholders (cf. Brown et al., 2010).

Another sociodemographic trend that is reshaping the form and prevalence of indoor ecosystems is the rising tide of intolerance toward minority groups and "outsiders" now evident in many countries. The recent surge of nationalism and anti-immigrant sentiments around the globe (e.g., the "America First" and "Brexit" movements in the US and the United Kingdom, respectively) has fueled a burgeoning refugee crisis worldwide, starkly evident now in the Middle East, portions of Africa, and the Mexico–US border. The victims of racism and xenophobic nationalism have been forced into nomadic, migratory lifestyles in lieu of secure and stable living conditions, while refugee camps offering transitory shelter and minimal amenities have sprung up in conflict zones. Interethnic hostilities and cross-national immigration policies, together with the immediate climate change dangers that especially threaten impoverished, minority, and homeless people, have only exacerbated the current refugee crisis (Chakalian, 2018; DiMento & Doughman, 2014). Further aggravating these societal and public health dilemmas are the extreme levels of socioeconomic inequality that exist throughout the world (Piketty, 2014; Sassen, 2014). To counter these interlinked crises of poverty, persecution, inequality, homelessness, and refugee status, new forms of modular semipermanent housing (i.e., portable, compact, hygienic, secure, and affordable dwellings) must be constructed and made available to vulnerable families and ethnic groups in the coming years.

In the case of more affluent cyber-enabled environments, changes in indoor settings sparked by the rise of the Internet and other cyber technologies have modified individuals' behavior and societal functioning in myriad ways. Digitized homes permit residents to order groceries, perform work, manage finances, take courses, consult news media, watch movies, and interact with friends online without ever having to leave the confines of their homes. These trends toward residential "cocooning" may increase separation and polarization among the members of diverse groups that reside in a community. The more time individuals spend alone or with like others in their homes and the fewer opportunities they have to interact with dissimilar others, the greater the potential for societal fragmentation, "narrowcasting" of information and communication sources, and loss of the public sphere in favor of solipsistic individualism pursued within privatized settings.

Looking Ahead

The emergence of the cybersphere, sustainability challenges of the Anthropocene, and contemporary sociodemographic trends have together radically reshaped the form, functioning, and distribution of indoor ecosystems in communities. As people spend so much of their time in built environments, the restructuring of indoor settings in effect has altered the very fabric of society and daily life. Some of the modifications in such spaces attributable to digitalization, climate change, and sociocultural shifts have been for the better. The Internet has made the spatial and temporal boundaries of indoor ecosystems less restrictive, affording tremendous conveniences for the occupants of residential, educational, occupational, commercial, and recreational settings—for example, by enabling them to collaborate with coworkers, interact with friends, and meet romantic partners located in distant places.

Simultaneously, the greater permeability of indoor ecosystems resulting from their online connections to remote locations has increased the polyfunctional and multitasking qualities of those settings. Notably, the transformation of residential environments from a domestic refuge away from work into a multi-activity hub could have potentially negative ramifications by enabling millions of household members to conduct most of their day-to-day activities inside their dwelling, without having to venture outside and encounter a diversity of other people in public venues, such as movie theaters, concert halls, and shopping centers. These changing patterns of residential life, to the extent that they become more pervasive in future years, could erode the foundations of public life and societal cohesion altogether.

Similarly, the effects of climate change on indoor ecosystems reflect a mix of potentially negative and positive outcomes. That is, built environments located in areas most immediately exposed to the dangers of climate change are doomed to extinction, as they are overtaken by inexorable sea level rise, flooding, and desertification. Conversely, the sustainability challenges posed by the Anthropocene have spurred technological innovations that, ultimately, will reduce the carbon footprints of buildings, increase their use of renewable energy sources, and enable them to become more self-sufficient and resilient.

We are now at a pivotal time in history when humans can seize the initiative to restructure indoor ecosystems in ways that support civil society, inclusive governance, and environmental sustainability. As a basis for creating indoor settings that are more healthful, efficient and robust, broad-gauged transdisciplinary action research spanning multiple scales (from local to global) and diverse fields will be necessary (Stokols, 2006). International treaties such as the Montreal Protocol, to ban ozone-depleting substances, and the Paris Agreement, to reverse climate change, have proven to be effective macrolevel strategies for advancing global sustainability goals (UN Environment Programme, 2018; UN Framework Convention on Climate

Change, 2018); however, they should be combined in future years with micro and mesoscale changes in the design and organization of indoor ecosystems as part of multi-level initiatives to protect the biosphere (Stokols, 2018). Achievement of these ambitious action-research goals will call for new educational approaches that prepare future generations of human and social ecologists to analyze environmental and societal problems from a transdisciplinary, multilevel systems perspective.

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Infrastructures of Care: Opening up "Home" as Commons in a Hot City

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Abstract

What does it mean to be at home in a hot city? One response is to shut our doors and close ourselves in a cocoon of air-conditioned thermal comfort. As the climate warms, indoor environments facilitated by technical infrastructures of cooling are fast becoming the condition around which urban life is shaped. The price we pay for this response is high: our bodies have become sedentary, patterns of consumption individualized, and spaces of comfortable mobility and sociality in the city, termed in this paper as "infrastructures of care," have declined. Drawing on the findings of a transdisciplinary pilot study titled *Cooling the Commons*, this paper proposes that the production of the home as an enclosed and private space needs to be rethought as an infrastructure that potentially undermines more social, convivial, and environmentally sensitive responses to a warming world. The paper asks, what role might design now play in developing alternative infrastructures of care that start with the idea of "home" as a distributed proposition?

Keywords: commons, home, infrastructures of care, sustainable design, urban cooling

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Introduction

Suburban Western Sydney in Australia is undergoing rapid population growth and urban densification, with a projected construction of 180,000-plus dwellings planned in the next 15 to 20 years (Greater Sydney Commission, 2018). Once covered in woodlands and bushy waterways, this region of the Sydney Basin is rapidly disappearing under asphalt and concrete, with the consequent loss of shade-giving tree canopy (Jacobs et al., 2014). Distant from coastal sea breezes, it is experiencing increasingly hostile and record-breaking summer temperatures that will be further exacerbated by urban development. Particular "hot spots" with land surface temperatures of 50°C (122°F) and beyond have been recorded, and these often coincide with low socioeconomic status areas (Amati et al., 2017; Australian Bureau of Statistics [ABS], 2018a; Penrith City Council, 2015).[2] As rising urban heat increasingly presents disruptive challenges to being "at home" in the world, this paper explores how these challenges are also opportunities to provoke us to design home environments differently.

New houses in Western Sydney, as all around Australia, are being designed around air-conditioning to deliver thermal comfort. Driving the move indoors, air-conditioning and its broad implications are a significant contributing factor to the rise of indoor ecosystems explored in this special issue. In a national survey of human activity patterns in the United States (US), Klepeis et al. (2001) found that people are spending around 90% of their time inside enclosed buildings or vehicles. Yet, the structuring-in of air-conditioning as the primary response to urban heat is having multiple detrimental effects on urban lifeworlds—that is, the world as lived. Increased demand for energy derived from fossil fuels is contributing significantly to global warming, people are being forced indoors into increasingly individuated social spaces, and household energy bills are skyrocketing.[3] With this move, the perceived need for publicly accessible infrastructures that facilitate a slower, more pedestrian-oriented city is being diminished. For those economically disadvantaged groups living in the Western Sydney region who have less capacity to access or pay for air-conditioning, livability is being increasingly compromised.

During the summer of 2016, a transdisciplinary team of researchers from the disciplines of design, geography, economics, landscape architecture, and cultural studies spoke to a group of 14 active seniors, 10 Aboriginal mothers with preschool-aged children, and a group of seven elderly carers living in the hot spots of Penrith

2 This correlation between distributions of income and tree canopy cover in urban centers is a global issue. For example, see Schwarz et al.'s (2015) study examining the burden of environmental hazard carried by low-income and minority populations across seven US cities. The authors point out some interesting disincentives for urban trees including a resistance to the "gentrification" that comes with tree cover, as it also brings rising rents.

3 See Nicholls et al. (2017) for a detailed qualitative study of the effect of electricity pricing and messaging on low-income households in Australia.

City in Western Sydney. The particular heat vulnerability of the elderly, the very young, and the economically disadvantaged is well established in the literature (Loughnan et al., 2013). However, we wanted to look beyond the assumption of vulnerability to explore what people living in these "hot spots" do during summer to cope with the heat. Our methods included observational site analyses and group interviews aided by visual prompts, including thermographic imagery. We sought to capture not only what people could say about what they do, but also the less conscious or "tacit" dimensions of practical activity, as "we know more than we can tell" (Polanyi, 2009, p. 18). The data produced helped us understand how features of the environment influence people's efforts to keep cool inside their homes and outside in public spaces. Thematic analysis also revealed details about everyday practices as people attempted to work around these conditions, and the aspirations people held for the future of their city.

The accounts gathered in the preliminary study, titled *Cooling the Commons*, complements the now significant body of quantitative literature on the effects of urban heat (Hughes et al., 2016; Lewis et al., 2017; Mellick Lopes et al., 2016) and studies that identify key design considerations to ameliorate these consequences (Osmond & Sharifi, 2017). This study contributes key insights into the social, cultural, and material contexts that inhibit or support cooling strategies, or that make space for individual agency (Bell et al., 2014).

The research findings point to the ways that individual and community capacity to cope with urban heat is constrained or enabled by housing design, housing tenure arrangements, the design of public spaces, networks, and everyday material circumstances. Lives are lived within the enclosed confines and open avenues of a set of infrastructural relationships that circulate in, around, and beyond the home. We can think of a particular set of infrastructural relationships as those that achieve *coolth*: the sensation of feeling cool in a heated atmosphere. In this paper it is argued that technical infrastructures of urban cooling that privilege air-conditioning are threatening the provision of other infrastructures that afford experiences of coolth, notably shade, shelter, public water, and places to comfortably rest and wait while moving about the city. Likewise, there needs to be a concerted effort to intervene in this process for the future well-being of inhabitants of a hot city.

The paper proceeds with a critical discussion of how air-conditioning, as a technical cooling infrastructure, has shaped urban lifeworlds. "Infrastructures of care" are next introduced as social and technical infrastructures that can be made and shared by communities in their efforts to keep cool, followed by a discussion of how this analysis helps to generate a provisional set of considerations for the design of future infrastructure of care.

Cool Enclosures

> Infrastructure is not identical to system or structure, as we currently see them, because infrastructure is defined by the movement or patterning of social form. It is the living mediation of what organizes life: the lifeworld of structure. Roads, bridges, schools, food chains, finance systems, prisons, families, districts, norms [are] all … systems that link ongoing proximity to being in a world-sustaining relation. (Berlant, 2016, p. 393)

In considering Lauren Berlant's (2016) reframing of infrastructure, not as a technical system or built structure but as a movement or patterning of social form, we can view the history of climate control over the course of the twentieth and twenty-first century as significantly changing the organization of urban life in ways we must now challenge. The earliest efforts in creating climate-controlled environments were, according to Stephen Healy (2008),[4] not in the house but in the context of temperature-sensitive manufacturing—from textiles to chocolate manufacture. In the early twentieth century there was a lively debate in the domain of public health that pitted approaches emphasizing the circulation of "fresh air" over the use of climate-control technologies that heated or cooled recirculated air. Initially, "fresh air" champions won the public health argument in the context of public buildings, but the advocates of climate control won the day through an appeal to a scientific understanding focused:

> upon the quantitative study of human comfort (after an earlier focus upon a chemical theory of air had been disavowed). Building upon earlier work, the laboratory published the "Comfort Chart" that "graph[ed] … the combinations of temperature and humidity at which most people felt comfortable." (Healy, 2008, p. 314)

Thermal comfort became an engineered condition, subject to what Shove (2003) called the "ratchet effect," by which imperceptible changes in designed conditions became the norm, constraining the possibility of retraction or backward movement. A working universal standard for the human body to achieve thermal comfort was set at around 22°C (72°F), regardless of the temperature outside (Shove, 2003, p. 26).

Healy (2008) charted how the concept of climate control spreads from industrial sites, to climate-controlled movie theaters, and shopping centers—all of which are sites of collective mingling. Eventually, climate control spread in the form of small air-conditioning units, to family homes, and then to automobiles.[5]

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4 We note that this Stephen Healy is a history of science scholar based in Australia who shares a name with one of the authors of this paper.

5 Dolores Hayden (2002) documented a similar trajectory with collectively used appliances, such as dishwashing machines and vacuum cleaners used in hotels and rooming houses, migrating to individual households in miniaturized form. As a template, climate control anticipates the "smart home" Sofia (Sofoulis, 2000) presciently described nearly two decades ago as an environment that caters to (the largely male) fantasy of a command-and-control home, separated from the outside world, silently and efficiently shaping conventions and practices of comfort (Shove, 2003).

The demand for air-conditioning also normalized over time, fundamentally informing the design of everyday urban life. Today, many urban dwellers' lives, work practices, and styles of dress, among other factors, are designed in anticipation of the 22°C (72°F) working temperature. Further, many indoor environments, from the home, to the office block, to the shopping (and data) center, and car, would be uninhabitable or grind to a halt without it.

Air-conditioned comfort is increasingly a feature of the built environment globally. Like the car industry in the last century, thermal comfort delivered through air-conditioning has become a primary signal of urbanization and rising affluence, and, therefore, of a modern, functioning economy (Davis & Gertler, 2015). The emerging middle classes in China, India, Indonesia, and South America now constitute the largest market for air-conditioning. As reported by the Lawrence Berkeley Lab, the world is set to install 700 million new air-conditioners by 2030, and 1.6 billion by 2050, mostly in developing countries with hot climates (De la Rue du Can et al., 2015).

Yet, while the desire for thermal comfort is understandable in hot cities, the structuring-in of air-conditioning is exacerbating global warming. In addition to energy consumed in use, there are the potent emissions from the HFC refrigerants used in air-conditioners, as well as the effect of peak load, which severely stresses urban energy grids and leaves communities vulnerable to possible breakdown (De la Rue du Can et al., 2015). It is also more energy intensive to cool rather than to heat air, and air-conditioning (and refrigeration) produce and release heat back into the environment, exacerbating the urban heat island effect.

At the level of bodily experience, the "thermal monotony" created by air-conditioning means that humans lose the capacity to acclimatize to temperature variations in the greater environment (Healy, 2008). The key issue here is "the manner in which technologies fuse prosthetically with humans" (Tonkinwise, 2009, p. 33). Air-conditioning technologies make a human body that is different, physiologically, to one that would exist without it, one that appears to be less capable of responding to thermal variability, and that is engineered into forgetting this capacity. The body produced by indoor, climate-controlled environments is more sedentary and passive (Sofia [Sofoulis], 2000), as well as more vulnerable to environmental diseases such as asthma. Here we find an ironic confirmation of Annemarie Mol's (1999, 2002, 2008) assertion of the body's multiple ontologies—a progressive winnowing of what the *human* body can be by technologies that foreclose on other possibilities. In reality, the commitment to air-conditioning does not ensure "steady-state" thermal comfort. Notably, SafeWork NSW (n.d.), the state government workplace health and safety regulator, reported that "problems with air-conditioning are very common" (para. 7), as the experience of its adequacy changes according to dynamics of human movement and people's different tolerances to temperature.

The delegation of active control to the built environment also modifies forms of sociality. During hot weather it encloses people in houses, cut off from others. For the body so acclimatized, the presence or absence of air-conditioning becomes a decisive factor influencing livability in a city, determining where you go, what you do, and with whom.

The conversations in Western Sydney afforded graphic insights into this infrastructure of cool enclosure that has been created by privileging built environment "solutions" to urban heat. Participants in the *Cooling the Commons* pilot found themselves increasingly restricted to indoor environments. For example, the group of carers described being completely reliant on air-conditioning and was largely confined to their homes during hot days due to the difficulties of getting around comfortably. An enduring image was one described by an elderly carer who was totally reliant on air-conditioning to transport their adult child between home and the community center. The carer explained that they routinely experienced being stuck at traffic lights in their car, and even with the air-conditioning on full bore still suffered the threat to their charge of potential heatstroke. Another common experience was the need to get back into a car that had been baking in the sun all day, and the problem of finding shade under which to wait while air-conditioning made the environment in cars more habitable.

In particularly hostile hot spots, many residents did not have access to air-conditioning at all, and were coping with already excessive outside temperatures and internal environments that intensified the heat. These residents were further disempowered, as they did not have the capacity to modify their home environments for cooling due to poor design (e.g., lack of insulation and the use of cheap sliding rather than lockable sash windows, which limit the easy and secure circulation of air), or because they were renting or in social housing.[6]

A group of Aboriginal mothers living in poorly designed public housing were one group facing excessive and destabilizing indoor heat. The director of the local neighborhood center explained that the upper levels of their homes become uninhabitable in summer, leaving people needing to crowd in downstairs and take up residence in the neighborhood center during the day. Some mothers who took part in the *Cooling the Commons* study explained that their main option for managing heat was to remain completely still. Their children in childcare were not allowed to play outdoors after midmorning due to the lack of shade, and rather than ride their bikes, school-aged children came home straight after school to, in their words, "just chill." These ongoing issues are exacerbated by the lack of public transport infrastructure to enable people to easily get to cooling refuges such as a local public swimming pool.

6 The particular vulnerability of renters to urban heat was also found in Nicholls et al.'s (2017) study.

Interestingly, the senior participants were highly critical of the "thermal indulgence" (Strengers & Maller, 2017, p. 35) of younger generations, arguing they had learned to rely too heavily for their comfort on air-conditioning. The idea that thermal comfort was something you needed to take responsibility for and manage was strong in this group. Evidenced by one participant, seniors were very aware of the costs associated with fans and air-conditioning, and this energy-aware dwelling was a source of pride:

> I have rules … it has to be at least 30 degrees [86°F; before I turn the air on]—usually my body can tell me. The other day it was 34 degrees [93°F] before I turned it on … as soon as it starts to cool down, we turn it off. (Participant, seniors group)

While this may be perceived as evidence of detrimental "thermal rationing" (Nicholls et al., 2017), these comments also point to different generational experiences and a loss of cooling know-how. They reflect a trajectory of cool enclosure that an infrastructure of built-environment climate control has charted.

Here, the term "enclosure" is used purposefully to connect with the long tradition of concern for enclosure of the commons. This does not refer to the process of legal exclusion and displacement of the English peasantry from the commons pasture, to make room for private property. This instance of enclosure radically reshaped the lifeworld of whole populations, confining their movements, cutting off options for survival, and proscribing new exploitative livelihoods within urban hells. The enclosure of urban life in individuated air-conditioned households with expensive energy bills is certainly not of the same order, but it does constitute a remaking of the built environment and reshaping of lifeworlds. Technical infrastructures of enclosed coolth are deeply structured into the ways in which cities are imagined, planned, and materialized, and distinctive forms of sociality have emerged in response. It is important to remember that the continued distribution of individual air-conditioned enclosures is largely considered an exercise of social responsibility, a type of caretaking. People need to be cooled, and air-conditioning performs this remedial function. However, this way of defining how we occupy our earthly home is fundamentally blind to the fact that we simultaneously contribute to its destruction. The next section examines the commons to imagine alternative infrastructures of care in a hot city.

Commoning Coolth

> The commons concept is a powerful vehicle for troubling troubled times.
> (Berlant, 2016, p. 395)

Increased urban heat is now troubling, and while one response is to shut our doors and close ourselves in a cocoon of thermal comfort, the price we pay is to still our bodies and close ourselves off from one another. Upon reviewing how technical cooling

infrastructures have produced home as an enclosed and private space with a strong boundary that demarcates cool livability, we turn now to explore infrastructures that instate home as a space of flow and encounter across porous boundaries (Crabtree, 2006; Power, 2009), and that enact a commons that is continually in the making (Linebaugh, 2008). The commons referred to include cooling knowledge, practices, shared spaces, and built environments that are widely accessible for use in achieving thermal comfort, which also require care to be maintained and that produce benefit for a wide community (Gibson-Graham et al., 2013).

This commoning framework is applied in seeking a different understanding of the built environment, a redefinition of home that allows us to respond to heat in ways that are less energetically intensive, that incorporate common outdoor environments as part of our shared home environment (see Figure 1), and, following Brault (2017), pursue more social, convivial responses to a warming world. We want to harness the troubling power of the commons to expand our concept of home as a life-organizing infrastructure.

Figure 1. Glenmore Loch, Glenmore Park: An oasis of coolth in one of Sydney's hottest suburbs.

Source: Mellick Lopes et al. (2016, p. 13); photograph by Helen Amstrong, December 2015.

Participants in the *Cooling the Commons* study showed practices of commoned coolth have not completely disappeared. They did what they could to keep cool with the resources to which they had access in and around their homes, and where possible migrated to cool refuges such as pools, rivers, or shopping centers on extremely hot days. However, as air-conditioning has become a standard for the delivery of

thermal comfort—each of those 180,000-plus new Western Sydney houses is highly likely to have air-conditioning—infrastructures that afford comfortable mobility in the broader public domain have fallen into decline and disrepair. This was clearly reflected in the experiences of the groups in this study. People perceived the removal of street trees, toilets, public drinking water facilities, and shaded seating over the years as a withdrawal of care that reinforced a deficit of trust in local government.[7] This points to the critical relationship between interpersonal care and care of place. As discovered, traditional caregiving was constrained by structural features of the built environment—in homes, cars, and childcare centers. For the study participants, cared-for commons that provide for safe and comfortable mobility and invite participation existed primarily as memory or aspiration. Next, a summary of findings about *residual*, *transgressive*, and *aspirational* commons help inform our provisional guidelines in the following section.

Keeping Common Knowledge Alive

In spite of their restrictive environments, not all participants had lost common knowledge related to cooling. Older residents spoke of shared knowledge of ways to manipulate indoor environments to create coolth without air-conditioning. They demonstrated a high degree of practical know-how and sensitivity to environmental conditions, having developed a number of "work-arounds" for keeping cool in their often thermally poor houses using available materials and skills learned from their parents. They spoke of the importance of openable windows, ventilation, eaves, and verandas, the absence of which they had noticed in new housing developments, as well as an overall lack of interstitial "breathing space." Some had what Strengers and Maller (2017) called "practice memories" of very low-tech solutions, such as placing a baby under a table with a wet sheet over the top, or freezing water in cake tins and setting up a fan to blow air over it. This group was also adept at do-it-yourself modifications, such as installing heat-removing "whirlybirds" on their roofs.

Caring for Residual Commons

Participants shared many stories about cooling practices that circulated *beyond* the indoor environment, involving the distributed amenity of trees, rivers, and swimming pools, and more appropriately "furnished" public environments. People recalled sitting and swimming in rivers on hot days and public amenities that both assumed and supported a walkable city. They mentioned with disapproval the lack of nearby shaded green space, which has been associated with an increase in heat-related illness and death (Bradford et al., 2015). Of course, the perception of "nearby" changes according to how accessible such environments actually are. For parents in this study, the streets were generally perceived as too hot to push prams

7 These findings about features of the built environment constraining people's movement in a hot city resonate with and build on those reported in Sofoulis et al.'s (2008) study *Out and About in Penrith* of nearly a decade earlier.

or walk, and paths were not pram friendly, broken up by roads. Seniors complained that there were few places to rest comfortably out and about: "The post office, myGov, and Centrelink; they feel like they are literally hundreds of miles apart" (Participants, seniors group).[8]

Participants were supportive of local council plans to reverse some of these trends and nurture the commons for wider participation.[9] However, it is not a case of "build it and they will come." As Star (2010) argued, infrastructures both shape and are shaped by conventions of practice. Such strategies speak to a civic life that has been undernourished for some time. Normative social practices that have grown up around current conditions, such as children playing indoors for large parts of the day, will be difficult to change, and require multiple actions and interventions in relation to both built and social environments on an ongoing basis (Hunter et al., 2015).

Tolerating Transgressive Commons

Indoor shopping centers and fast-food restaurants are not only major sites of recreation in Western Sydney, but also cool places that can be accessed free of charge. During heat waves people in the region occupy these air-conditioned spaces for extended periods of time, transgressively commoning "privately" owned space. An important precedent study, *Out and About in Penrith* (Sofoulis et al., 2008), found that children identified play structures associated with the fast-food restaurants located inside shopping centers as the "park" (p. 39). This report concludes that such slippages of meaning are invited by the availability of both amenity (i.e., air-conditioning and toilets) and society in those environments, which are often not available in traditional outdoor parks. This delineates a further sociocultural context for the retreat indoors: a "conceptual infrastructure" (Berlant, 2016, p. 394) of the commons.

Among the groups, there was a sense of a right to occupy cool spaces in extreme circumstances. In another example of transgressive commoning, teenagers had resorted to swimming in the decorative water feature of an adjacent new housing development on hot days, as the local shuttle bus had been cancelled.

Imagining Future Commons

Another "emergent" commons was found in people's shared aspirations for the cool future city. These aspirations included the recovery of basic amenities that still existed strongly in memories of place. The provision of shade, shelter, and water in

8 The participants are referring to the shopfronts of government agencies that deliver social security payments and other social services to Australians.

9 For example, Parramatta City has new walkable city and bicycle plans, and in 2015 launched the Our Living River strategy, which is a plan to make at least some of Western Sydney's degraded rivers swimmable again by 2025.

public environments was viewed as a necessary support to a far from basic range of social affordances, including meeting and gathering, resting and waiting, swimming, walking, and the everyday exchange of knowledge and ideas. However, participants went beyond this to describe multipurpose environments, such as parking lots or roads, that could be used for different activities at different times of the day, and called for a more extensive use of the rivers and riverside parks. They also imagined alternative social futures: the seniors were keen to share their cooling expertise with others, and the gardeners across the groups were interested in sharing knowledge about on-site water management, as well as supporting conversations about trees and their social, cultural, and environmental significance. Community cooking was also an aspiration in the groups, a way to share knowledge and enjoy social interaction in a local setting. It was noted that this would require access to material infrastructures beyond the currently ubiquitous local park barbecue.

These commoning practices foreshadow a future home space that goes well beyond the individualized enclosures currently on offer as "home," and the ontologies they produce. The technical infrastructures of coolth that both assume and produce a passive and static body (whether that body is positioned inside or outside an air-conditioned cocoon) chip away at the capacity for civic life. Conversely, the infrastructures we seek to promote are both social *and* technical, requiring a multiplicity of resources distributed across and between private and public domains. In the following section, our learning from the *Cooling the Commons* project supports the generation of a preliminary set of considerations for designing infrastructures of care.

Designing Infrastructures of Care

> [A]t some crisis times like this one, politics is defined by a collectively held sense that a glitch has appeared in the reproduction of life. A glitch is an interruption within a transition, a troubled transmission. A glitch is also the revelation of an infrastructural failure. (Berlant, 2016, p. 393)

As climate change threatens the reproduction of life, infrastructures of thermal comfort through enclosure are exposed as failing to care for people and the planet. The time is ripe to mount a challenge to these infrastructures and the embodied and public geographies of thermal restriction they support. Care is a world-making practice (Slater, 2016), as is design (Fry, 1999). The ability of designed artifacts and systems to alter the condition and behavior of other things in multiple incremental ways constitutes the ethical force of design. Elaine Scarry (1985) described this force as an empathetic projection through which the designer says to another, "in … this small way, be well" (p. 292). In the context of this study, the question becomes what lifeworlds are being cared for, and what diminished or undermined, by design?

We have seen how heat reaches into people's lives in different ways, depending on their physical, material, socioeconomic, and even cultural circumstances. In the context of rising heat, city inhabitants need different ways to be at home beyond the skin of an enclosed, private domain. This requires a far more convivial sociomaterial environment that *precedes* artificial air, rather than assumes it.

The last section of this paper explores the possibilities for infrastructures of sociality and circulation, which enable communities to be at home in places where "the body multiple" can find expression. Enumerated here are some key considerations for a careful design practice that could support future homes as a care commons and that recognizes the significance of design in the patterning of sociomaterial relationships. Important to note are that attempts to design in another way are constrained by the modern city, as it is largely a heat-amplifying hot zone. As Tonkinwise (2009) argued, what is now required is not a more systemic form of designing, but one that performs "a plurality of more humble, agile propositions that allow for the evolution of less ecologically harmful ways of keeping cool" (p. 37).

Open and Porous Infrastructures of the Commons

People need designed commons that are accessible and appropriately furnished with amenities and "attractors." A significant challenge here is negotiating the terms of ownership and not necessarily "giving in" to the neoliberal narrative of exclusivity, in that every home has every *thing* and spare capacity is ignored.

There is a need to consider how to support the acclimatization to more open and porous infrastructures of the commons, including their sensorial dimensions. For example, if one cooks out in the open, along with food they will be sharing smells and sounds with their neighbors. Therefore, in addition to the infrastructures for community cooking, might be the need for new protocols to govern how social spaces are shared. These would want to be anticipated in advance rather than reactively, as part of a more careful design *ethos*.[10]

Distributing Spare Cool Capacity

How might spare cool capacity—created in part by the settings of thermal indulgence and monotony in autonomous, air-conditioned environments—be better shared? This is of particular importance, as single-occupant dwellings are on the rise in Australia, with one in every four being a lone household, skewed to older age groups (ABS, 2018b). Older people are not only deemed more at risk of heat-

10 There are numerous examples of a lack of anticipatory care in design decision-making related to transient usage. The intrusive effect of light spill from sportsfield floodlights on human and nonhuman residents is but one obvious case in point.

related illnesses than younger people, but are also at risk of social isolation; hence, this trend is significant in terms of home rethought as a sociothermal infrastructure of care (Power & Mee, in press).

Sharing Cooling Centers

In Pittsburgh, Pennsylvania, public buildings in areas of high vulnerability have been reconceived as cooling centers where at-risk residents can seek refuge from extreme heat. The optimal location for cooling centers was identified through the use of a "heat vulnerability index" (Bradford et al., 2015). This research notes that the repurposing of existing buildings may be preferable to purpose-built "cooling centers," as people may not wish to be labeled as "vulnerable" and in need of special facilities. For a rapidly developing but dispersed geospatial context like Western Sydney, a "patchwork" approach to the provision of artificially cooled air would build on social practices that *transgress* existing environments and could facilitate the development of new social networks. This suggests the need for a shift in focus from the design of individually enclosed and autonomous dwellings to shared infrastructures such as libraries, hospitals, schools, childcare centers, swimming pools, and community centers, among others, which are open to the circulation of air and people, as well as to multipurpose use. A careful consideration of how these infrastructures might be freely accessed during extreme heat events implies that contextual sensitivity should be part of their design. Such material infrastructures also require social response plans designed by the communities who will inhabit them, so that, for example, vulnerable families or lone residents might be identified and their care anticipated. Arguably, this sort of participatory care planning should form part of the induction of people into any new community.

Participating in Planning, Repairing, and Maintaining Infrastructures of Care

Commons designed to make space for people to make their mark and contribute their own practical knowledge and skills are a necessity. Reflecting on those keen gardeners in the *Cooling the Commons* study, a key example here would be a community garden, which can be understood as an "enabling platform" (Jégou & Manzini, 2008) to reduce radiant heat effects, support ecological literacies, and facilitate learning communities (Mellick Lopes & Shumack, 2012). The garden is a living design that calls for time and attention but gives back in the form of food, habitat, and social learning: a knowledge commons.

In response to the effect of declining infrastructures that are vital to sustain the comfortable mobility of people in a hot city, equally necessary are designed environments that are repairable and maintainable, and that invite the participation of residents. Design that has internalized the normality of air-conditioning has

to relearn the importance of basic "passive design" features such as appropriate orientation, shading, ventilation, and weatherization, but their effective use requires human occupants to become more sensitive, anticipating changes in temperature throughout the day, and more engaged in actively controlling indoor climate.

Stewart Brand (1994) argued that modern designed homes prioritize the "show surface" and do not tend to invite ongoing maintenance and care—thus, the *need* for incremental maintenance and care is forgotten, leading on occasion to catastrophic failure. The technical delegation of care to air-conditioning further exacerbates the decline of a "maintaining eye" and a skilled hand. Designed environments that not only allow for people to manipulate them, but also to practice their care of and investment in them, require commoning infrastructures such as shared tools, spaces, and knowledge.

Performing Preparation for Extreme Heat

Finally, people need support to become care commoners, such as forms of induction and instruction, which can help facilitate the performance of unfamiliar social and technical practices, including the management and maintenance of commons.

One important form of induction in relation to extreme heat is a community weather preparedness plan. Most are familiar with strategies to prepare for flood and fire, but equally needed are plans to prepare for extreme weather. Rather than generic measures and checklists designed to help individual households fend for themselves, a community preparedness plan would require people to assess where the vulnerable members of their community are, where the spare cool capacity is, and plan to bring them together on hot days. This might involve the design of a purposive social network that is activated on the basis of certain indicators such as weather forecasts. An important precedent here is Akama et al.'s (2014) work on bushfire preparedness—the researchers worked with communities to identify and visualize social bonds, bridges, and links to help people think like a community with a common concern during times of emergency. Such an approach makes an important contribution to supporting the adaptive capacity of communities living in extreme conditions (Akama et al., 2014).

Conclusion

> The commons is an action concept that acknowledges a broken world and the survival ethics of a transformational infrastructure. (Berlant, 2016, p. 399)

The sobering reality that we confront is an Australia where 50-degree (122 °F) summer days may become a normal event in Sydney by 2040, sooner in other metropolitan areas, even if the international community abides by the terms of the 2015 Paris

Agreement (Lewis et al., 2017). Certainly, air-conditioned environments will have to be one response to a much warmer world, but, arguably, the equitable distribution of coolth will have to accompany adaptive responses. As we move toward these futures of designed circulation, there is a need to develop the infrastructures and practices of sociality that can sustain them. The *Cooling the Commons* participants remind us that this is a process of the generational circulation of ideas and practice, in which historical and new knowledge and practices must continue to cross-fertilize to imagine new practices of urban habitation.

The *Cooling the Commons* study was an initial exploration of sociomaterial responses to the complex and dynamic problem of urban heat in a specified geographic location. As a transdisciplinary team of researchers, we seek to further expand and test some of the preliminary design considerations emerging from that study in a research program that aims to actively "improve the situation of inquiry" (Mitchell et al., 2016). This requires the development of integrated concepts that can translate the memories, improvisational transgressions, and aspirations we identified in *Cooling the Commons* into an approach to design apprehensible to policy-makers, planners, and developers alike. For this we need to perform engaged research that is, from the outset, change-oriented, and that works with, and cares for, commons infrastructure. Concurrently, we seek to challenge the practices that are constitutive of ever hotter urban futures; while good design may ameliorate the worst effects of the heat without compromising our sociality, bad design—that is, more impermeable heat-absorbing surfaces, energy-demanding buildings, and isolating structures—will serve to make the problems worse.

The multiple design interventions we propose, rather than simply reducing home to house-as-enclosure, instead seek to reimagine the home as a porous and socially connected space tied to other spaces that enhance community preparedness in the face of a much warmer Australia. Following De Angelis and Harvie (2013), we see the prospects for the cool commons as a break in the historic trajectory of thermal enclosure. Pursuing this alternative makes new demands upon us as researchers, our fellow citizens, and decision-makers. We hope it is clear that we do not propose that designed recalibrations of the material environment in themselves constitute a cool commons. As anthropologist Stephen Gudeman (2001) reminded us many years ago, the commons do not exist without a community that both uses and cares for it.

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"It's Just a Never-Ending Battle": The Role of Modern Hygiene Ideals and the Dynamics of Everyday Life in Constructing Indoor Ecologies

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Abstract

Recent research suggests that the greatest threat to children's health from home environments across much of the industrialized world may no longer be pathogenic microbes, but impoverished microbial communities and the chemicals used in everyday products, including those for cleaning. This paper proposes that concepts of hygiene should be updated, given this reorientation of harm. However, little research has been conducted, which a) integrates knowledge from the diverse disciplinary fields concerned with indoor environments (such as microbiology, chemistry, and design), and b) examines how individuals conceptualize and enact hygiene to create healthier indoor environments for their families, including the extent to which their practices achieve this.

To gain insight into factors influencing how hygiene is enacted in the home, as well as the consequent effects on the composition of indoor environments, it is necessary to transgress traditional disciplinary approaches to investigate indoor environmental health and integrate knowledge from experts and lay people who inhabit these spaces. To do this, recent scientific and design literature addressing key determinants of environmental health in homes are consulted. This is combined with qualitative research into the ways in which parents define, perform, and measure hygiene

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within domestic spaces. The data collected concerns homes in Sydney, Australia, with the findings showing that common hygiene practices with potentially harmful outcomes often emerge from compromises between competing priorities within complexes of home practices. Factors influencing the dynamics that determine which activities are prioritized and how they are performed are dually highlighted. Some notable factors include confusion and uncertainty associated with the sensory proxies used to determine cleanliness and risk of harm, increased sensitivity to the potential presence of microbes over other potentially harmful microspecies, and the health histories and experiences of parents and children.

Keywords: cleaning practices, home microbiome, hygiene, indoor ecology, social practice theory

Introduction

Human ecology is concerned with the coevolution of complex cultural–economic–technological systems and physical–chemical–living systems, and the effects of their often-unpredictable emergent properties on the health of humans and ecosystems (Dyball & Newell, 2014). Much of the current literature in the field of human ecology is focused on macroscale interactions between human societies and regional or global environmental conditions, while dedicating relatively less attention to microscale (or indoor) ecosystems.[2] As such, this paper proposes that the microecology of the indoors warrants greater attention, particularly as it is now considered not only the fastest growing biome on Earth, but also an increasingly significant source of human and environmental health hazards (Martin et al., 2015). Air pollution in the home is now ranked the ninth largest Global Burden of Disease risk (Forouzanfar et al., 2015). Those most susceptible to its effects, including the very young and elderly, and those with compromised health, are likely to have higher exposure than those who spend less time indoors (Kumar et al., 2016). The types of health hazards present in home environments are complex, varied, and geographically contingent (Lyytimäki, 2012). In much of the developing world, key sources of indoor pollution include smoke from fires and cigarettes, while in developed countries pollutants primarily emanate from consumer products (Kumar et al., 2016). Products commonly used in home cleaning and bathing practices also contain classes of chemicals, such as phthalates and some solvents, identified as harmful to human and environmental health (Clayton et al., 2011; Gosens et al., 2014). Of the approximately 80,000 chemicals registered for use in consumer products, only a small percentage have been tested for their long-term effects (National Toxicology Program, 2018). However, recent research has demonstrated that many of those used in common personal care and cleaning products have carcinogenic or endocrine disrupting effects (Bergman

2 A notable exception here is Lyytimäki (2012).

et al., 2013; Weschler, 2009; Zoeller et al., 2012), which are particularly harmful to children. Endocrine disrupting chemicals (EDCs) have in the past been linked to health conditions including diabetes, obesity, some cancers, and impaired reproductive and neurological development (Bergman et al., 2013).

In addition to chemical pollutants, a crucial determinant of indoor environmental health is the microbial communities that thrive therein. Homes can become sites in which pathogenic bacteria and viruses are transferred between people, and fungus can develop in damp areas, which may cause allergic reactions. However, a lack of microbial diversity in homes, and the absence of farm or domesticated animals that carry particular microbes to "train" human immune systems, have been associated with the rise in childhood allergies (Rook et al., 2013) and leukemia (Greaves, 2018). The design of domestic objects, homes, and the use of antibacterial products have all been associated with declining microbial diversity in homes (Dunn et al., 2013; Flores et al., 2013; Rintala et al., 2008). For example, the use of chemically treated finishing such as antimicrobial paint, chemical cleaning products, and home designs that restrict airflow between the indoors and outdoors can all contribute to a decrease in microbial diversity, potentially encouraging more resistant microbial species to thrive and colonize (Adams et al., 2016; Martin et al., 2015; Meadow et al., 2014).

Despite clear evidence from chemistry and microbiology fields that practices central to modern lifestyles influence indoor environmental health, there remains a gap in the literature examining how different material, biological, and cultural forces come together to create particular "microecologies" in one's home. Moreover, no evidence could be found of research that examines how modern ways of defining and maintaining a hygienic home affects the composition of domestic microecologies, which, in turn, influence health outcomes.

This paper begins to address this gap by moving beyond discipline-specific investigations to integrate perspectives on indoor environmental health. It examines how home hygiene is enacted in practice, and how these practices might contribute to suboptimal indoor home environments. The transdisciplinary approach that broadly guided this research is defined here through four criteria: problem oriented, participatory or collaborative, transgressing disciplinary boundaries, and seeking to integrate disparate fields of knowledge (Brown et al., 2010; Schoot Uiterkamp & Vlek, 2007; Wickson et al., 2006). Based on this orientation, the following section details how and why an approach focused on social practices was adopted to trace relations between social and material elements within home environments, which may influence the composition of domestic microecologies.

Research Approach: Tracing Home Hygiene Practices

Although heterogeneous, theories of social practice generally focus on the dynamic interplay between material things, meanings and beliefs, and embodied knowledge at different scales of social life (Hui et al., 2016; Shove, 2004). A commonly cited definition of practice provided by Reckwitz (2002) describes a practice as:

> a routinized type of behaviour which consists of several elements, interconnected to one another: forms of bodily activities, forms of mental activities, "things" and their use, a background knowledge in the form of understanding, know-how, states of emotion and motivational knowledge. (p. 249)

Research that foregrounds the importance of practices allows insights that integrate the latent and explicit influences of hygiene in the design of domestic interiors and objects, the deliberate and the unquestioned ways of performing particular activities (e.g., dishwashing and toothbrushing), and the more deliberate cognitive decisions and beliefs about what constitutes a healthy environment. All routine activities conducted in one's home, such as cooking, watching television, and getting ready for work, determine the flows of materials in, out, and around such buildings. However, some practices, such as cleaning, have a more direct role in structuring a home's microecology, due primarily to the common use of products containing antimicrobials and other EDCs, and the frequency and ubiquity with which they are used (Halden et al., 2017; Sherriff et al., 2005). Some scholars (see Maller, 2018; Wakefield-Rann et al., 2018) have argued that common conceptualizations of materiality in theories of social practice do not sufficiently account for nuances in material agency. They consequently propose that elements of other more-than-human theories are integrated into investigations of practice to explore material agency in greater depth. Nonetheless, this paper contends that practice theories provide a compelling lead framework to enable a necessary investigation and articulation of the ways in which the dynamics of everyday practice structure the composition of indoor environments.

Conceptualizing and Practicing Hygiene

The ways that cleaning practices are conducted are closely linked to how hygiene is understood and measured. Hygiene is defined as the "conditions or practices conducive to maintaining health and preventing disease, especially through cleanliness" (Oxford English Dictionary, 2016). However, since the mass popularization of germ theory, hygiene has increasingly become synonymous with sterility, thus, narrowing its focus on the extermination of "germs" (Campkin & Cox, 2012; Pink & Mackley, 2015; Shove, 2003; Smith, 2007). Moreover, Shove (2003) and others (see Campkin & Cox, 2012; Smith, 2007) have argued that cleanliness

conventions have escalated and become standardized across the industrialized world in late modernity. These escalating and increasingly complex standards of hygiene, and the market's capitalization of such trends, have meant that the networks of products mobilized in daily cleaning practices command ever-higher levels of energy, materials, and chemicals to produce the desired functionality (Shove, 2003).

This paper adopts the term "microspecies" to help broaden its investigation of home hygiene to account for the complex interactions between microbes and other significant microentities, which influence health and disease outcomes (Wakefield-Rann et al., 2018). "Microspecies" include microbes (i.e., bacteria, archaea, protists, fungi, and other microscopic animals and plants), and active organic and inorganic chemicals that exist at a microscale (i.e., invisible to the human eye) in homes. For the purposes of this research, the separation of living microbes from non-living chemicals obscures important shared traits related to how they act, react, and influence the environments in which they exist. Unlike visible species, microspecies can only make their presence known through proxies that must be read by humans, such as odor, discoloration of surfaces and clothes, skin rashes, and illness. The complex interactions between microspecies, guided by the actions and objects that populate daily life, shape a home's "microecology," and determine if it constitutes a hygienic and healthy environment for human habitation.

Research Sample and Recruitment

This research draws on data collected from a qualitative study conducted in Sydney, Australia, with 10 parents of children under five during 2017. A key aim was to investigate the ways in which competition between complexes of practices structure the enactment of hygiene in domesticity. This necessitated significant depth of engagement with each participant, and the adoption of multiple research methods. The exploration of complex phenomena in this research benefited from a sample size of 10 (Creswell, 1998; Malterud et al., 2016; Morse, 1994).

Respondents were primarily female (9/10; 90%), which may reflect availability and degree of engagement with domestic environmental health issues, as suggested by other research (Mackendrick, 2014). The characteristics of the final participant sample affords insights into the complexes of practices performed by women from English-speaking backgrounds, who work full or part time, and are of a middle to high socioeconomic status. Although the latter component was not deliberately selected for in the sample, insights into the domestic practices of this group can be considered valuable given the expansion of a "middle class" in Australia and globally. Additionally, the normative lifestyle practices of such social groups may form the basis of aspirational changes made by upwardly mobile families (Koo, 2016).

Given the limitations of the study, a multitude of potential variables that could contribute to the constitution of home microecologies were not investigated. In particular, further research that examines differences in rural and urban practices, cultural practices, house size and composition, and geographic location would add further nuance to studies concerning how hygiene is defined and prioritized, and how it is expressed when the dynamics of practice shift under different influences.

Methods used included a "cleaning diary," semi-structured interviews, and practice reenactments in participants' homes. The cleaning diary required participants to record all domestic cleaning or hygiene-related activities conducted over a period of seven days. This method, adapted from Sofoulis's (2005) water diaries, highlighted the associations and motivations that shaped key forms of engagement between participants, products, other objects, and perceived sources of environmental risk or "uncleanliness" that transpire throughout a day or week. Although there are clear limitations to self-reporting methods, the diaries provide a valuable indication of the frequency of particular activities, how cleaning and hygiene are defined by participants, and how cleaning is entwined with other practices. After completing these diaries, participants were invited to partake in a semi-structured interview with practice reenactments in their homes, in which they demonstrated their use of particular products and the ways they approached cleaning different parts of their house.

A combination of the cleaning diary, interviews, and practice reenactments allowed participants' practices to be accessed from different angles, rather than relying exclusively on narrative descriptions of different activities. The diaries provided a sense of the temporal dimensions of practice, while the situated interviews and reenactments enabled participants to demonstrate how they engage with particular materials and why. By situating interviews in participants' homes, there were opportunities to be reminded of certain activities, product choices, irritations, quirks, and other features of their homes that guide how they clean while physically moving through space.

Interview data were professionally transcribed and thematically analyzed with NVivo qualitative data analyses software. The thematic codes centered on the focal areas listed above, and how competition within and between practices and practitioners influence how, when, and by whom the home is cleaned, as well as how different activities are prioritized. What follows is an examination of the findings from this research, and how the interactions between practices that structure the flow of daily life shape how and when cleaning is performed, and its implications for home microecologies.

Hygiene Outcomes and Competition Within Complexes of Practices

The interviews and reenactments situated in participants' homes revealed that all had owned products that contained chemicals known or suspected to contribute to suboptimal indoor environments and health conditions; the most common sources of which were antimicrobial and fragrance chemicals. However, the types, ways, and degrees of product use were determined by numerous factors attributable to competition between rival interests within bundles and complexes of practices. Key factors influencing these dynamics include how hygiene priorities shift after having children, the way time and resources are allocated to different practices under time pressure, how these dynamics influence the delegation and performance of tasks, and the implications for the composition of domestic microecology.

Within social practice literature, coexistent practices are often described in terms of "bundles" of practices, which are loosely intertwined through colocation and coexistence, such as watching television and eating dinner (Shove et al., 2012). Conversely, "complexes" of practice are more integrated and interdependent arrangements, which concern such acts as handwashing and eating. A focus on the dynamics of complexes and bundles of practices, rather than exclusively examining meanings or attitudes toward home hygiene, has generated insights into how competing priorities, such as family time, leisure time, work, the aesthetic of one's home, and geographic and infrastructural elements, influence how hygiene is enacted.

The majority of parents interviewed reported that time pressures had a significant influence on how they prioritized tasks related to cleaning. For eight of the 10 participants who were engaged in paid employment, the arrival of children simultaneously reduced the amount of time available for maintaining such spaces, while introducing a range of new hygiene concerns.

After having children, greater emphasis was placed on removing potential germs from floors and benches, while activities such as tidying became less of a concern. Participant 6 stated:

> there's probably lots I do now that I never would have been so fussed about. Just in terms of keeping, probably, surfaces way more clean, way more often. Probably, yeah, frequency is the biggest—would be the biggest thing, for sure. Then, yeah, probably floors. Just in terms of using Dettol and stuff. I would have never have thought—I just would have used a floor cleaner rather than an antibacterial thing like that.

This heightened concern over the germs children might encounter (particularly on surfaces) meant the cleaning methods sought were less time and labor intensive, but effectively addressed perceived hygiene risks. As a result, antibacterial surface sprays and wipes were reported as popular options by all participants. These products enable the effective removal of food, toilet mishaps, or any kind of grime without having to clean an entire surface or area. This is illustrated well by Participant 3: "I've got these Dettol antiseptic wipes that I use to wipe the floor and her [participant's daughter] surface because I actually put the food straight on there, so she's feeding off that surface."

The preference for children to dwell in clean environments, coupled with the undesirability of prioritizing cleaning over other pursuits, such as family time or work, means that parents often delegate a certain amount of cleaning to professional services and objects. Although all parents interviewed conducted some amount of cleaning, six of the 10 employed a professional cleaner: one weekly, one fortnightly, three monthly, and one as needed. A common reason provided was that the perceived time required to clean one's home adequately would detract too much from the time they spend with family. Children also create more constant and new types of mess compared to adults, thus, seeing parents more often engage in frequent "spot cleaning," and, consequently, delegating the less urgent and more substantive tasks to professionals:

> The stuff we've let go since we had [child], because we just don't have the time, is vacuuming, which we basically now have a cleaner that comes every four weeks and does it. We don't really do dusting. We don't clean in the inside of the oven. We don't clean the bathtub or the walls of the shower space. We let the cleaner do all that … The stuff that we do, continue to do, is the vital kitchen-related [jobs] … cleaning dishes … wiping surfaces, kitchen table, high chair. (Participant 5)

Tasks performed by cleaners are often more time and product intensive than those parents reported to conduct on day-to-day bases. An implication of outsourcing more substantial cleaning tasks is that parents are often unaware of what products are being used to clean their homes. Only one of the six participants who hired a professional cleaner specified the products they wanted used, while the others indicated they were unaware of such details:

> Do you know what? … they come while I'm at work, so I'm not even here. I actually have no idea what they [cleaners] use or what they do … so I'll come home from work on the day the cleaners have been … Before I give the boys a bath that night, I actually wash out the whole bath with water, because I can feel that it's got—you know how you can feel it's got residue on it? … I'm like, oh God, I don't want him soaking in something, I don't know what it is. (Participant 9)

Many of the materials and interactions influencing domestic microecologies are not the result of decisions directly made by parents about a particular microspecies of concern. Rather, the emergent cleaning practices include products selected according to attributes desired by cleaners who are required to achieve a cost-effective, yet satisfactory appearance of cleanliness for their client. Of all the parents who used professional cleaners, only one directed their cleaner to use "more natural products" (Participant 2). For the majority of participants, the delegation of cleaning reduced their awareness of the types of microspecies introduced to their homes through cleaning practices. Consequently, a result of delegation is often a greater reliance on chemical agents, rather than on cleaning practices that involve a significant investment of time and effort.

Time pressure resulting from competition between practices also influences how and where parents shop for products to maintain home hygiene. When asked what factors guide product choices, convenience was a significant aspect. When asked why certain products were selected, Participant 1 noted, "whatever's convenient at the time. So if we're over at [shopping center] doing shopping, that will be where we purchase things." Even when parents are concerned about particular product attributes, purchasing decisions were not always made on that basis. Rather, competition between practices within a given timeframe would be resolved by adopting the most convenient bundling of activities, even when that meant compromise on product choice.

Hygiene outcomes emerge from specific resolutions of competing practices, not only in the context of individual decision-making, but also between members of a household. The specific ways of cleaning, how it is valued and prioritized by different individuals, and the combinations of personal care and cleaning products used in different rooms by different people all influence the composition of a home's microecology. In some cases, one person was responsible for the majority of housework and shopping; however, in most cases, these tasks were shared to varying degrees. Consequently, divergent hygiene, aesthetic, and time-related priorities were at play. As Participant 6 explained:

> [my partner] and I have a continual disagreement about personal care products … He likes things that really foam up, like a good body [lather], and I'm just like, that's all not really good for you … but he wants [sports brand] stuff with beads in it or whatever.

When asked about the use of antibacterial personal care products, Participant 6 also stated:

> that's another thing that [partner] and I disagree about … He's pro, and I'm anti … Because I just don't feel like it's a necessary step, and I feel like it's quite hard on your skin, especially for kids. I would rather that they just washed their hands.

These examples demonstrate that the flow of microspecies through one's home from different products is guided by a confluence of interests and the tensions between them. Hence, the way practices are prioritized echoes back to transform the meanings used to justify and make sense of how they end up being performed. This effect was particularly apparent in relation to the exposure of children to "dirt" or "grime." In eight cases, after expressing concern about not having time to clean their house to a suitable standard, participants stated that some exposure to dirt was acceptable, or even beneficial. For example, Participant 9 indicated she felt less guilty about her existing practices when she learned that some exposure to germs was valuable:

> I think—actually two things. Maybe just time-wise, I just didn't have time to get on top of him, to get him clean and hands washed. Secondly, I watched a [documentary] on—it was about allergies, but it was about kids that are exposed to different types of bacteria really early on in their life are less likely to have an allergy later on in life … So, then I think I was more conscious of, well, maybe that—yeah, not—everything doesn't have to be so clean … Well, it gave justification for me not being very tidy. I don't know. I was like, see, I'm doing something good for him.

Despite the persistence of germ-centric narratives and practices of hygiene risk in the home, the necessity of relinquishing some control over dirt–child interactions recounted by Participant 9 did seem to facilitate a partial erosion of the belief that such interactions are necessarily harmful, even where instinctive commitment to the belief remained. Similarly, residual discomfort with how competing practices had been prioritized was expressed in parents' attempts to limit the direct exposure of their children to chemicals. Participants expressed a desire to avoid products (such as surface sprays) containing chemicals, particularly on children's skin, despite continuing to use them other surfaces with which children interact in other ways. For example, Participant 6 stated:

> yeah, I just think … as natural as you can get it as possible, because I think that there's a real issue with plastics and chemicals … particularly with little boys; in boys it can influence reproductive systems. So, I've tried to reduce the amount of ingredients—chemical ingredients—that go on their skin.

The inconsistency of chemical avoidance around children can be understood as a manifestation of competing practice demands. Antibacterial chemical sprays and wipes generally offer the most convenient options for dealing with the perpetual mess generated by young children, particularly if one is already busy. These products are also imbued with sensory attributes designed to reassure users they are effectively cleaning, such as scent (e.g., lemon and pine), and lather and shine, all of which are achieved through the addition of chemicals (Wakefield-Rann, 2017).

A number of social theorists have noted the different ways that changing relations between practices have been recognized as influencing the temporal rhythms of daily life (see Blue, 2017; Hui et al., 2016; Schor, 1998; Southerton, 2006). As they

argue, the perceived decrease in available time does not result from any single factor, but instead from the "squeeze of practice-related injunctions of sequencing, coordination and personalized scheduling" (Shove et al., 2012, p. 95). As Southerton (2006) noted, each practice is accompanied by a set of requirements that enables competent and meaningful engagement to be achieved. These requirements must be balanced with those of other practices, so that the sets of practices carried, and their respective demands in terms of duration and timing, determine the overall sense of time pressure (Southerton, 2006, p. 440).

Overall, this section has argued the manner in which hygiene is performed in participants' homes emerges from a negotiation between competing practices and priorities experienced by each individual, and between those who share such responsibility. Participants demonstrated the need to accommodate and synchronize numerous practices that require significant time commitments, such as work, food preparation, taking care of children, shopping, and cleaning. The need to negotiate the requirements of each practice resulted in a mediation of the materials, meanings, and bodily competencies that often give priority to faster, labor-saving methods, such as the use of surface sprays and wipes to conduct reactive cleaning when needed, rather than time-consuming, routinized, and systematic cleaning of whole areas or rooms. As such, this paper next presents findings relating to the crucial elements and perceived practice requirements that influence the ordering of practices, which affect how hygiene is defined and maintained in the home.

Sensory Proxies Biased Toward Microbes

The elements forming a practice determine the amount of time, energy, thought, and skill required for its performance. These relative demands influence how practices subsequently interact with other practices, including how they are prioritized. The preceding section detailed how parents often feel they do not have time to clean their homes to a standard they deem acceptable, resulting in the delegation of particular tasks to others and the use of products perceived to be more effective and efficient at eliminating microbes. However, this section presents findings that suggest the way hygiene and "cleaning well" have been defined in practice instead necessitate a degree of engagement and rigor not achievable without significant time and labor commitments. Participant 9 captured this notion:

> I just found that … even with one kid, never mind two … everything was always filthy. I think it's the adjustment to having a child in the house and being tired. So I got a cleaner once a fortnight, and we've kept it since.

This section draws on the data to examine the standards and sensory proxies that have come to represent hygiene and "cleaning well," and the implications these have for how and when cleaning is performed. In particular, it highlights a significant oversensitivity embedded within cleaning practices to the potential risks posed by microbes.

The sensory qualities of microspecies play a significant role in how their capacity to cause harm is assessed. A unique characteristic of microspecies (compared to macrospecies, such as humans and pets) is their lack of detectability, which sees individuals instead rely on sensory proxies, such as scents or visual clues, to determine their presence. However, these are not always reliable indicators of microspecies' presence, or of the type of threat they may pose. If a house constantly presents signals of germs—such as discolored white tiles, dirty marks on flooring, or lingering bathroom odor—the time and energy that parents perceive they must dedicate to cleaning becomes considerable, influencing how tasks are performed and prioritized in dynamic daily negotiations between practices.

In all cases, the study research indicated that participants were more sensitive to sensory proxies for microbes than chemicals. This finding supports existing research that suggests the minds and senses, particularly of people in Western industrialized cultures, have been trained to perceive microbes through multiple sensory inputs, including foul odor, sticky surfaces, or visible dirt or discoloration (Smith, 2007), while other microspecies lack the proxies that enable their detection. This exemplifies what Murphy (2006) termed a "regime of perceptibility," in which the skills required to perceive harmful chemicals have not been as culturally or physically entrained as those required to perceive "germs." This "regime" was expressed not only through narratives, but also in product designs that make certain forms of dirt more detectable, and in the ways bodies are trained to recognize and react to the presence of particular materials and substances.

The design of one's home, interior furnishings, and building materials all influence how participants determined how and when certain areas required cleaning. All participants were particularly sensitized to the presence of visible dirt on flooring, and its implications for their children's health. The non-porous, light-reflecting qualities of floorboards reassured participants that dirt would not be "hidden" as it would in carpet. The following quote from Participants 8 illustrates how floorboards reveal dirt in particular ways that other surfaces, such as carpet, may obscure:

> Because it's all floorboards in this house … I get up in the morning and the sun comes beaming through this window here and it will show every single cat hair … I always think, I thought that floor was clean. It's actually just covered in cat fur [laughs]. So that's when I think, okay, I've got to clean the floors today. So even though without the sun shining on, it's actually—it looks okay, it's really not. It really just needs cleaning.

The revelation of "dirt" on surfaces influences the flow and prioritization of practices by commanding immediate attention. The ways in which dirt and other substances materialize on surfaces also guides product choices. For example, three participants noted their aversion to soap because of the "scum" it creates on shower tiles and glass. The aesthetic qualities of surfaces were also identified as key deterrents for parents attempting to use less chemical-intensive products for cleaning, such as vinegar and bicarbonate soda. The expected "sparkle" and "shine" of surfaces, which are thought to represent cleanliness, are often not achievable without such harsh intervention. As Participant 1 noted, "I have tried some other things and I've tried some natural methods. I've tried vinegar and water and … That didn't quite do it. It didn't get that sparkle."

These examples corroborate historical accounts of domestic objects demonstrating how the design of cleaning appliances has not only been guided by the increased demand for convenience and efficiency, but also by an imperative to make pathogen-carrying dirt more visible (Smith, 2007). In their history on the aesthetics of modern homes, Lupton and Miller (1996) described the process by which hygiene became the driving aesthetic in bathroom design from 1890s England, where white porcelain fixtures made from vitreous china and enameled iron were liberated from their moisture and germ-gathering dark wooden enclosures, and made flush with both floors and walls, thus, rendering dust and grime immediately visible. Similarly, when vacuum cleaners became standard household appliances in post-war periods within Europe, the United States, and Australia, dirt on flooring was able to be aggregated and made visible in the dust-collector of such machinery, hence, providing persuasive evidence of the necessity and virtue of the task and its performance (Lupton & Miller, 1996).

The intertwining of hygiene, design, and aesthetics throughout the twentieth century complicates the meanings, materials, and skills that constitute cleaning practices. Although microbes are made more perceptible by many modern furnishings and objects, cleaning may be further motivated by a desire to maintain surface aesthetic than by the perceived need to remove microbes. However, due to the legacy of hygiene in twentieth- and twenty-first-century design, definitions of a presentable and attractive home are inextricably bound to a "clean" aesthetic of uninterrupted, simple surfaces, which require active and ongoing maintenance.

This section has argued that the evolution of cleaning practices, alongside definitions of hygiene that require dirt to be revealed and removed, has resulted in aesthetic norms that demand significant time and labor investments. Parents' inability to meet these perceived norms, given that other practices demand their attention, has made faster and more efficient cleaning options more attractive. A key way that greater efficiency is achieved is through targeted applications of chemical-intensive products, such as antibacterial sprays and wipes. As such, focus now turns to the

instances in which parents have become sensitized to non-microbial environmental risks in the home, and how this has influenced the performance and negotiation of domestic cleaning practices.

Health History Sensitizes Parents to New Microspecies

Despite the relative dominance of microbes over other microspecies (such as chemicals) in the perceptual landscape of one's home, disruptive factors were identified that increased the sensitivity of parents to chemicals in particular circumstances. The reactivity of children's skin, especially due to eczema, was the most pronounced factor that sensitized parents to new microspecies affecting children's health. Rashes that appear as a result of eczema and other allergies are disruptive events that introduce new variables to consider within cleaning practices, often causing confusion and uncertainty. Such disruptions to normal cleaning practices made many parents begin to read the labels on cleaning and personal care products for the first time. The two most notable disruptions were reactions in children's bodies, particularly on skin, and the health experiences of mothers. These two types of incidence enabled the perceptual dominance of microbes to partially recede, and chemicals and other allergens to become more apparent. In relation to learning about chemicals in products, Participant 2 noted:

> I'd never thought about it before … then I think it all started because my son had eczema and I think then the first thing was to consider what washing powder you're using because it can be irritating to the skin. Then that was what started the whole journey into reading more about these types of things.

The other significant factor that sensitized parents to new microspecies was the health experiences of mothers. For example, Participant 2 had undergone a long process of diagnosing "ongoing low energy and digestive problems." A lack of solutions led her to newly examine the ingredients of products, and prompted her to start removing certain chemicals from her family's diet and home practices. Participant 2's increased awareness of chemicals in products resulted in a heightened sensitivity and an aversion to the proxies for chemicals, such as strong product scents:

> With the laundry powder, I can't stand the strong commercial [products]—like, I can smell when the neighbors are doing their washing. I just can't—I hate that smell. Like, a friend just gave me some pants that didn't fit her and I just can't stand the smell of them because I've quite a strong sense of smell, I think, and I can't stand the really strong—like, I like things that have the natural, pleasant smell, not if it's really super strong.

Other participants' health experiences influenced their sensitivity to chemicals in other, more conditional ways, which resulted in a practice change for a limited period of time. For example, Participant 1 explained how she became more aware of the chemicals in products, and began to avoid them when she commenced in vitro fertilization (IVF):

> I mean, the reason why I was sort of a little bit more conscious of it is because I had to do IVF with both the boys. So I guess I was trying to sort of think, okay, I'm not going to jeopardize anything … So I think at the time I made sure that I wasn't using any nail polishes unless they were chemical free … I avoided any sort of hair products and even getting my hair dyed, and things like that for a while.

The participant acknowledged the potential for particular chemicals to cause harm by adjusting her practices, and had limited her use of certain personal care products by avoiding her hairdresser; however, most of these practices were abandoned after the children were born. When asked if these chemicals and products were only ceased during pregnancy, Participant 1 stated, "yeah, yeah probably … Also, going back to work and things like that."

Participant 1's experience meant her practices were altered for a duration in which she believed particular products might cause her body harm. However, the demands of other practices, such as working and looking after two children, meant she reverted back to using products in practices that enabled her to achieve a state of personal and home hygiene efficiently, which satisfied her usual high standard. In contrast, the chronic nature of Participant 2's health condition resulted in a permanent alteration to her practices to avoid harsh chemicals.

This section has highlighted that participants often dissociate "vulnerability" from mainstream practices and chemical use, except when alerted to the susceptibility of particular bodies by rashes and other symptoms. This finding suggests it is frequently assumed that mainstream practices are not harming our bodies, except when particularly reactive bodies express vulnerability. Depending on other experiences, this expression can be understood as exceptional rather than a symptom of something ongoing and ubiquitous. Moreover, Participant 1's reversion back to her old practices once the risk posed by chemicals in products was perceived to be less acute demonstrates the persistence of a notion of cleanliness centered on the elimination of microbes.

Developing a New Research Agenda

Ordinary domestic routines, and particularly cleaning practices, are contributing to unhealthy indoor home environments. To improve the environmental health of homes, the conceptualizations of hygiene embedded in current normative procedures

must become more nuanced and encompassing of a broader range of hygiene risks beyond microbes. Practices that implicitly define "good" home hygiene and "cleaning well" as the extermination of dirt and germs require a significant amount of time, vigilance, and labor. This paper has highlighted that in the context of homes characterized by significant competition between practices for time, parents often feel they do not have the capacity to meet normative expectations of cleanliness. This combination of time pressure and high-demand cleaning practices results in the delegation of cleaning tasks to professionals and products that are perceived to clean fast and effectively. Most products, such as antibacterial wipes and surface sprays, generally contain a range of chemicals that help them smell fresh, create a "sparkly" surface, and sterilize with antibacterial agents. However, scientific research suggests that none of these product attributes are more effective than soap and water in creating a home environment free of potential pathogens (Aiello et al., 2007). They are creating a *sense* of cleanliness, while contributing significantly to the amount and diversity of chemicals in a home's microecology.

To investigate how cleaning practices could be reformed to address actual risks posed by microspecies in domestic spaces, it is proposed that the research approach presented herein is extended to develop a new transdisciplinary agenda. Based on the findings presented in this paper, a method for investigating indoor environmental health that continues to include, but does not prioritize, scientific understandings of the problem and potential solutions are evidently required. The dominant research discourses on indoor environmental health often presented in scientific journals frame such issues based on disciplinary orientation—notably particulate matter in indoor air (Meadow et al., 2014), chemicals in consumer products (Loretz et al., 2008), or the microbiology of built environments (Adams et al., 2016). A single discipline's exclusion of all variables within these indoor "ecosystems" and how they interact with one another leads to narrow definitions of the problem, and obfuscates solutions that do not fit disciplinary framings. Scientists examining the microbiome of built environments have begun to call for a new research program that accounts more for chemical use practices (National Academies of Sciences, Engineering, and Medicine, 2017). However, the integration of relevant scientific knowledge is only half the task. Unless social scientists, policy-makers, product manufacturers, and "users" are engaged to analyze how and why certain practices are leading to the development of particular microecologies, the designs of effective interventions will remain obscured. Finally, in addition to social and physical scientists, this paper has demonstrated the crucial role the design of both built environments and objects play in the reproduction of dominant domestic cleaning practices. Urban planners, architects, and designers will consequently contribute in any attempt to reorient material engagements to sensitize people to risk, and encourage practices that more accurately reflect the actual needs required for hygienic human habitation.

For a transdisciplinary research agenda addressing suboptimal home environments to be effective and genuinely transdisciplinary, the boundaries that separate and stratify the disciplines and interest groups detailed in this paper must be transgressed. This will involve critical reflection on the politics of knowledge, which has prioritized scientific methods of knowing over "softer," more qualitative forms of inquiry or lay experiences in indoor environmental health research to date (Brown et al., 2010). As the body of research into social practices now attests (Blue, 2017; Hui et al., 2016; Shove et al., 2004), the outputs of this new research agenda must move beyond targeted messaging to individuals around behavior change. Rather, they must address the systemic, structural, material, bodily, and cognitive drivers of current practices at multiple scales, and across diverse populations. Such a research agenda has the potential to match knowledge about health risk with knowledge about the material culture, meanings, and habituated actions that constitute current home hygiene practices to gain a more sophisticated understanding of how this issue can be addressed, and by whom.

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Mapping Urban Aerosolized Fungi: Predicting Spatial and Temporal Indoor Concentrations

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Abstract

The prediction of bioaerosols, specifically airborne fungi, can be achieved using various mapping techniques, potentially enabling the determination of ambient indoor concentrations within environments where people spend most of their time. The concentration and composition of indoor air pollutants are determined by a multitude of variables, with building ventilation type being the most predominant factor in most scenarios. A predictive statistical model-based methodology for mapping airborne fungi was developed utilizing satellite-based technology. Mapping was carried out for total aerosolized fungal spores and the diversity of aerosolized fungi in Sydney, Australia, over four seasons. Corresponding data for a range of environmental parameters known to influence airborne fungi were also used, notably green space density, land cover, altitude, meteorological variables, and other locally determined factors. Statistical models previously developed from the combined meteorological and environmental variable data were used to establish spatiotemporal models for airborne fungi across the study area for each season. Results showed that the models produced reasonable predictions of monitored

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aeromycota concentrations; although, the accuracy of these predictions for individual survey periods was variable. Using known indoor/outdoor (I/O) ratios of airborne fungi for the area, the prevalence and concentrations of indoor aeromycota were modeled for buildings with both natural and mechanical ventilation. As accurate manual assessment of the aeromycota is labor, time, and cost intensive, the current findings should assist in the prediction of fungal aerosols in both urban and indoor environments. Additionally, understanding the indoor microbiome has great importance for the health and well-being of the occupants concerned.

Keywords: airborne fungi, fungal diversity, indoor microbiome, GIS, outdoor exposure

Introduction

Ambient bioaerosols include microorganisms, particles originating from plants and animals, and toxins originating from microorganisms (Calvo et al., 2018). Bioaerosols are abundant, with fungal spores being one of the most prevalent suspended particles in the ambient environment, accounting for up to 60% of ambient organic particulate matter (PM), with a diameter of ≤ 10 μm (393.7 μin) (i.e., PM_{10}; Bauer et al., 2008; Kallawicha et al., 2015). Exposure to high concentrations of fungal aerosols is associated with asthma, allergic rhinitis or sinusitis, and atopic dermatitis (Fisher et al., 2012). Further, the importance of fungal spores is highlighted in urban environments, where the prevalence of allergies has been estimated to be higher than in rural environments (Majkowska-Wojciechowska et al., 2007). Many studies have investigated the distributions of fungal spores and the associations between airborne fungi and air pollutants, meteorological factors, and other environmental events (Almeida et al., 2018). Although the variations of bioaerosol distributions within cities are not yet fully clear, studies have indicated that levels of other air pollutants (e.g., nitrogen dioxide) have significant within-city differences, with this trend likely extending to bioaerosols (Kallawicha et al., 2015; Maya-Manzano et al., 2017).

When inhaled, fungi contribute to adverse health effects. A large proportion of people experience allergic responses to specific fungi, and have respiratory conditions that are exacerbated by fungal exposure (Baxi et al., 2016; Carrer et al., 2001; Dutkiewicz, 1997). Further, the health effects of inhaled fungal particles can include exacerbation of asthma, allergic rhinitis or sinusitis, hypersensitivity pneumonitis, allergic respiratory ailments, and atopic dermatitis. The health effects of aerosolized fungi also vary based on the differing pathogenic properties of the fungi themselves (Dutkiewicz, 1997).

As individuals in urban societies spend most of their time indoors (Leech et al., 2002; Lyytimäki, 2012), where microorganisms too inhabit, indoor environments represent a major interface of contact between the two entities (Tong et al., 2017). Understanding the factors that shape the indoor microbiome and its distribution

patterns has great importance for occupant health and well-being. Indeed, the indoor microbiome has in recent years received much research interest (Adams et al., 2015; Crawford et al., 2009; Kemp et al., 2003; Lee et al., 2006; Li & Kendrick, 1995; Sautour et al., 2009). The concentration and composition of indoor bioaerosols may be determined by a multitude of variables, with the microbial source and building ventilation type likely to be the most predominant factors in most scenarios (Prussin & Marr, 2015). The relationship between these two variables can be complicated at times, as in many buildings the inflow of outdoor air may change temporally, as will ventilation requirements associated with thermal conditioning or other indoor environmental quality requirements (Irga et al., 2018).

Three different ventilation strategies are utilized in modern urban buildings, whether residential or commercial. Natural ventilation occurs through windows, doors, skylights, and roof ventilators, and such air is not conditioned and rarely filtered (Irga & Torpy, 2016b). Mechanical ventilation, by which the air is forcibly supplied to an indoor environment by centralized heating, ventilation, and air-conditioning (HVAC) systems, usually filter the supply air to prevent the distribution of contaminants (Irga & Torpy, 2016b; Kemp et al., 2003). The third ventilation type, which is common in tropical and subtropical climates, is mixed-mode ventilation, combining natural and mechanical ventilation methods (Irga & Torpy, 2016b). Although natural ventilation has numerous benefits, the concentration of indoor airborne pollutants can be higher in naturally ventilated buildings, due to outdoor air pollution being transported indoors through openings and leaks in the building envelope (Crawford et al., 2009; Irga & Torpy, 2016b). However, it is largely unknown if these three different ventilation types affect the microbiome within their associated buildings. Thus, this paper aims to quantify the seasonal outdoor airborne fungal spores and subsequent indoor airborne fungal spores based on building ventilation type across Sydney.

Research Purpose and Transdisciplinary Implications

Predictive models for airborne fungi would be of substantial value, informing building ventilation system choice, design, and operation to minimize health effects on occupants, as well as provide a greater understanding of the relationship between outdoor exposure levels and subsequent indoor exposure levels. Further, accurate empirical assessment of the aeromycota is labor, time, cost, and training intensive. Thus, mapping techniques are valuable to enable the prediction of total concentration of airborne fungi encountered at a specific space and time. Given that the types and concentrations of aeromycota in indoor air respond to variations in urban design as well as environmental and meteorological variables, transdisciplinary research that integrates mycology, biotechnology, spatial sciences

and statistics, and built environment engineering knowledge will also be necessary to produce generally effective outcomes. The application of these findings further extends across numerous disciplines that encompass human environments, as they will influence building practices and design to predictively control occupants' exposure to aeromycota. Coupling spatiotemporal fungal distribution models with building infiltration factors (i.e., the ratio of fungal spores likely to penetrate into an indoor space from the outdoor environment) may allow for predictions on the concentration of fungal propagules in any indoor setting.

The fungal aerosol distribution maps presented in this paper have been developed to facilitate the study of human exposure to potentially allergenic fungi. Combining these models with hospital admissions data for asthma would be valuable in studies examining the effects of allergenic fungi. By producing detailed maps of the locations of allergenic fungi, it may be possible to identify fungi associated with increased hospital admissions for asthma in a specific region or season (McInnes et al., 2017). This level of detail could help with the accurate measurement of health effects as well as monitoring for climate effects through changes in source distribution, and changes to fungal allergenicity. Similarly, aeromycota mapping may also help affected individuals self-manage their allergy or asthma. Sensitive individuals have the potential to limit their exposure when coupled with readily available information, such as weather data, and with an understanding of their ventilation system (i.e., whether to close their windows if they are in a naturally ventilated building or turn on their air-conditioning systems in a mechanically ventilated system). Once linked with health effects, these maps allow for increased guidance, with respect to ventilation management practices, to limit exposure to the most allergenic fungi or to those who have compromised health. The application of these findings further extends into architecture, development, and urban planning, as they will influence one's decision-making to maximize both workability and livability of buildings through the minimization of aeromycota exposure.

Materials and Methods

The current work used geographic information system (GIS) mapping techniques to predict the concentration and diversity of airborne fungal bioaerosols. Statistical models based on a previous empirical assessment of fungal bioaerosols in urban Sydney were employed therein (Irga & Torpy, 2016a).

Site Description

The study was conducted in the Sydney metropolitan area (approximately 4.5 million inhabitants) of eastern Australia (33.8688°S, 151.2093°E). The city includes both constructed urban environments with a limited proportion of vegetated ground area, and natural environments occupied by diverse dry sclerophyllous

vegetation. The study area has the characteristics of a warm–temperate maritime climate (Vaneckova et al., 2008). The mean annual temperature is 21.9°C (71.4°F), with the monthly averages ranging from 17.1°C (62.8°F) during winter to 25.7°C (78.3°F) during summer, while the mean annual precipitation is 1,216 mm (48 in), with a monthly average ranging from 76.0 mm (3 in) during spring to 126.0 mm (5 in) during autumn (Table 1).

Table 1. Climate-descriptive statistics for urban Sydney, Australia.

Statistics	Summer	Autumn	Winter	Spring
Mean maximum temperature (°C)	25.7 (78.3°F)	22.3 (72.1°F)	17.1 (62.8°F)	22.0 (71.6°F)
Mean minimum temperature (°C)	18.4 (65.1°F)	14.6 (58.3°F)	8.8 (47.8°F)	13.5 (56.3°F)
Mean monthly rainfall totals (mm)	98.9 (3.9 in)	126 (5 in)	103.5 (4.1 in)	76 (3 in)
Mean monthly number of days of rain ≥ 1 mm (0.04 in)	8.5	9.1	7.8	7.8
Mean daily sunshine (hours)	7.1	6.2	6.3	7.4
Mean monthly number of clear days	6.2	8.6	11.5	8.3
Mean monthly number of cloudy days	13.1	11.4	9.1	10.8
Mean 9 am temperature (°C)	22.1 (71.8°F)	18.0 (64.4°F)	11.8 (53.2°F)	18.0 (64.4°F)
Mean 9 am relative humidity (%)	70.7	73.3	70.3	63.0
Mean 9 am wind speed (km/h)	8.9 (5.5 mph)	9.1 (5.7 mph)	12.8 (8 mph)	11.9 (7.4 mph)
Mean 3 pm temperature (°C)	24.5 (76.1°F)	21.8 (71.2°F)	16.9 (62.4°F)	20.7 (69.3°F)
Mean 3 pm relative humidity (%)	61.7	59.3	52.3	55.0
Mean 3 pm wind speed (km/h)	18.1 (11.2 mph)	13.9 (8.6 mph)	15.5 (9.6 mph)	18.9 (11.7 mph)

Source: Bureau of Meteorology (2018a).

Data

The current work utilizes the empirical data generated by Irga and Torpy (2016a) for model development. Briefly, field sampling was conducted to determine the diversity and relative abundance of airborne fungal genera in Sydney, with the aim of determining seasonal and meteorological relationships, while also identifying potential source relationships. The field sampling involved monitoring airborne fungal spores across 11 sites with a range of varying predictor characteristics. Samples were collected monthly at each location using a Reuter centrifugal air sampler, followed by seven days of incubation and genus-level identification microscopic morphology for each sample (Irga & Torpy, 2016a). The models predict aeromycota

concentration in colony-forming units (CFU/m^3) and diversity (number of genera encountered), and are expressed in the supplementary data published by Irga and Torpy (2016a).

Four data sets were necessary to generate the maps: percentage grass cover, wind speed, rainfall, and temperature. These variables were utilized, as they significantly correlated with aeromycota concentration (CFU/m^3) and diversity (number of genera encountered), and added predictive power to the statistical model, as published by Irga and Torpy (2016a). To enable temporal comparisons, input data were limited to the middle month of each season, as those months were considered the most representative. Thus, January was selected for summer, April for autumn, July for winter, and October for spring. Additionally, data from 2014 were collected where possible, as this corresponds to the year in which the majority of samples were taken to generate the statistical model.

Further, the indoor/outdoor (I/O) ratio data from Irga and Torpy (2016b) was used to predict indoor exposure. Briefly, paired indoor and outdoor samples were taken across 11 buildings in urban Sydney (Irga & Torpy, 2016b) during the same study period as the field study previously described (Irga & Torpy, 2016a). Commercial buildings that were proximal to central Sydney with a general distribution across the central urban area were selected, while building ventilation types were classified as natural, mechanical, and mixed-type ventilation (Irga & Torpy, 2016b). These data, coupled with the predicted outdoor aeromycota levels, allowed for the development of predictive indoor exposure models.

Percentage Grass Cover

Percentage grass cover was derived from the normalized difference vegetation index (NDVI), which is a numerical indicator of terrestrial-based vegetation founded on the red and near-infrared reflectance ratio gathered from satellite remote-sensing measurements (Bhandari et al., 2012). The ratio is based on the chlorophyll present in plants absorbing red light while leaf structures scatter near infrared light (Pettorelli et al., 2005). This index rose with increasing "green" coverage, and was used in the current work as a proxy for vegetation cover (Pettorelli et al., 2005). Typical NDVI values ranging from 0.2–0.5 were considered indicative of sparsely vegetated landscapes (Palanisamy & Gurugnanam, 2014), while NDVI values less than 0.2 were typically representative of non-vegetated areas such as exposed soil, rock, or sand (Bhandari et al., 2012; Carlson & Ripley, 1997; Scanlon et al., 2002; Turner et al., 2013). Conversely, NDVI values higher than 0.5 were considered to indicate densely vegetated landscapes (Bhandari et al., 2012; Scanlon et al., 2002; Turner et al., 2013). NDVI data were further processed to obtain a proxy for grass cover (see Processing and Analysis), and were obtained from the Advanced Very High-Resolution Radiometer instruments carried on the United States National Oceanic and Atmospheric Administration (NOAA) (–11, –14, –16, and –18

satellites). These were received and processed by Australia's Bureau of Meteorology (BOM, 2018b), and were provided in 0.05° x 0.05° gridded monthly averages across Australia (BOM, 2018b).

Rainfall

Mean monthly rainfall total (mm) data from 1961 to 1990 were collected from the BOM's network of weather stations, and processed by averaging the months across years. An analysis technique using an optimized Barnes successive correction was next applied to the station-weighted averages to produce the data sets (Jones et al., 2009). Again, the data were obtained in a 0.05 x 0.05° gridded output (BOM, 2016a).

Temperature

Mean temperature (°C) data were sourced from the BOM (2016b) and obtained in the same manner as the rainfall data, in a 0.025° x 0.025° gridded output.

Wind Speed

Daily near-surface wind speed was obtained from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) as daily averages from a network of low-set anemometers. These were subsequently interpolated and smoothed using a trivariate thin plate spline as a function of longitude, latitude, and distance inland from the coast (CSIRO, 2018; McVicar et al., 2008). As monthly averages were required, four randomly selected days across each of the months of interest were averaged. The data were provided in a 0.01 x 0.01° gridded output (CSIRO, 2018).

Processing and Analysis

All gridded data were converted to raster images and resampled to a resolution of 0.01° x 0.01° (approximately 1 km x 1 km [0.6 mi x 0.6 mi]), if they were not already in that resolution. All raster data were vectorized to allow for processing and overlaying, and clipped to represent the area of urban Sydney that was sampled by Irga and Torpy (2016a). All data for each seasonally representative month were overlaid through spatial joining to ensure the data required for aeromycota concentration and diversity (see Equations 1 and 2, Supplementary Data) were present in each pixel.

Two of the data sets required further progressing before the equations could be applied. NDVI data were converted with the use of a scaling NDVI equation (Equation 3, Supplementary Data) to obtain an index representing grass cover. As near-surface wind speed was provided as daily averages during 2014, four randomly selected days from each of the four months were selected to calculate

monthly averages. A linear wind speed correction factor of 0.1667 was applied to the averaged data due to the original instrument used by Irga and Torpy (2016a) being limited to a maximum reading of 10 m/s (33 ft/s). Thus, a 'wind speed index' with a maximum of 10 m/s (33 ft/s) was used as a surrogate for wind speed.

After all data sets were overlaid and processed, both equations were run for each pixel to develop predictive models for all seasons, both for total aeromycota density and diversity. Further, the I/O ratios were modeled for building ventilation types classified as natural, mechanical, and mixed-type ventilation for each season.

Results and Discussion

Comparison of Spatial and Temporal Trends in Outdoor Aeromycota for Urban Sydney

The current study provides the most comprehensive mapping of aeromycota across urban Sydney to date, elucidating both spatial and temporal patterns. The predicted total aeromycota concentrations across urban Sydney for each season are shown in Figure 1. Concentrations ranged from 330 CFU/m^3 (9.3 CFU/ft^3) to 1,765 CFU/m^3 (50.0 CFU/ft^3). Clear spatial and seasonal differences were detected, with high concentrations occurring in summer and spring. This supports expectations, as these seasons tend to have more green vegetation and higher wind speeds that assist with aerosolization and dispersal (Lin & Li, 2000; Pyrri & Kapsanaki-Gotsi, 2017), relative to autumn and winter (see Table 1; Figure 1). Further, both seasons have higher monthly rainfall totals resulting in greater rates of removal, as rainfall washes fungal particles out of the atmosphere (Pyrri & Kapsanaki-Gotsi, 2017; Troutt & Levetin, 2001). Spatial differences across the four seasons were primarily governed by increased wind speeds in the coastal suburbs, which had higher predicted concentrations of aeromycota.

The predicted aeromycota diversity across urban Sydney for each season is shown in Figure 2. The predicted diversity of fungal genera was quite homogenous across the city for all seasons, ranging between 6 and 9 genera for each 80 L (2.8 ft^3) sample (Figure 2). This is likely a result of the highly urbanized environment supporting a very limited fungal diversity due to the altered environmental conditions (Irga & Torpy, 2016a; Parajuli et al., 2018). Spring's higher diversity of aeromycota was matched by its high concentration of total aeromycota, which was most likely due to the low rainfall in this season and, thus, lower removal rates, in combination with higher wind speeds throughout the day assisting with aerosolization (see Table 1; Figure 2). Winter had the highest diversity, which appeared to be driven by moderate to high wind speeds aiding dispersal, along with low temperatures. Summer supported the lowest fungal diversity, resulting from high temperatures

being inversely related to genera diversity. Further, diversity tended to be higher within central Sydney, which could be due to the altered landscape creating human-made wind tunnels (Yuan et al., 2017). Overall, all four seasons displayed a similar spatial distribution, with lower diversities in the north.

Several investigations have studied the spatial variation of airborne fungi (Arobba et al., 2000; Frenz et al., 1997; Gonzalo-Garijo et al., 2006; Irga & Torpy, 2016a; Kallawicha et al., 2015; Pyrri & Kapsanaki-Gotsi, 2017). High average temperatures and high relative humidity favor microbiological growth, therefore, acting as a source for bioaerosol proliferation (Kallawicha et al., 2015; Oliveira et al., 2005). Sunlight intensity, magnitude of air currents, wind direction, and wind speed also play major roles in bioaerosol concentration and their transportation and dispersal from one environment to another (Ghosh et al., 2015; Oliveira et al., 2005). For example, recently in Taipei, Taiwan, spatial and temporal differences in aeromycota were observed, with higher concentrations noted on a rural to urban gradient during the warmer months (Irga & Torpy, 2016a; Kallawicha et al., 2015).

Further, predictor variables for fungal exposure levels in urban environments may need to consider meteorological factors, air pollutant concentrations, land-use types, and socioeconomic factors (Irga & Torpy, 2016a; Kallawicha et al., 2015; Maya-Manzano et al., 2017; Parajuli et al., 2018; Wollan Anders et al., 2008). Notably, Parajuli et al. (2018) investigated the land-use types surrounding Finnish homes to gauge if indoor concentrations and diversities of aeromycota were affected. They found the more the percentage cover of impervious surfaces increased within an urban environment, the more diversity of aeromycota decreased. Additionally, Kallawicha et al. (2015) identified various factors that positively correlated with the concentrations of aeromycota such as temperature, relative humidity, and rainfall, while wind speed was negatively correlated with high fungal numbers. Correlations between land uses and types varied dependent on the types of fungi detected, but both *Aspergillus* and *Penicillium* were positively correlated with commercial and residential areas (Kallawicha et al., 2015).

Wollan et al. (2008) found temperature and solar radiation had strong influences on the distribution of macrofungi across Norway, while precipitation did not produce a clear relationship, unlike the current study. Pyrri and Kapsanaki-Gotsi (2017) found air temperature, solar radiation, and wind speed had significant positive correlations with the total fungal concentration, and the prevalence of almost all genera studied (Irga & Torpy, 2016a), with temperature being the single best predictor for total aeromycota. Additionally, relative humidity and atmospheric pressure were negatively correlated with the genera examined, except for *Penicillium* (Pyrri & Kapsanaki-Gotsi, 2017). Further, Pyrri and Kapsanaki-Gotsi (2017) found meteorological factors tended to have statistically significant positive or negative correlations with total aeromycota concentrations and diversity, while air pollutants typically had insignificant or weak correlations.

It is clear that different environmental variables affect the airborne fungal community within different geographical areas. Thus, it is likely that individual predictive models will be required for different areas. Currently, the inconsistent approach taken by different studies, notably concerning the specific range of environmental variables assessed, confounds direct comparisons. Further work will be required before accurate comparisons will be possible.

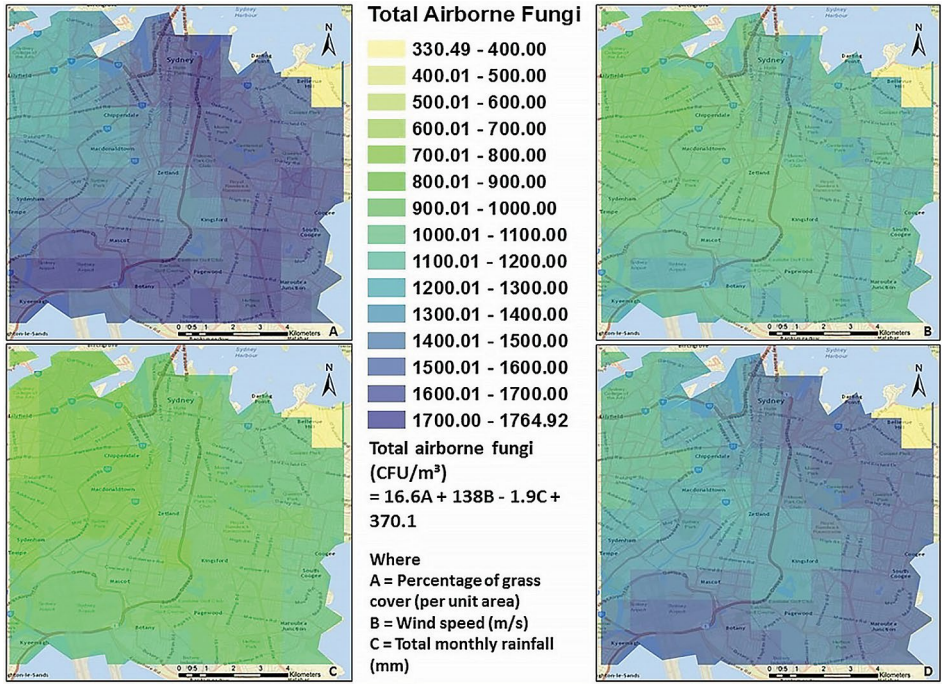

Figure 1. The predicted total aeromycota densities across urban Sydney based on percentage of grass cover, wind speed, and total monthly rainfall during summer (A), autumn (B), winter (C), and spring (D), with a spatial resolution of 0.01 x 0.01 degrees. Total airborne fungi equation sourced from Irga and Torpy (2016a).

Note: British imperial conversions for these calculations are available in the supplementary data for Equation 1.

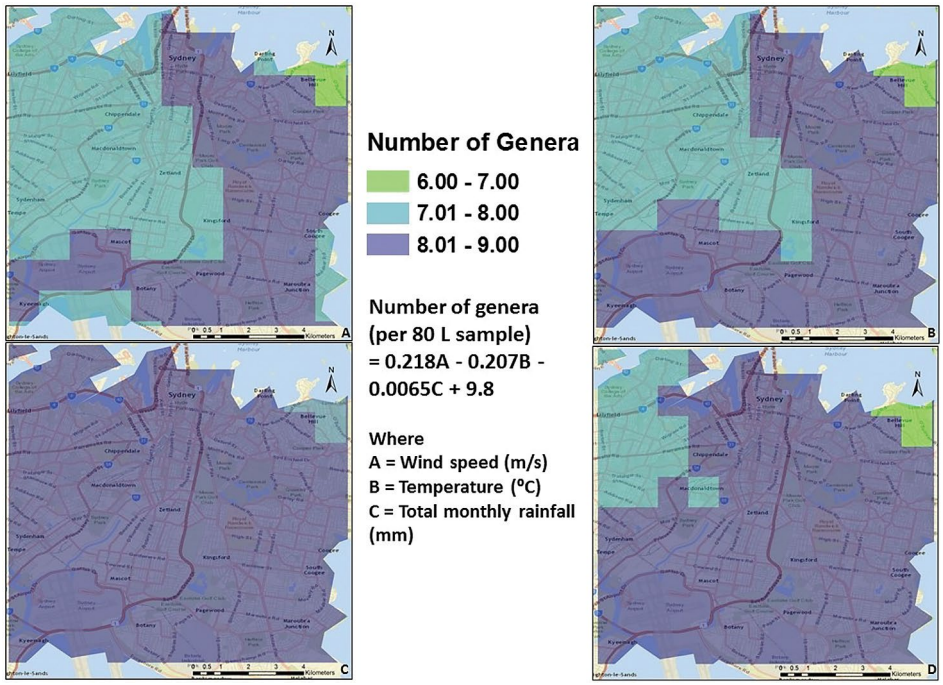

Figure 2. The predicted aeromycota genera diversity across urban Sydney based on wind speed, temperature, and total monthly rainfall during summer (A), autumn (B), winter (C), and spring (D), with a spatial resolution of 0.01 x 0.01 degrees. Number of genera equation sourced from Irga and Torpy (2016a).

Note: British imperial conversions for these calculations are available in the supplementary data for Equation 2.

Predicting the Concentration of Aeromycota in Indoor Environments

To better understand the microbial population assemblage to which humans are exposed, the changes in occurrence and distribution of aeromycota within indoor environments must be investigated. Indoor exposure is primarily caused when fungi is translocated indoors from outdoor environments through HVAC systems or natural ventilation (Li & Kendrick, 1995; Medrela-Kuder, 2003).

As the distribution of microbes in outdoor air is geographically and temporally variable, these patterns transfer to indoor environments (Irga & Torpy, 2016a; Kallawicha et al., 2015; Lee et al., 2006; Li & Kendrick, 1995; Medrela-Kuder, 2003; Oliveira et al., 2005). Building ventilation strategies have been shown to influence the input of microbial communities from outdoor sources through ventilation and other forms of infiltration into the indoor atmosphere (Kemp et al., 2003; Medrela-

Kuder, 2003; Sautour et al., 2009). The source strength of outdoor air and its relative contribution to the indoor aerobiota varies based on ventilation type: within mechanically or naturally ventilated buildings, it is dependent on the inlet filtration efficiency, the rate of ventilated airflow, and the source of ventilated air. Rooms with natural ventilation (i.e., open windows) or modest-supply mechanical ventilation systems show microbial profiles that are similar to outdoor air, with low influence from other sources (Crawford et al., 2009; Irga & Torpy, 2016b; Li & Kendrick, 1995). Therefore, as I/O ratios of airborne fungi for buildings with both natural and mechanical ventilation have been determined (Irga & Torpy, 2016b; Kemp et al., 2003), the species' distribution and concentrations of indoor aeromycota can be predicted. The relationship between indoor and outdoor aeromycota concentrations based on season and ventilation type for urban Sydney is displayed in Table 2. Additionally, the predicted total aeromycota concentrations across urban Sydney for each season and each ventilation type are shown in Figures 3, 4 and 5. Consequently, with knowledge of building location, season, and building ventilation type, it is possible to predict the concentration of aeromycota within an indoor space using these models.

Table 2. Indoor/Outdoor ratios of aeromycota based on season and ventilation type of building.

Ventilation type	Summer	Autumn	Winter	Spring
Mechanical	0.18 ± 0.009	0.57 ± 0.399	0.38 ± 0.146	0.46 ± 0.137
Natural	0.74 ± 0.148	0.54 ± 0.330	0.42 ± 0.088	0.55 ± 0.256
Mixed	0.56 ± 0.313	0.48 ± 0.042	0.58 ± 0.222	0.65 ± 0.097

Source: Irga and Torpy (2016b).

The ventilation types were predicted to have a marked effect on the indoor aeromycota concentrations, with the greatest bioparticle reductions predicted with mechanical ventilation in all seasons except autumn (Table 2). Indoor concentrations in naturally ventilated buildings were predicted to follow a similar trend to the outdoor concentrations (Table 2). Summer was predicted to have the lowest similarity among building types due to increased window usage, while winter had the greatest similarity, as openings in the buildings would remain closed to prevent heat loss (Lee et al., 2006). Mixed-ventilation indoor concentrations had a less predictable trend, as the ratios were the lowest for autumn and highest for spring (Table 2).

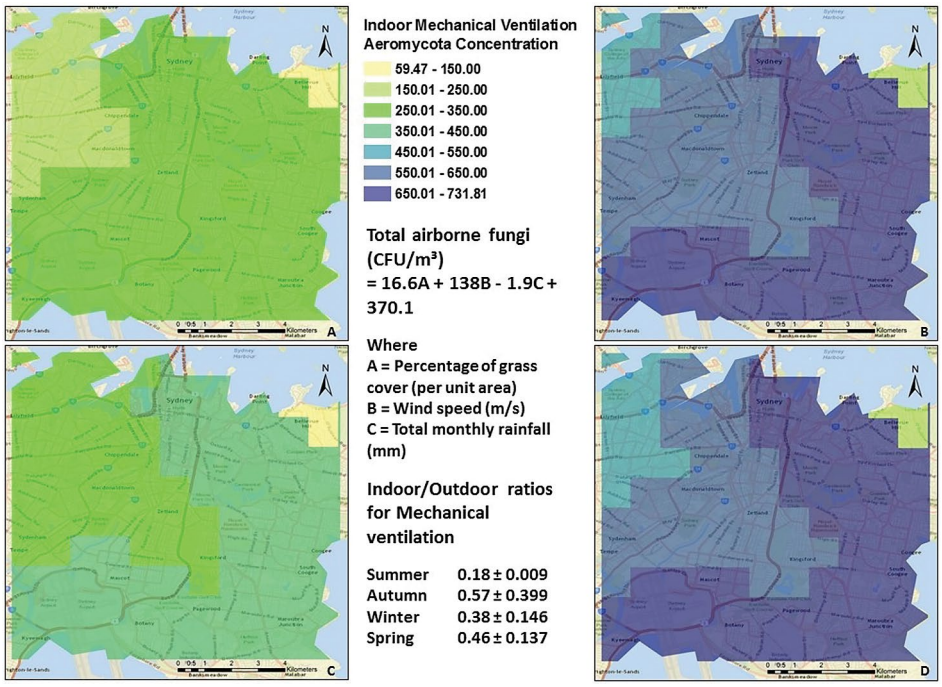

Figure 3. The predicted total indoor aeromycota densities in buildings that have mechanical ventilation across urban Sydney during summer (A), autumn (B), winter (C), and spring (D), with a spatial resolution of 0.01 x 0.01 degrees. Total airborne fungi equation sourced from Irga and Torpy (2016a) and Indoor/Outdoor ratios sourced from Irga and Torpy (2016b).

Note: British imperial conversions for these calculations are available in the supplementary data for Equation 1 and the ratios from Table 2.

After applying the mechanical ventilation I/O ratios, the lowest total indoor aeromycota concentrations generally occurred in summer, while the higher indoor concentrations were experienced in autumn and spring (Figure 3). This ventilation type resulted in the lowest indoor exposure occurring in summer, but the highest exposure for the outdoor concentrations (Figures 1 and 3). Indoor exposure for buildings with natural ventilation followed the same trend as the outdoor concentrations (i.e., the I/O ratios were close to 1), with the highest concentrations occurring in summer and then spring, and the lowest in winter and then autumn (Figures 1 and 4). Buildings with mixed ventilation were predicted to have lower indoor exposure during autumn and winter, and higher contact in spring (Figure 5), which did not correspond with the outdoor concentrations. While the seasonal trends may have differed based on ventilation type and associated ratio differences, the spatial pattern did not differ, with highest concentration distribution tending to the east of the study area, and the lowest concentrations tending toward the northwest.

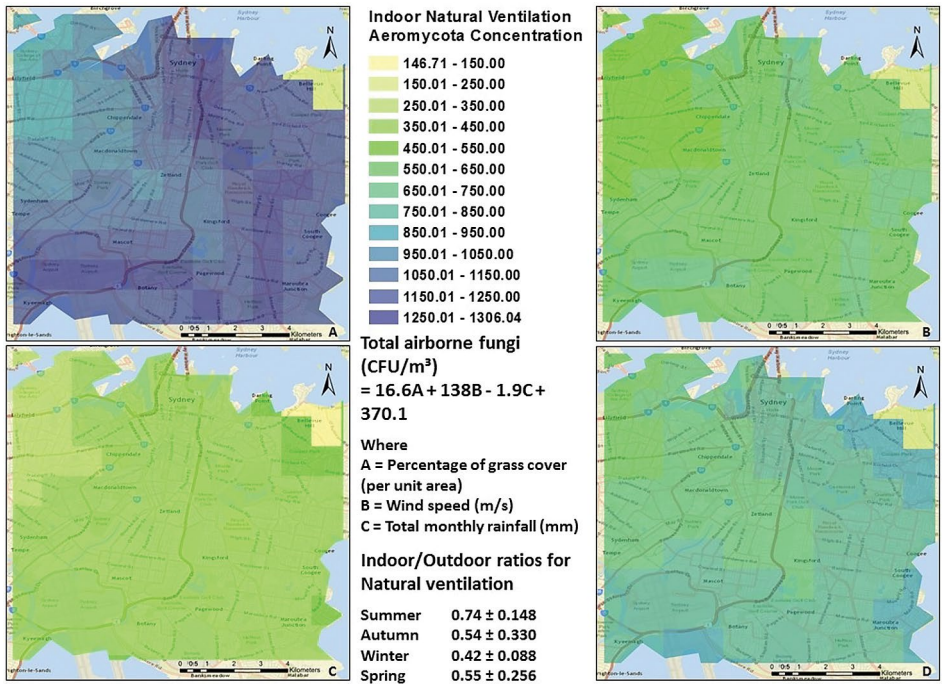

Figure 4. The predicted total indoor aeromycota densities in buildings that have natural ventilation across urban Sydney during summer (A), autumn (B), winter (C), and spring (D), with a spatial resolution of 0.01 x 0.01 degrees. Total airborne fungi equation sourced from Irga and Torpy (2016a) and Indoor/Outdoor ratios sourced from Irga and Torpy (2016b).

Note: British imperial conversions for these calculations are available in the supplementary data for Equation 1 and the ratios from Table 2.

The current study's findings were similar to other published literature that focused on quantifying the effect of ventilation type on indoor fungal bioaerosol concentrations and diversity, particularly when related to mechanical ventilation. For example, Kemp et al. (2003) compared two buildings in central business districts and investigated the potential reduction offered by mechanical HVAC systems. This demonstrated that HVAC systems could reduce indoor fungal counts at the supply air outlets down to 13–27% of the levels in the outdoor air. Additionally, HVAC systems were effective at removing some potentially pathogenic and allergic taxa (Kemp et al., 2003), while mechanical HVAC systems were found to reduce aeromycota concentrations and diversity at both the air outlet and within the system at the cooling coils (Kemp et al., 2003). Li and Kendrick (1995) also found that HVAC systems reduced the concentrations of most airborne fungi, thus, resulting in individuals residing in buildings with air-conditioners exhibiting significantly less severe fungal allergy symptoms.

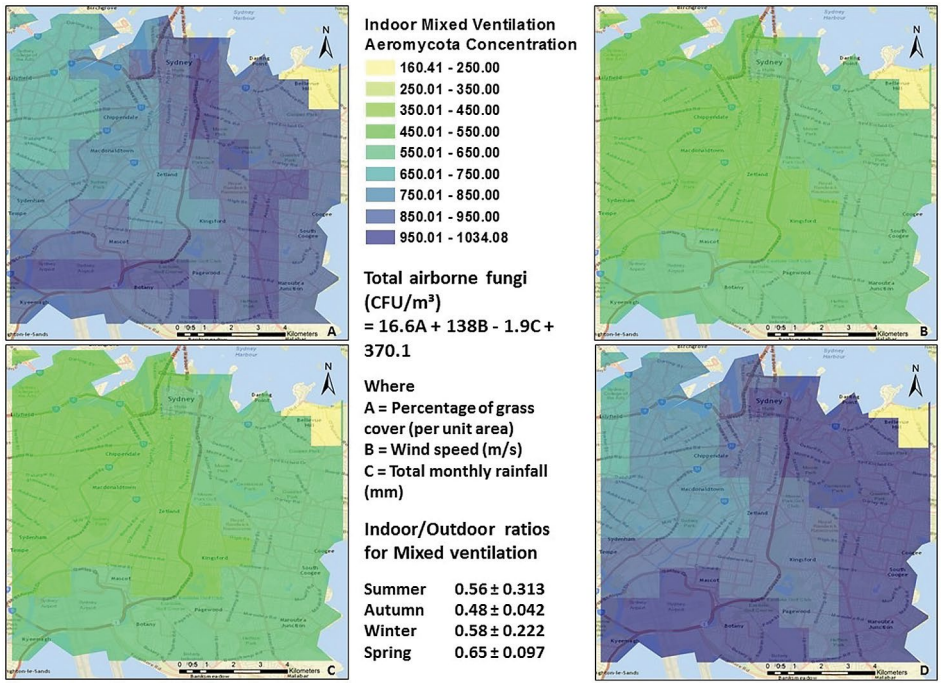

Figure 5. The predicted total indoor aeromycota densities in buildings that have mixed ventilation across urban Sydney during summer (A), autumn (B), winter (C), and spring (D), with a spatial resolution of 0.01 x 0.01 degrees. Total airborne fungi equation sourced from Irga and Torpy (2016a) and Indoor/Outdoor ratios sourced from Irga and Torpy (2016b).

Note: British imperial conversions for these calculations are available in the supplementary data for Equation 1 and the ratios from Table 2.

Sautour et al. (2009) investigated the difference between the outdoor environment and heavily ventilated indoor environments by conducting a one-year aerosolized fungal exposure study between outdoor and indoor air inside two hematological units of a French hospital. During this study, a total of 52 weekly outdoor samples were taken along with 231 and 124 indoor samples across the two hospital units, with a mean outdoor viable aeromycota concentration of 122.1 CFU/m^3 (3.5 CFU/ft^3) while the indoor concentrations were 4.1 CFU/m^3 (0.12 CFU/ft^3) and 3.9 CFU/m^3 (0.11 CFU/ft^3), respectively (Sautour et al., 2009). Again, this indicated the potential effectiveness of HVAC filters in reducing indoor bioaerosol levels.

Model Improvements

In addition to location and building ventilation, architectural and interior building design have been implicated in influencing the bioaerosols that accumulate indoors. This is because variations in building form and interior spatial arrangements can alter how occupants utilize built spaces, and even affect the magnitude and directionality of indoor human–microbe interactions (Meadow et al., 2014). If interior building design could be incorporated into the model, its fine scale accuracy could be improved.

With the data currently available, this study's models can only predict fungal behavior on coarse temporal and spatial scales. Further sampling at finer scales in both space and time would result in models with a greater probability of accurate predictions. In turn, this would allow users to make more informed decisions regarding their health based on fungal bioparticle exposure, without a need for the currently widespread practice of manually sampling air.

Conclusions and Further Work

This study demonstrates that differences in atmospheric fungal spore concentrations can be expected within an urban area. The present study is, to the knowledge of the authors, the first published urban-scale airborne fungal propagule study, which uses an integrated interdisciplinary approach to the construction of a predictive model for airborne fungi across a time scale, with added reference to indoor concentrations. The applied methodology is novel and uses widely available, validated data and land-use information, synthesized with statistical techniques. With additional empirical data and the construction of more complete predictive model functions, the flexibility of the model, coupled with the ease of availability of the predictor data, will allow for the production of high-resolution maps that can be modified according to changes of any of the predictor variables. Further value from these models is related to the capability of predicting aeromycota concentrations without the need for expensive ad hoc on-site measurements. If the sources of fungal spores in urban areas can be further characterized, the next step will be to further develop a local-scale dispersion model to develop and apply a fungal spore emission inventory, and use this as a basis for understanding and explaining air movements transporting fungal distribution on a local scale. This improved understanding can be used to develop an integrated urban-scale exposure system for exposure to allergenic fungal spores in a similar vein to those developed for chemical air pollutants and allergenic pollen.

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Glossary

Aeromycota: Aeromycota is a term for aerosolized fungi.

CFU: CFU refers to colony forming units.

Genera: Genera is the plural form of genus.

GIS: GIS refers to geographical information systems, a variety of software tools that facilitate data capture, processing, management, manipulation, analysis, and visualizations.

Microbiome: Microbiome is the collection of microorganisms and microbes, such as fungi and bacteria, which inhabit an environment.

Sclerophyllous vegetation: Sclerophyllous vegetation refers to vegetation that has hard leaves, which are closer together on the stem, and that hang parallel to direct sunlight. This type of vegetation is common in Australia.

Supplementary Data

Total airborne fungi (Equation 1) and number of genera encountered (Equation 2), as published in Irga and Torpy (2016a), are detailed as follows.

Equation 1

$$\textit{Total airborne fungi}\ (CFU/m^3) = 16.6A + 138B - 1.9C + 370.1$$

$$\textit{Total airborne fungi}\ (CFU/ft^3) = 16.6A + 42.06B - 48.26C + 35.315$$

Where

A = Percentage of grass cover (per unit area)
B = Wind speed (m/s) [ft/s]
C = Total monthly rainfall (mm/in)

Equation 2

Number of genera encountered (*per* 80 *L sample*)
$$= 0.218A - 0.207B - 0.0065C + 9.8$$

Number of genera encountered (*per* 2.8 ft^3 *sample*)
$$= 0.0664A - (0.115B - 32) - 0.1651C + 9.8$$

Where

A = Wind speed (m/s) [ft/s]
B = Temperature (°C/°F)
C = Total monthly rainfall (mm/in)

NDVI data were converted with the use of a scaling NDVI equation (Equation 3) to obtain an index representing grass cover.

Equation 3

$$Fractional\ vegetation\ cover\ = \frac{NDVI\ - NDVI_s}{NDVI_\infty\ -\ NDVI_s}$$

Where:

NDVI is the vegetation index value of an individual pixel

$NDVI_s$ represents the typical NDVI of bare soil areas for the study area

$NDVI_\infty$ is the value of a pure green vegetation pixel for the study area

NDVIs and $NDVI_\infty$ are seasonal and geographical constants that were extracted from a histogram of the NDVI of the study area across the months; these were subsequently confirmed through the use of satellite imagery to ensure the NDVI constants was representative of soil and pure green vegetation. To ensure only grass cover was considered by this index, any pixel with an NDVI greater than 0.35 or less than 0.12 was excluded, based on the methods used by Bhandari et al. (2012), Scanlon et al. (2002), and Turner et al. (2013). These were also validated through the random selection of 20 pixels on a satellite image of the study area to manually confirm the presence of grass cover.

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Technological Innovation and Democracy in the Design of Earthquake-proof Dome Buildings in Yogyakarta

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Abstract

A settlement may be viewed as a sociotechnical network consisting of buildings and social groups that together performs a certain function. A key question that has invited considerable debate in recent literature is how a collection of human and nonhuman elements converge to jointly function, thus, delineating the boundary between indoor and outdoor environments. The purpose of this paper is to address this question by employing actor–network theory (ANT) to investigate the design and construction of earthquake-proof dome buildings within the late 2000s Sleman Regency in Yogyakarta, Indonesia. The design trajectory of these domes was shaped by local and global actors, and negotiated the boundary between humans and their environment. The empirical findings in this paper identify the disentanglement of certain local groups during the design and construction process, which led to a fragile indoor–outdoor boundary, and contested the very uses of these structures. This paper discusses the issue of bringing technological innovation into a democratic composition of a collective, chiefly by introducing ANT in the design and construction of Yogyakarta's earthquake-proof dome buildings. It also seeks to improve both scholarly understandings and existing post-disaster reconstruction practices, in turn.

Keywords: actor–network theory, composition of the collective, indoor–outdoor boundary, post-disaster resettlement, technological innovation

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Introduction

On May 27, 2006, a 6.4 Richter scale earthquake struck the Indonesian island of Java, causing widespread damage in the province of Yogyakarta and its nearby regions. Although its magnitude was not extremely high, the World Bank (2006) reported considerable casualties. Shortly after the disaster, a team of geologists from Tokyo University conducted research on the affected areas and concluded they were no longer feasible for settlement. The local government used this conclusion to decide on a post-disaster resettlement program, which was supported by the World Association of Non-Governmental Organizations (WANGO) in collaboration with Domes for the World (DFTW), to provide the appropriate technology for earthquake-proof communes (Marcillia & Ohno, 2012; Saraswati, 2007). However, when the design and construction processes were complete, the new settlement gradually transformed into a tourist attraction, rather than a town endowed with resilience, or the capacity to adapt to change (Pickett et al., 2013).

Human ecology plays an important role in the study of residential resilience (see Mainka & McNeely, 2011; Pickett et al., 2013). Disasters triggered by natural phenomena bring about dramatic changes for people, their environment, and settlements, to which post-disaster resettlement planning must pay closer attention. A further analysis of such township leads one to issues related to indoor environments, which constitute the primary focus herein. Post-disaster resettlement planning, often implemented with the introduction of new technologies, can significantly change the shape of indoor–outdoor environments.

Generally, human ecology centers on humans and nonhuman entities, and the mutual influence between them. As a scientific field, human ecology deals with facts (i.e., the question of "how things are"), but also deals with values (i.e., the question of "how things should be") in an explicit and direct way. Thus, while human ecology considers the conditions of plantations, animals, other geographical elements, and human individuals and social groups, it also addresses questions of whether particular associations of nonhuman and human entities are desirable or not. For example, a settlement that enjoys the capacity to adapt to change is generally considered desirable, but to achieve this status certain conditions must first be realized. Dealing with complex human–environment relationships, and the facts and values underpinning them, requires a transdisciplinary approach to inquiry, which typically involves transgressing disciplinary boundaries (Russell et al., 2008; Schoot Uiterkamp & Vlek, 2007; Wickson et al., 2006). The question of facts and values considered relevant to a problem has practical as well as theoretical importance.

The key question addressed in this paper regards how human and nonhuman entities converge to mutually function, thus, delineating the boundary between indoor and outdoor environments. This paper will address this by employing actor–network theory (ANT) in an empirical investigation within the context of post-earthquake resettlement in the Ngelepen village Yogyakarta. Through empirical data, this paper describes the various actors and their respective roles in the design, construction, and adoption of dome buildings, and how they negotiate the boundary between humans and their environment, and between indoor and outdoor environments. The data were obtained by conducting field observations and semi-structured interviews for a two-month period in December 2010 and January 2011, as well as a two-day period in July 2018 involving 15 informants from local government, nongovernment organizations, university researchers, and local residents. Through a transdisciplinary approach, the paper contributes to scholarly understandings of how certain indoor and outdoor environments come into existence as the result of post-disaster recovery or resettlement policy practices. Therefore, its findings are relevant to post-disaster resettlement planning, architectural design, and technological innovation. The coming discussions involve a literature review on human ecology, its relevance to post-disaster recovery problems, the transdisciplinary nature of this subject, and how ANT provides a valuable method to conduct such an inquiry. Both the research design and methodology of this paper are presented, followed by the empirical findings and a discussion of the practical and theoretical contributions of this research.

Scholarly Context

While there has been significant literature on the human ecology approach to post-disaster recovery, little attention has been paid to the relation between facts and values implied within investigation. Human ecology may be employed to study a wide array of practices, such as conservation, urban settlements and infrastructures, and indigenous people living in biologically diverse areas. Marten (2001) characterized the discipline as concerning "the relationships between people and their environment" (p. 1), and emphasized its focus on the analysis of "consequences of human activities as a chain of effects through the ecosystem and human social system" (p. 3). For Marten (2001), ecosystems include everything nonhuman, such as biological entities, physical entities, and human-built structures in a particular location, while social systems include everything human, such as social organization, structure, and culture.

Human ecology plays an important role in the study of human resilience to environmental change (Pickett et. al., 2013), including natural phenomena such as earthquakes, tsunamis, and volcanic eruptions, which under certain circumstances cause disastrous outcomes. Attempts to rebuild settlements that are heavily damaged

by earthquakes, in particular, can bring desirable or undesirable consequences to people's livelihoods and other living entities (DeClerck et al., 2006; Mordechai & Pickett, 2018; Tafti & Tomlinson, 2015).

Mukerji (2015) proposed an approach to post-disaster recovery that employs the concept of social capital to analyze community recovery after disaster. This paper highlights the importance of connecting social capital with broader "contexts that can dictate collective action … and new resources that the emergence linking of capital networks can bring to the communities" (Mukerji, 2015, pp. 946–948). Thus, while human ecology addresses complex relationships between humans and environments, it also raises questions of value. In regard to post-disaster resettlement or recovery, research addressing whether or not certain relationships between humans and their environment generate resilience is a value judgment, thus, rendering it good/desirable or bad/undesirable. For example, in McKinney et al. (2015) and Mikkelson (2016), questions of value are explicitly posed in relation to environmental inequality and democracy, respectively. In investigating ecosystems, or in the design and planning of built environments, the notion of ecosystem function is also often adopted (Marten, 2001; Pickett et al., 2013). Hence, in relation to the notion of function, Vermaas et al. (2011) drew a distinction between structural description and functional description, and emphasized that "functions … cannot be contemplated in isolation of the goals of human action and if one presumes that from the moral angle those goals can be evaluated as good or bad" (p. 15). Thus, human ecology deploys scientific facts and structural descriptions in its study of biological and physical entities, but likewise deals with questions of human–social values and moral judgments, either implicitly or explicitly.

This paper advocates for a transdisciplinary research approach to produce required knowledge. Notably, it intends to address complex problems, particularly those involving the interface between human and natural systems, and employs methodologies that reflect and respond to a problem and its given context. Additionally, it involves collaborative knowledge generation between researchers and stakeholders, which provides a "reality check" for research processes and outcomes, in turn (Wickson et al., 2006). To establish connections between facts and values (or science and morality) in a single framework of study requires transdisciplinary research, since both elements traditionally belong to separate domains of inquiry. These difficulties are reviewed extensively within the context of ecology in Latour (2004), and of science, technology, and democracy in Barrotta (2018).

Based on his work in ANT, Latour (2004) proposed an approach that is relevant to addressing the above-described fact–value distinction question within the context of human ecology. Originally formulated and furthered by Latour (1987), Callon (1986), and Law (1990), ANT offers an approach to study society and nature in a symmetric manner. For ANT, society and nature, and both social and technical entities, are not "out there" already held together by a unifying force, or a pre-given

set of rules. Instead, they emerge from heterogeneous associations between humans and nonhumans. As they enter into association, the competencies and roles of those entities are defined through trials, with their actions subsequently dependent on their relations. Meanwhile, competencies and agencies are being contested through association—hence, the term "actor–network theory" (Latour, 2005).

By resorting to the notion of human and nonhuman associations, Latour (2004) builds a framework for studying the link between humans and their environment, and the implied connection between facts and values. By observing how scientific facts are obtained and presented, Latour (2004, p. 103) extracted two different phases: perplexity and institution. Perplexity refers to the uncertainties that emerge when new propositions are put forward, or when new human–nonhuman existences are considered, to, therefore, stimulate debates, while institution occurs when attempts are made to bring these deliberations into closure. Examining how values are conceived in discourses and practices, Latour (2005, p. 105) occasioned two subsequent phases: consultation and hierarchization. Consultation occurs when every candidate for existence is evaluated by involving a spokesperson—effectively, a jury that corresponds to its own recalcitrant problem—while hierarchization occurs when attempts are made to bring heterogeneous human–nonhuman entities into an homogeneous order of relative importance. These four phases help separate, yet reconcile, the questions of fact and value, in turn. Latour (2004, p. 109) then regrouped perplexity and consultation to question processes of consideration, and used hierarchization and institution to question how order is subsequently arranged. Essentially, the four phases are together understood as constitutive of the process of composing the "collective."

Latour (2004, pp. 136–161) elaborated on a set of instruments, skills, and knowledge commonly deployed by professions such as scientists, politicians, economists, and moralists, which are relevant to this process of composing a "collective." In perplexity, an important role here is generally played by scientists who, equipped with measurement instruments, display devices and laboratories, and make phenomena more visible. Meanwhile, politicians promote a sense of urgency or danger, and act as spokespersons of entities that demand consideration. Economists help detect invisible entities and involve them for the possible attachments between humans and nonhumans as goods and consumers or producers, while moralists function by pinpointing those who require attention. In consultation, scientists investigate all candidates, politicians form concerned parties and reliable witnesses, economists discover for each type of attachment the apposite process of interest, and moralists ensure each candidate is evaluated by a jury corresponding to its own recalcitrant problem. In hierarchization, science brings heterogeneous entities in an homogeneous hierarchy, politics make it possible to arrange incommensurable beings from largest to smallest, economy provides a common language to an

heterogeneous set of entities, and morality reminds us to find one order, not two. Finally, in institution, scientists shelter facts, while politicians have the potential to divide collectives into friends and enemies in their requirement to bring closure.

While Latour (2004) dealt with problems of political ecology in general, this paper incorporates his work into the specific quandary of indoor settings. Through empirical research, this study employs Latour's complex four-phase framework to describe how a collection of human and nonhuman entities converge to function together, thus, delineating the boundary between indoor and outdoor environments during post-disaster resettlement.

Methodology

The research design and methodology for this paper were developed using ANT. Aside from its practical and societal importance, the post-earthquake resettlement in Yogyakarta was chosen as an empirical case study due to its theoretical relevance. The case involves cultural plurality that bred controversy (Saraswati, 2007), and concerns the introduction of new technology and innovation. It is hoped that exploring such an incident generates an empirical base for further theoretical discussions on environmental change, cultural plurality, and technological innovation. This particular case study is part of a broader research project that addresses practical and theoretical issues in technological innovation, environment, and democracy within an Indonesian context.

Context of the Case Study

Approximately 18 percent of the total area of the province of Yogyakarta in the Sleman Regency consists of 17 subdistricts, 86 villages, and 1,212 hamlets. The regency ranges from 100 m to 1000 m (328 ft to 3,280 ft) above sea level, and is endowed with a wet tropical climate and rainy season, with air temperature ranges between 26–28°C (79–82°F), and average rainfall of 16.2 mm (0.65 in). Being adjacent to Mount Merapi—one of the most active volcanoes in the world—the Sleman Regency has fertile land, with nearly half of the area used for agricultural activities supported by irrigation infrastructure. As the regency is located along the Indo–Australian–Eurasian plate subduction line, this makes it particularly vulnerable to earthquakes. In a broader context, the spatial planning of the entire Yogyakarta province follows the so-called "imaginary axis," which derives from traditional Javanese culture and describes the journey of human life from birth, adulthood, and finally death. Mount Merapi occupies an important position in Javanese culture, as it is believed to be the central kingdom of spirits. Elements of a traditional house, or "Joglo," are also associated with certain values and norms in

Indonesia (Dakung & Proyek Inventarisasi dan Dokumentasi Kebudayaan Daerah, 1983; Santosa, 1997); with its rectangular form, such a building serves as a reference for which to structure traditional Javanese homes (Santosa, 1997).

At 5.53 am local time, a 6.4 Richter scale earthquake with an epicenter 20 km (12 mi) south of Yogyakarta struck the Indonesian island of Java for approximately 57 seconds. Although its magnitude was not extremely high, the World Bank (2006) reported the quake caused roughly 6,000 casualties, injured 50,000 people, and displaced 500,000 others, with a total loss of US$3.1 billion, in turn. A small village called Ngelepen located on the sloping hills in the Sleman Regency was severely destroyed following the disaster. Most of its residents including those living in nearby villages earn their livelihood from agricultural activities. Some of them work on their own lands, others as farm laborers, and a few are ranchers and sheep breeders. However, the village's ground was broken apart roughly 20 m (66 ft) in width, 300 m (984 ft) in length, and 7 m (23 ft) deep. Many houses were destroyed and some were displaced from their original locations.

Responding to the disaster, local government officials undertook urgent measures. The Sleman district's Major relocated all 32 families living in Ngelepen as well as 32 others from nearby villages, whose homes were severely damaged. Now located in Sumberharjo, the new settlement is a dome village known as New Ngelepen, which houses 64 families transferred from both regions. Formed on a 2.5 ha (6.5 ac) block of land owned by the local government (and previously used for sugarcane plantations), the construction of this new town was supported by the humanitarian aid program sponsored by WANGO in collaboration with the DFTW, a nonprofit organization based in Utah. Essentially, it provided the technology to help construct these earthquake-proof settlements, known also as "monolithic EcoShell domes" (South, 2013, p. 3). However, after the design and construction processes were completed, the new settlement has since transformed into a tourism hot spot, rather than a domain built for resilience.

Research Design and Techniques

While traditional qualitative methods remain relevant for research purposes, this paper incorporates concepts from ANT to guide the study design—primarily the rule that researchers must "follow the actors" (Latour, 2005, p. 227) and the concept of "translation" (pp. 131–135). As such, relevant actors (i.e., human and nonhuman) must be chosen and subsequently followed to address the key research question; that is, various actors will play their respective roles in the path of New Ngelepen dome-settlement design, construction, and adoption. Since the resettlement program involved the introduction of new technology, this paper adopts the notion of diffusion (i.e., design and construction) and the innovation introduced, in turn (Rogers, 1983). However, while others such as Rogers (1983) focused on both communication processes and channels, this paper instead centers

on the translations and associations between human and nonhuman actors. This was achieved by first selecting an informant from the local government who was responsible for implementing the resettlement program, and who could identify various other parties involved. From this point, a number of academics, other local government officials, an intermediary agent, and local residents were identified. During the interviews and field observations, multiple factors were explored, including the structural elements of the buildings, the site plan and environment proposed in discussions or debates within both design and construction stages, and the adoption of the new settlement. Further considered were those who took part in these deliberations, the issues associated with the nonhuman objects represented by each of the respective parties, and how translation occurred (i.e., changes in design and shifts in focal issues) during those stages. The notion of structural and functional description analyzed in Vermaas et al. (2011) were particularly helpful in guiding the exploration. Interviews and field observations were next conducted over a two-month period in December 2010 and January 2011, while documents related to the resettlement program were collected during the subsequent research period. These concerned spatial and regional planning documents obtained from the local government, and design documents from both DFTW and other local researchers. The total number of informants was 11, with interviews taking up to 60 minutes.

The data from this empirical research were partially used as a basis for completing a master's thesis (Pramularsih, 2011), which focused on the negotiation processes that shaped placemaking in the New Ngelepen settlement. However, it is acknowledged that the data contain rich information that allows for further theoretical exploration. One such element, which was not addressed in Pramularsih (2011), to address first regards the fact–value distinction associated with human and environment relationships. For this, the existing data were further coded and processed using Latour's (2004) framework of "composing the collective," and categorized according to both indoor and outdoor environmental changes, as well as the four aforementioned phases: perplexity, consultation, hierarchization, and institution. Relevant data were also sourced from websites, including other research that maintains regular updates in relation to the New Ngelepen settlement. From these sources, it was concluded that critical events occurred in the settlement during the period between 2006 and 2010. Before finalizing the results presented in this paper, two days of observations and interviews were piloted in July 2018. With regard to other research on post-disaster recovery or environmental change (Mainka & McNeely, 2011; Mordechai & Pickett, 2018; Mukerji, 2015), this research differs in its transdisciplinary approach through its use of ANT.

Ethical Statement

The authors took various measures to guarantee the integrity and quality of the research. Commencing the fieldwork and interviews, all potential participants received full information regarding the purpose, methods, and intended possible uses of the study, with their safety guaranteed. Depending on mutual agreement between the researchers and each individual participant, total confidentiality and anonymity were maintained, with all informants agreeing for interview stating their voluntary willingness to take part in the study. Although there was disagreement among the participants with regard to the successes of the New Ngelepen settlement, the researchers maintained their independent position throughout the activities, and hope the results will be useful to those who contributed, as well as broader related social groups to reach resolve.

Findings

The empirical findings associated with the post-disaster resettlement program are presented in three stages concerning:

1. the design and construction of the settlement
2. the adoption of the settlement by local residents
3. the conception and adoption of the settlement as a tourist attraction in the post-construction stage.

Findings that are relevant to changes in both indoor and outdoor environments are highlighted in each stage. How the findings were analyzed according to the framework of composing a collective is described herein.

Design and Construction of the Settlement

Prior to the presence of both WANGO and DFTW following disaster, a team of geologists from Tokyo University had conducted research on the earthquake-affected areas in the Yogyakarta province. The team found that the geological structure of the Ngelepen area was severely destroyed by the quake and, therefore, no longer technically feasible to support settlement. This finding was reported to local government officials and used as a basis for relocation.

In July 2006, two architects from DFTW, Frederick Crandall and Rebecca South, arrived at Ngelepen and introduced their "monolithic EcoShell dome" technology through a series of talks with representatives from international agencies (such as the United Nations Development Programme and the World Health Organization) and local government officials. In South's (2013, p. 4) document *Ecoshell 1* the structures are characterized as "super-strong dwellings, impervious to fire,

tornadoes, hurricanes, earthquakes, and termites." Crandall and South assigned a local, Mr. Yoss, as a DFTW liaison to select a native academic to represent the communities. He then made contact with Professor Ikaputra from Gadjah Mada University (a government-owned college located in Yogyakarta), who is an architect with academic interests in heritage studies and disaster resilience within built environments, as well as a former member of the University Post Disaster Support Team for the Tsunami Aceh Revival Program. Mr. Yoss organized a meeting that brought together DFTW and WANGO representatives, local government officials, and Mr. Ikaputra. While the idea of strong dwellings proposed by the DFTW was widely acceptable, the dome-shaped design was challenged, especially by Mr. Ikaputra, who, in an interview, voiced his concerns by making reference to the locality's cultural environment:

> The guideline that we made is about earthquake resistance, not the shape of the building. Wherever I go in Indonesia, if I introduce dome building[s], it has always been rejected; culturally different … If I have to speak in the name of culture, I reject the project, it is against my heart. But, ultimately, I accept the project for humanitarian reason[s] … Civil engineers prefer strong … monolithic structure[s], but architects look at technical aspects plus living culture.

Thus, for Mr. Ikaputra, the local communities hold certain cultural values that demand consideration in terms of building design. However, fellow colleague Professor Iman Satyarno emphasized that the structural properties of the domes and their social acceptance are two separate issues:

> Look at the Monolithic Dome website … I also design a dome building. We have made calculations. It can resist earthquake[s]. Technically, it is safe … The structure of the building was my responsibility, but for user satisfaction, it was Mr. Ikaputra's responsibility. In building design, there are two aspects: structure and social. I focus on the structure, the construction—technical specifications.

For Mr. Satyarno, a civil engineer who served as a consultant to the local governments, building designs should primarily respond to physical environments (i.e., physically safe domains). Responding to the controversy regarding the dome shape, Mr. Adi, who heads the Building and Environment division of the local government, held a different view on this matter, stating, "the DFTW architects introduced the dome building … To me, if the building is maintained properly, if it is kept in its original shape, it is unique. It could serve as a marker or a reminder of the earthquake phenomenon."

Despite disagreement, the project continued to follow DFTW's original proposal. As such, Crandall led the development of the proposed dome designs and specified they be 35 sq m (277 sq ft) in width, 7 m (23 ft) in diameter, and 4.6 m (15 ft) in height. The buildings would have one doorway, and be divided into four equally

sized rooms: living room and kitchen with no partition between them, and two bedrooms. When Mr. Ikaputra examined the design, he criticized the indoor environment by again making reference to traditional culture:

> In architecture, the Joglo house is widely known as our reference … They [DFTW architects] introduced a new design reference that may not be suitable for Yogyakarta's culture. It could be suitable only in terms of resistance against [an] earthquake … In Crandall's design, he only provides one doorway. When people come into the building, they will enter directly the living room and kitchen … It is a mistake. In Javanese culture, the host cannot receive guests before taking a bath. In that condition imposed by the design, the host would jump out through a window, because they need to take a bath before receiving the guests … We need another doorway.

Mr. Ikaputra then proposed an indoor design alternative that, for him, was more suitable to Javanese culture:

> With my background in history, culture is the key. I did study for some time in Japan. In Japan, they succeed to combine the old and the new. It is a cultural process. Regarding dome design, I proposed a local contextualization by adding a "tritisan." At first, they rejected my idea, but at the end they accepted.

Evidently, Mr. Ikaputra prompted the Joglo be used as a reference point to model the domes, the key feature of which is the presence of a "tritisan," which, in traditional Javanese architecture, serves as a marker on a home's porch, and covers the underside space against sunlight and rain. In traditional Javanese communities, people interact not only in the outdoors and indoors, but also in between. They converse under the tritisan, while keeping their front doors open. In addition to a front doorway, a back doorway is important, as it is associated with outdoor activities at the back of a house, such as plant cultivation and sheep breeding. As the front and back are associated with very different activities that must be isolated one from another, Mr. Ikaputra's alternative indoor design, which consists of a front doorway and back doorway, ultimately divides the entire interior into one living room, two bedrooms, and a kitchen near a back door. By referring to the Joglo design, Mr. Ikaputra further divided the interior vertically by adding a mezzanine and a ladder located in the kitchen. Each room is provided with an opening, either in the form of a window or "bouvenlight" (upper window), as well as ventilation holes for natural daylight and air circulation.

In negotiating Mr. Ikaputra's design proposal, Crandall sought to adapt his vision to suit traditional culture. He proposed a design equipped with "mustoko" (a dome-like roof placed on mosque buildings), which Mr. Ikaputra rejected, since it is traditionally associated with religious practices and meaning. Conversely, Crandall objected the use of a tritisan, as it would increase construction costs. After some debate, the two agreed on a compromised design that was closer to the original DFTW design in external appearance (i.e., without a tritisan, thatched roof, or any

other decoration), but adopted Mr. Ikaputra's proposal for the interior. Crandall decided that the dome should be coated with fine plastering and white waterproof paint. Considering the tropical climate, the white color was selected to reflect the heat of the sun and, thus, maintain a low temperature inside the buildings. Although Mr. Ikaputra spoke on several occasions about local culture and mentioned the issue of cultural adaptation, an interview with a local resident, Mr. Sakiran, revealed a different interest:

> If you ask each of the 71 households, none of them had previously owned or occupied a Joglo house. Their houses were already made of concrete. What triggered the polemic [*sic*] was the shape of dome buildings, which is very different from what they were familiar with.

As a local resident who occupied the dome building, Mr. Sakiran showed disagreement with Mr. Ikaputra's intent to reference traditional culture. In the post-construction stage, Mr. Sakiran played a leading role in urging local residents to transform the dome settlement into a tourism attraction for economic reasons.

The site plan design stage began soon after the domes and interiors were settled. The design team included the Sleman Regent, relevant local government officials, Mr. Ikaputra, Frederick Crandall, and Rebecca South. The Regent suggested that toilet and washing facilities be located outdoors for common use, as he believed it is among traditional practice to perform washing activities outside while engaging in social interactions. The team agreed to provide one toilet and washing facility for every block of buildings, which was centrally located. The team then added public facilities such as a mosque, a kindergarten, a polyclinic, and a warehouse. The main gate of the settlement is located in the middle of the area facing toward the South Sea, in accordance with the imaginary-axis belief in Javanese culture.

An examination of the Regional and Spatial Plan Document of the Yogyakarta province (Regional Planning Agency, 2009) revealed this so-called "imaginary axis" as a straight line drawn from Mount Merapi down to Keraton (the palace of the Javanese kingdom), and ultimately to the south coast of Java. In traditional Javanese belief, Mount Merapi occupies the spirits that guide in the journey of human life, as signified by this axis. Indeed, it also served in the regional and spatial plan as a general guideline in the settlement's geographical orientation.

Several changes occurred during the actual construction phase. Upon designing the site plan, it was agreed that a communal warehouse would be built. However, it was not implemented, as local residents preferred to store their belongings inside their domes. A wall fence was added in the process, which served as a partition separating the settlement from the cemetery, located in the northern sector.

Adoption of the Settlement

The first stage of adopting the new settlement involved selecting eligible local residents and allocating them to dome units. First priority was awarded to those who lived in the area where massive landslide occurred, and second to those whose homes were severely damaged. To prevent disruptions that could emerge from differences in spatial inequality, the local government officials resorted to a random rule (implemented by a lottery) to decide upon each resident's allocation to a dome house. Upon adopting the settlements, some could not adapt to the round shape of the buildings, thus, creating difficulties when inserting rectangular-shaped furniture. In turn, this meant residents preferred to live in their relatives' homes in other villages.

Those who stayed in the settlement made spontaneous changes to both indoor and outdoor environments. Residents were not comfortable with the communal toilet and washing facilities provided, contradicting both the Sleman Regent's and Mr. Ikaputra's suggestions; as a result, the residents built private toilets behind their dome houses. The absence of cages for livestock in the settlement also discouraged many, according to Mr. Sakiran: "We built communal cages for livestock several months after the project had been completed. The residents did not immediately occupy the buildings; they were still reluctant. They own livestock that stay up the hill. Who will look after them?"

As the majority of residents also work as farmers or ranchers, they previously stored farming equipment, harvests, and seeds inside their homes. For cooking needs, many were still dependent on firewood. An interview with an informal leader of the people explained:

> the dome buildings could be suitable for small families that do not depend on farming activities. For farmers, the buildings are not suitable. Such families own many devices and tools. They need much more space for the devices, tools, and harvests. We then built communal cages. Almost all families own livestock … The addition of [an] extended kitchen is not permissible. However, not all householders can afford to purchase gas for domestic needs. Some of them still use firewood for cooking … In such cases there is no option other than to add an extended space to function as a kitchen.

Early into settlement adoption, conditions were hot and bright due to minimal vegetation and a glare effect emitting from the white paint of the buildings. In the domes' design stage, the color choice was decided by considering the indoor environment, while apparently disregarding the outdoor experience. The importance of vegetation in creating a comfortable outdoor area was also not addressed while designing the site plan. During the day, the mezzanine room on each building's second floor is relatively hot because of the shallowness of the space between itself and the roof, while in the rainy season, water seeped into some domes through the

porous walls and floors, which made the walls moist. An interview with Mr. Sakiran revealed more: "When we discussed the site plan, we agreed to maintain the Yogyakarta's culture … To me, this is not only about culture, but also how to make the dome house comfortable. Apparently, when raining the rainwater seeped into several houses."

Facing uncomfortable conditions, the residents began to make various adjustments to indoor and outdoor environments. They began to plant trees and vines, which were grown on one side of the dome for coverage, therefore, reducing heat and glare. Residents also added tritisan and canopies atop door frames, windows, and vents to prevent rainwater from entering their homes. They also added a semipermanent gazebo that directly attached to the dome house, and a larger canopy to create enough open space for residential activities.

Tourists' Turn

The emergence of Yogyakarta's dome settlement has attracted the attention of people from nearby villages and abroad. Since the early stage of its construction, many visitors had come to explore the outdoor and indoor environments of the new town. Mr. Sakiran, who led the development of tourism in New Ngelepen, described the situation:

> In the beginning, it was not a deliberate process. When the dome buildings' construction began, people from nearby villages and elsewhere came to visit this area. They seemed to be interested in the shape of the buildings, their features, and construction method. Realizing that the visitors kept increasing in number, they came here by cars or motorcycles, and brought their children; I and my friends were thinking of providing services to those visitors. We provided services for parking and information regarding dome buildings.

The local government also responded to the emerging attraction of the New Ngelepen village. Mrs. Nunuk of the regional planning office described the government's response:

> In the beginning, because of the earthquake, the area was designated for a resettlement. But because of its uniqueness, we develop[ed] it as a tourism attraction. We have developed several tourism packages that explore other heritage buildings such as Boko Queen Temple and Green Temple. Now we have included the dome settlement into a single tourism package. It started in 2010. Thus, we decided that dome settlement will only be developed in New Ngelepen, not in other areas, to keep its uniqueness. The main objective is for local economic empowerment. We have provided trainings [*sic*] to create attractions such as a Teletubbies performance.

As the settlement gradually transformed into a tourist attraction, the number of visitors continued to increase, and the demand for services soon developed. The residents subsequently formed a local organizing group led by Mr. Sakiran, who together developed tourism services such as homestays, information services,

and other attractions. Its organizers continue to earn revenue from these facilities, which are shared between all involved parties. However, as their activities developed, a number of issues emerged:

> There is a human resource issue. I don't blame the residents. They used to be traditional farmers; they don't know tourism at all. If they see a piece of land, no matter how small it is, they will immediately cultivate something on that land. But this kind of habit makes things messy … [a] lack of aesthetic. This habit is not appropriate for tourism … But that is the challenge … not easy. To manage the tourism services, we need to learn how to serve visitors, how to provide information to visitors. But the residents are reluctant to learn. If we could develop the area into a tourism destination, we could earn money from it. We could make promotion via television programs. (Mr. Sakiran)

Despite the constraints described by Mr. Sakiran, the tourism activities continue and bring about gradual changes to the indoor and outdoor environments of the dome settlement. Some of the residents have since opened kiosks that sell food and beverages, while others make toys as souvenirs and objects for stage performances, such as clown costumes and Teletubbies statues. Gradually, the residents began to make the dome buildings colorful and even agreed to name the surrounding hills "Teletubbies Hill."

Discussion

This section presents the research findings in relation to the "composition of the collective" framework, and, more specifically, to the settlement's design and construction stage, as well as its adoption of the domes turned tourist attractions. This will feed into the four perplexity, consultation, hierarchization, and institution phases to demonstrate how human and nonhuman associations delineate the indoor–outdoor boundary, and help define the New Ngelepen settlement. This section next discusses how the results may be used in the practices of post-disaster resettlement policy, and their contribution to the relevant literature.

Indoor–Outdoor Delineation as Composition of the "Collective"

Perplexity

Although earthquakes are not a new phenomenon to Yogyakarta's residents, the DFTW architects brought with them new perspectives through their scientific demonstrations. They sought to draw the residents' attention to the ground-level shock triggered by the earthquake, and how that propagates through the structural elements of their architecture. Likewise, they focused on how best to counter the effects of the quake through the construction of resistant structures

(i.e., the monolithic dome houses). Other groups of scientists, such as the geologists from Tokyo University, made visible the geological conditions of the areas touched by disaster. As different researchers from local colleges took part in either scientific grouping, both considered opposing perspectives: the building structure and indoor environments, and the geological structure and outdoor environments. At first, the local government focused on the latter in its post-earthquake resettlement program, then on the geologists' findings. However, the DFTW's monolithic dome technology, with its emphasis on super-strong dwellings, drew the government's attention to the interior. Meanwhile, Mr. Ikaputra reminded every party to consider traditional Javanese culture therein, as embodied in the Joglo design, with its own dual indoor–outdoor orientation, while Mr. Sakiran emphasized the growing number of tourists visiting the dome settlement with their cars, motorcycles, and children. Thus, in the Ngelepen post-earthquake resettlement, the indoor–outdoor environments became associated with various humans and nonhumans who were variably considered by scientists, local government figures, and by individuals such as Mr. Ikaputra and Mr. Sakiran alike.

Consultation

During the entire process of dome settlement design and construction, ground quake and geological conditions were well represented by the researchers, as various scientific results circulated from one meeting to another. One key formal requirement when implementing the resettlement project concerned the participation of local residents, for which Mr. Ikaputra was assigned as a local representative. However, while he constantly spoke on behalf of traditional Javanese culture, he failed to adequately represent the residents themselves, including their habits, augmented practices, environment, and livestock needs. While the Joglo represents certain culture preferences among the Javanese communities, it did not speak well for the local residents in Ngelepen. Since the beginning of the construction process, the dome-shaped buildings had attracted the attention of visitors, but it was only Mr. Sakiran and his colleagues who consulted tourists regarding their demand for services. Only in the late post-construction stage did local governments confer with those visitors (as tourism consumers) and the local residents (as tourism producers). Thus, in the design and construction of New Ngelepen, the indoor–outdoor boundaries were delineated without sufficient consultation with local residents and visitors.

Hierarchization

During the domes' design and construction processes, heterogeneous entities were brought together to agree on how best to rank and compose the new settlement. Trials were conducted to order several elements, including the earth and occasional ground quakes, landslides and the geological conditions beneath the ground, the dome buildings with their quake-proof structural features, the Joglo house with its historical texts, the imaginary axis of Javanese culture in the Regional and Spatial

Plan Document, ambient air, the nearby river, plantations, livestock, Mount Merapi, and the South Sea. Evidently, DFTW's architects constructed dome buildings with indoor arrangements as sturdy residential dwellings, Mr. Ikaputra modified the interiors and added a tritisan to build associations with the Joglo house and Javanese culture, the local government officials (supported by Mr. Ikaputra) constructed communal toilets and washing facilities at the heart of the dome settlement (chiefly to promote a sense of community among residents), and, by making reference to the imaginary axis in the Regional and Spatial Plan Document, the designers then implemented the overall geographic orientation of the settlement facing toward the South Sea.

During the design and construction stage, local residents and visitors were relatively silent, as they were represented by "Javanese culture" or considered strangers; however, they began to make their presence known in the post-construction stage. Residents planted trees and vines to make indoor and outdoor environments more comfortable and healthy, built communal cages to bring their livestock back into their environment, and constructed additional buildings (e.g., storage facilities, backside kitchens, and toilets) to expand their indoor activities. Upon consulting visitors and the local government, Mr. Sakiran and his colleagues began to consider the settlement as a tourism commodity, and built parking lots, homestay facilities, and kiosks. Thus, the particular shapes that resulted were due attempts to order heterogeneous entities and priorities in the new dome settlement, including safe indoor spaces with quake-proof buildings for DFTW's architects, culturally attached indoor–outdoor environments for Mr. Ikaputra and the local government, spaces supporting agricultural livelihood for many of the local residents, and indoor–outdoor settings supporting tourism consumption and production for Mr. Sakiran's party.

Institution

The DFTW architects' front doorway design drew a clear boundary between indoor and outdoor space, with emphasis on interior safety from external threats. However, the addition of a back doorway following Mr. Ikaputra suggestion made this border porous. In the post-construction stage, the local residents were adding extra buildings around the back to expand indoor activities and build connections to the outdoor environment. This could potentially reduce the safety of the expanded interior, since the additional buildings were not constructed as part of the monolithic structure. To prevent disputes triggered by residential preference, the local government officials employed a random rule for allocating tenants to buildings. However, as the settlement transformed into a tourism attraction, the dome buildings became a commodity (as homestay facilities or objects of attraction), with some gaining more visitor preference than others. Thus, attempts to institutionalize the heterogeneous entities into a durable collective with a clearly delineated indoor–outdoor environment faced counterinstitutional pressure. As people from nearby

areas and abroad visited the settlement, new associations have developed between the residents, the entities in the settlement, and the visitors themselves. Decorations were added to make the domes appear visually similar to the "Teletubbies" homes, and this, in turn, transformed the settlement into an attraction for visiting kids. The association between the domes' geometric shape, its monolithic structure, and the ground quakes has gradually disappeared, but new associations with visitors' worlds have emerged. As such, it is important to now present the human and nonhuman elements that helped delineate this indoor–outdoor boundary, and organize the New Ngelepen dome settlement into a single picture following Latour's (2004, p. 115) framework (Figure 1).

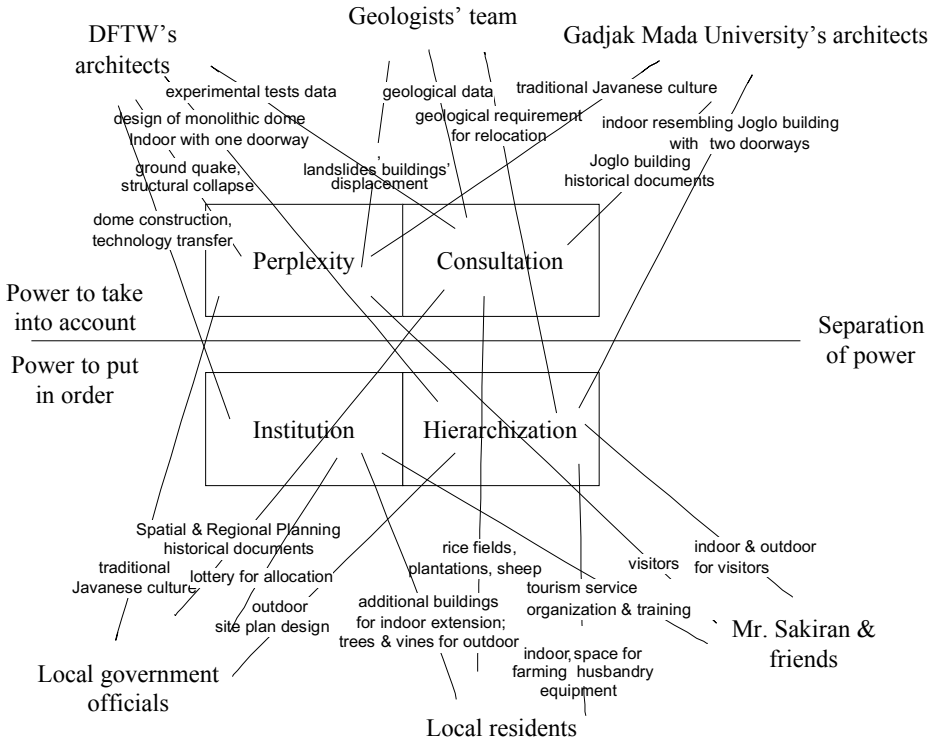

Figure 1. Various parties involved in the composition of the New Ngelepen dome settlement as a heterogeneous collective, demonstrating a lack of representation for local residents and visitors, contested indoor–outdoor designs, and both institution and counterinstitution.

Source: Figure adapted from Latour (2004).

Relevance to Post-disaster Resettlement Practice

The results highlight lessons that are relevant to post-disaster recovery and resettlement policy practices employed to improve outcomes. They suggest that in post-disaster resettlement policy, it is important to analyze and address the consequent changes in both indoor and outdoor environments in separate but interrelated ways. As the Ngelepen case demonstrates, attempts to protect interior spaces by adopting a certain construction technology did not fully consider the consequences for the settlement's outdoor counterpart, while the design of the site plan imposed limitations for indoor activities. Since both spaces are interrelated, the design and construction of said technologies must consider their connectivity.

In post-disaster circumstances, the level of uncertainty is high in terms of what and how outcomes have been exerted, as well as who has been affected. Instead of focusing on technical functions and cultural meanings in a separate and independent manner, it is of analytical benefit to direct attention toward associations of human and nonhuman entities. For this reason, the interaction between various types of science becomes important. In the Ngelepen resettlement case, had agriculture and tourism researchers been involved in the earlier stage of the new settlement construction, the local residents and visitors would have been better represented. While cultural context is crucial (Marcillia & Ohno, 2012), one should not jump to either cultural typology or category for justification. Instead, it is better to explore different voices that represent various social groups affected by such environmental change, both in terms of indoor and outdoor settings. Circulation of various scientific facts related to such environmental transformation could help numerous social groups in consultations, and in developing a bigger picture of the "collective." As the level of uncertainty regarding the effects of disaster is high, no one is certain about how to best order life within phases of recovery. Instead, different social groups likely bring their own preferred criterion for ordering. In these circumstances, it is important to explore each individual version, and combine them in an homogeneous hierarchy by making distinctions between indoor ordering and outdoor ordering.

The findings discussed in this paper draw on the theoretical work of Latour (2004) to investigate a practical case of a post-disaster resettlement problem that involves the diffusion of new technology. It is believed the results may be instructive and improve understanding for other cases and broader geographical contexts of post-disaster recovery or disaster risk-reduction policies. Ideally, they will improve wider outcomes, particularly as such cases are characterized by unanticipated social and environmental changes, by which attempts to mitigate these would likely involve technologies (e.g., buildings and infrastructures) new to the many affected social groups.

Contribution to Relevant Literature

The results draw on the notion that an heterogeneous association exists between humans and nonhumans, as proposed by ANT—within the context of human ecology, the theory's transdisciplinary approach to inquiry into fact–value distinction problems particularly clarifies. The results show that both indoor and outdoor environments do not merely exist "out there," but instead come alive through the provisional associations between humans and nonhumans, which, in actual situations, evolve through trial. Moreover, these two spaces are distinct and not completely detached from one from another.

Results in this paper also have implications for the literature on the diffusion of innovation, particularly in addressing what Rogers (1983) referred to as "the judgments as to the desirable and undesirable consequences of an innovation on individuals and their social system" (p. 381). Hence, presenting such findings within a "composition of the collective" allows for these very consequential judgments of innovation, as well as for broader social groups and environments to emerge, potentially enabling more inclusive and sustainable innovation opportunities, in turn.

Conclusion

The research question addressed in this paper concerns how a collection of human and nonhuman entities converge to function together, hence, delineating the boundary between indoor–outdoor environments. To address this query, it is crucial to deal with the relationship between humans and their settings, and the fact–value distinction, which, consequently, requires a transdisciplinary approach to inquire. As such, the researchers adopted an ANT framework as an approach to guide the analyses and address the research question. The post-earthquake resettlement in Yogyakarta was chosen for empirical study due to its cultural plurality and the introduction of new technology and innovation to the region.

The findings conclude that indoor and outdoor environments are not distinct and abstract entities. Instead, they come into existence through the provisional associations between humans and nonhumans, which evolve through processes of translation. These theoretical conclusions suggest that, in post-disaster resettlement policy practices, it is important to address the effects of ruin on changes in both indoor and outdoor environments in an interrelated manner. Likewise, when new technology is introduced for the purpose of disaster-risk reduction, its design and construction must, too, account for this spatial interrelationship. During post-disaster events in which the level of uncertainty is high, it is also demonstrated that value resides in exploring different voices that represent various social groups

affected by indoor and outdoor environmental change. Since no one entity holds the knowledge to best order life in times of recovery, it would be beneficial to explore different versions of ordering within an homogeneous hierarchy, which maintains differentiation between both spaces.

The case chosen for research is limited in its variables considered, which implies limitation to the theoretical results of the paper. Cases that are beyond the scope under current review could be nature-triggered disasters that have effects widely spread across geography (e.g., mud volcanoes), as well as environmental issues that involve various stakeholders collectively deciding upon standard practices—indeed, this has been the case for some green building and settlement policies. Future research could extend the research to further test the theoretical strength and practicality of the study results on such cases.

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Danger From the Outside in: Resident Perceptions of Environmental Contamination in Home Environments

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Abstract

Research examining human experiences of environmental contamination highlights the significance of place in influencing responses. However, a dearth of information exists on how indoor contamination affects experiences of living with legacies of land and groundwater pollution. This paper addresses this shortfall by drawing on evidence derived from an online survey, 10 semi-structured interviews, and a focus group to examine factors associated with lifescape change in home environments. The findings suggest that perceptions of the visibility and transferability of contaminants, and whether such contaminants are located in either indoor or outdoor domestic spaces, influence residents' experiences, in turn. Through its focus on interactions between people and pollution, this article makes an original contribution to research on the spatial dynamics of individuals' experiences with contamination. In concluding, this paper highlights the need for public health communication to provide clear guidance aimed at reducing feelings of uncertainty within domestic spheres.

Keywords: environmental contamination, home environment, lifescape change, ontological security, risk perception

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Introduction

Legacies of land and groundwater contamination in urban residential neighborhoods present a significant risk to public health (Fazzo et al., 2017). Australian cities, like many across the globe, are affected by contamination from decades of heavy industrial activity (Landrigan, et al., 2018). Understanding and addressing the effects of environmental contamination on human well-being is essential for improving public health outcomes (Mudu et al., 2014).

The scholarship focusing on human responses to environmental contaminants has increasingly acknowledged the psychological significance of living in contaminated settings (Davidson, 2018; Few & Tran, 2010). Previous research on the human geography of environmental contamination has likewise examined how a wide range of environmental contextual factors, such as sense of place (Bonaiuto et al., 2016; Venables et al., 2012), resident proximity to contamination (Burningham & Thrush, 2004), and type of contaminant present at a site (McIntyre et al., 2018), each affects resident responses to pollution. This has drawn extensive attention to how contamination negatively affects perceptions of security typically associated with the home (Edelstein, 2002, 2004; Prior & Partridge, 2009). However, there remains a lack of information regarding how said experiences of contamination within such domestic spheres affect residential living.

Research on the meaning of home environments emphasizes the importance of such spaces providing a sense of existential security, which is a form of human reassurance through which people gain confidence that their survival is secure enough to be taken for granted (Dupuis & Thorns, 1998). The home environment represents an important feature of human ecology, which is the study of the interactions between humans and the environment. Of particular significance to understanding the sense of security associated with home is the concept of "lifescape." Essentially, lifescape is an abstract notion that represents the intersection of an individual's agency, emotions, health, socioeconomic circumstances, and cultural norms that shape one's life, and that which transpires within specific material and social environmental contexts (Lubkemann, 2008, p. 193). Home environments are fundamental for the production of such a concept, as they enable individuals to realize the livelihoods they seek to pursue.

Change that affects these spaces also affects lifescape and has implications for human well-being (Davidson, 2018). Previous research examining responses to environmental contamination has shown how its presence is associated with experiences of change. According to Edelstein (2002, 2004), lifescape change represents a deep fundamental disruption of underlying ontologies, or the taken-for-granted assumptions upon which societies operate. This means that changes to lifescape can threaten one's sense of order, stability, and predictability, which

otherwise provide humans an ongoing sense of direction or purpose (Edelstein, 2004). Essentially, lifescape change refers to a significant interruption of "normal" patterns of everyday life and sense of security.

According to Edelstein (2004), contamination has been shown to affect five key dimensions of lifescape:

1. Normal optimistic assumptions about life are replaced by a focus on risk and uncertainty.
2. Local environments become perceived as a source of uncertainty and danger.
3. People's trust in social or institutional support systems breaks down.
4. Routine feelings of a sense of control over one's future are replaced with feelings of isolation, threat, insecurity, and a sense of powerlessness.
5. Home environments usually associated with a sense of security, status, and identity instead become viewed as places of danger.

In turn, changes to daily routines are accompanied by critical questioning about their meanings, once people become less likely to take them for granted (Alexander, 2012; Edelstein, 2002, 2004; Davidson, 2018; Prior & Partridge, 2009).

Lifescape change is also associated with the emergence of ontological insecurity in environments affected by contamination (Edelstein, 2002). As ontological insecurity refers to feelings of existential insecurity that result when emotional needs are not met (Alexander, 2012; Giddens, 1991, p. 55; Herman, 1992), the inverse (ontological security, or purpose in life) becomes enforced through the constancy of daily routine. Research has shown that ontological insecurity following environmental contamination may be reflected in critical questioning of underlying values, social norms, and modes of interaction between social groups; that is, environmental contamination has the capacity to significantly disrupt one's social environment (Edelstein, 2004). In Western societies, underlying ontologies involve taken-for-granted beliefs in humans' ability to ably control their settings, and that the natural environment will always support the human need for food and water (Edelstein, 2004). However, contamination threatens the continuity of these very assumptions, which result in feelings of helplessness and trauma (Davidson, 2018; Edelstein, 2004; Herman, 1992). Lifescape change that occurs from contamination to individuals' home environment can also result in the emergence of a stigmatized identity, by which community members become viewed by others and by themselves as contaminated peoples (Edelstein, 2004; Prior & Partridge, 2009). Most significantly, from a human ecology standpoint, changes to lifescape due to environmental contamination reveal how pollution influences the relationship between humans and environments.

Previous studies focusing specifically on experiences of contamination within home environments conceptualize "home" as consisting of features of the social, natural, and material environment to which people form deep attachments (Edelstein, 2002; Prior & Partridge, 2009). Yet, despite the wealth of research on such spaces, the ways in which individuals' attachments to the interior are affected by contamination has received very limited scholarly attention. One notable exception is Larrea-Killinger et al.'s (2017) examination of how contamination transforms a domestic space into a potentially toxic object. Other research examining its significance for ontological security, lifescape, and human well-being explores how home environments are associated with a sense of personal control, as they offer freedom from public surveillance (Dupuis & Thorns, 1998). Such indoor spaces provide a secure base for identity construction, as notably projected through the ways we fashion our homes (Dupuis & Thorns, 1998). Having a place to call one's own has deep cultural significance in Western society, including in Australia, where colonial histories were rooted in ideas of building a home in new environments (Kearns et al., 2000). Therefore, given the importance of indoor home environments for providing many a sense of security, it follows that examining human responses to contamination therein can aid understanding how aspects of such built spaces help shape human experience, in turn.

Other research focusing on the spatial dynamics of environmental contamination observe how the concept is socially constructed or defined. Studies examining the spatial dynamics focus on the perceived or actual distribution of contamination across particular geographic spaces and at different scales. However, these studies show that not all societies react equally to the presence of the same forms of pollution. A number of these draw upon Mary Douglas's (1966) theory of contamination as consisting of "matter out of place," in that contaminants defy symbolic and socioculturally constructed boundaries of "orderliness" by entering spaces people feel should be free of contamination, such as water supplies (Bickerstaff & Walker, 2003; Davis, 2005; Eakin et al., 2010; Jewitt, 2011; Loyd, 2009; Meade, 1976; Scott et al. 2012; Segrott & Doel, 2004; Sultana, 2012). Several draw on a cultural construction of contamination to explain how certain types of pollutants associated with living in a city are more likely to be accepted by residents, regardless of actual health risk (Cupples, 2007; Eiser et al., 2007), while others measure the significance of subjective perceptions of risk in relation to stress and trauma (Davidson, 2018; Freudenburg, 1997; Luria et al., 2009; Vyner, 1988; Whitmarsh, 2008). Overall, these studies emphasize the importance of the sociocultural environment in shaping responses to contamination.

Understanding how indoor environments affect responses to contamination is of interest to human ecology, as they can reveal how particular features of built environments can affect the interrelationship between humans and their environments. Knowledge about how residents living in areas affected by

environmental contamination is also fundamental to the development of effective public health communication strategies, which can help residents better cope with issues of contamination in their neighborhood surroundings (Mudu et al., 2014). However, the development of guidelines to improve risk communication outputs represents a transdisciplinary research problem that requires input from a variety of stakeholders (including residents, government representatives, environmental agency representatives, and industry personnel) to ensure they meet the needs of both community members and the organizations with which they liaise.

This study was developed as part of a wider transdisciplinary research project that aims to develop new evidence-based guidelines for improving the communication of information about contamination, as well as the engagement of community members in remedial decision-making. The research is transdisciplinary in nature, as it focuses on achieving a collective understanding of experiences with environmental contamination, created from multiple actors within a wide range of institutions (including both scientific and non-scientific communities), who each bring their own unique perspectives, experiences, and contributions for the advancement of knowledge (Brown et al., 2010, p. 4; Schoot Uiterkamp & Vlek, 2007, pp. 176–177). Essentially, the study aimed to examine evidence of lifescape change among residents affected by environmental contamination within home environments around Australia. This was achieved by focusing on two indicators of lifescape change associated with the production of ontological insecurity. The first concerned the emergence of a situation in which home environments became associated with a sense of danger, while the second focused on changes to daily routines, which reflect how normal assumptions about life become replaced by a newfound focus on risk and uncertainty. This contention was selected for the importance of lifescape in influencing human security, and because change to lifescape resulting from contamination can reveal how contaminants deeply alter the relationship between humans and their environments (Edelstein, 2004).

From this, the following research questions were defined:

- RQ1. Are residents' perceptions of their abilities to personally control exposure to contamination at a site reflective of losses of trust in the safety of their home environments? If so, why?
- RQ2. Do any changes to residents' daily habits resulting from learning about contamination in their home environment indicate that taken-for-granted assumptions about the constancy of daily routines had been replaced by a focus on risk and uncertainty? If so, which ones and why?

Methodology

This study was a cross-sectional analysis that collected online questionnaire responses from 496 adults living in 13 contaminated urban sites across Australia, including the Australian Capital Territory, New South Wales (NSW), Queensland, South Australia, Tasmania, and Victoria. Purposive sampling was used to select the sites, with suitable locations being identified through consultation with the Australian Remediation Industry and each state's Environmental Protection Agency. A range of environmental contaminants, including heavy metals, chemicals, and chlorinated solvents, were known to have affected each location. As such, the University of Technology Sydney's (UTS) Human Research Ethics Committee provided ethical approval to commence research.

As this study aimed to achieve a collective understanding of experiences of environmental contamination, a mixed-method, combined quantitative and qualitative approach was chosen. This offered an inclusive approach that enabled an extensive number of stakeholders to participate in a variety of manners. The sample size and breadth of the study across 13 Australian case study sites was also designed to ensure that findings were not isolated to a specific region. However, this likewise meant the findings may not be generalizable beyond an Australian context.

1. Survey Questionnaire and Measures

A mixed quantitative and qualitative approach was applied to gather data. A structured online survey was conducted between 2014 and 2015, as designed through engagement with remediation experts. Two questions within the online survey were designed to assess issues pertaining to lifescape change:

1. Question 3. How much personal control do you feel you have over your own contact with the contamination at [name of neighborhood site], with 0 being no control and 10 being total control?
2. Question 6. Have you changed any daily habits since becoming aware of the contamination at [name of site] in your suburb?

Residents who answered "yes" to Question 6 were subsequently asked in Question 7 to briefly describe what daily habits they had changed. Questions about feelings of a lack of control over exposure can be used to enquire if home environments are viewed as a source of danger, while questions about changes to daily routines can help determine if residents have become disconnected from their daily routines.

2. Semi-structured Interviews and Focus Group Workshop

The online survey was followed in 2017 by ten 90-minute, semi-structured interviews with selected residents, and environmental contamination and remediation experts from NSW. Two interviews contained more than one participant, with 12 applicants participating overall. The interviews were conducted to elicit further information regarding how residents experienced a sense of danger in their home environments as a result of a lack of control over exposure to contaminants. This also concerned if changes to their daily routines reflected disconnection associated with lifescape change.

The semi-structured design of the interviews allowed researchers to enquire on the reasons why residents felt they had experienced factors associated with lifescape change. Each interview participant was asked the following questions:

1. Which types of contaminants concern you the most and why?
2. How has contamination affected your livelihood or routine?

These queries enabled participants to respond in their own words, and recognized their agency for guiding the interpretation of the results (Ozerdem & Jacoby, 2006). Participants were sourced through recommendations from remediation experts, from a remediation community action group, and upon recommendation by members of community action groups. All participants provided full informed consent prior to participation.

A focus group workshop was subsequently conducted in September 2017. This involved government, industry, environmental agency personnel, and residents, and explored how official communications about contaminants could be improved.

3. Data Analysis

Descriptive statistics frequency analyses were used to develop findings from the questionnaire, and were performed using SPSS Statistics 23.0. This helped illustrate both the frequency of responses to Question 3 on each position on the Likert scale, and the number of participants answering "yes" or "no" to Question 6. Coding of both interview and focus group data pertaining to the question "Which types of contaminants concern you the most and why?" involved initially scanning the transcripts for evidence suggesting that perceptions of a lack of control over exposure to contaminants resulted in a loss of trust in one's environment. This was achieved by highlighting statements that indicated uncertainty, distrust, confusion, and perceptions of danger or risk of harm from such settings. Three key themes were also identified: visibility and contamination, contamination within indoor

environments, and changing meaning of an indoor environment. These themes were subsequently used to create a conceptual framework through which the data were organized into headings.

Responses pertaining to the second interview question, "How has contamination affected your livelihood or routine?", involved repeating the same procedure for evidence of changes to daily routines, and evidence that these changes reflected disconnection from individuals' habits. Statements pertaining to a loss of taken-for-granted assumptions about daily activities were highlighted. Three themes were identified and used to draw a conceptual framework to organize the responses: change to thought, change to action, and change to action in indoor environments.

Responses to Question 7 were manually coded according to whether respondents reported changes to indoor or outdoor daily activities, routines and habits, according to the themes that emerged from interviews and focus group data. This method of analysis follows the basic principles of grounded theory (Strauss & Corbin, 1998), and was chosen for its useful and flexible approach to exploratory studies in social science, which requires a continual interplay between data collection and analysis to develop theory (Bowen, 2008, p. 2).

Findings

Control Over Exposure to Environmental Contaminants

Responses to Question 3 in the online survey revealed that 156 of the 496 (31.4%) respondents felt they had no control over their own contact with contaminants at their given sites, while only 23 (4.6%) felt they had maximum personal control over contact with contaminants. A summary of the frequency of resident responses to the survey question "How much personal control do you feel you have over your own contact with contamination at your site?" is provided in Table 1.

Table 1. Descriptive statistics frequency analysis of online resident survey (Question 3).

Frequency statistics Question 3: How much personal control do you feel you have over your own contact with contamination at your site?					
	Likert scale response	Frequency	Percent	Valid percent	Cumulative percent
Valid	0	156	31.5	34.8	34.8
	1	59	11.9	13.2	48.0
	2	32	6.5	7.1	55.1
	3	24	4.8	5.4	60.5

Frequency statistics Question 3: How much personal control do you feel you have over your own contact with contamination at your site?					
	Likert scale response	Frequency	Percent	Valid percent	Cumulative percent
	4	29	5.8	6.5	67.0
	5	37	7.5	8.3	75.3
	6	13	2.6	2.9	78.2
	7	19	3.8	4.2	82.4
	8	31	6.3	6.9	89.3
	9	25	5.0	5.6	94.9
	10	23	4.6	5.1	100
	Total	**448**	**90.3**	**100**	**N/A**
	Missing	48	9.7	N/A	N/A
	Total	**496**	**100**	**N/A**	**N/A**

Over 60% of respondents answered 0–4 on the Likert scale, which suggests that more than half the residents experienced attributes associated with lifescape change. Essentially, this is because one's lack of control over exposure is indicative of a situation in which home environments become perceived as a source of danger (Edelstein, 2002, 2004).

Overall, the semi-structured interview and focus group responses provide a wealth of information regarding why residents felt they lacked control over pollutant exposure. They also indicate that such powerlessness resulted in perceptions of a lack of trust in the safety of one's home environment. However, responses to the interview question "Which types of contaminants concern you the most and why?" revealed that residents were more concerned about exposure to certain forms of contaminants compared to others.

Perceived Invisibility and Intangibility of Contaminants Within Home Environments

Certain forms of contaminants were associated with increased concern about the dangers of exposure and lower abilities to control such risks compared to others. Residents were more likely to associate concerns about this lack with invisible forms of old legacy contamination—or, those that were intangible, did not have a distinct smell, and were visibly undetectable. Essentially, legacy contamination refers to pollution from historic waste associated with former industrial activity in the area, before special environmental statutes were enforced (Brand et al., 2017). These undetectable contaminants were thought to be more dangerous and more difficult for residents to control than those that were more visible, regardless of their specific type (i.e., chemical or heavy metal). Invisibility was also associated

with greater anxiety over control of exposure than more visible forms of industrial pollution associated with heavy industrial activity, which occurred on these same sites throughout previous decades:

> If we smelt anything strange or anything unusual in the way of the environment, we'd just sniff the air. Then we could get in touch with State's pollution control. That was the sort of guide we had to contamination … Now it's a worry that we are breathing things in that could have toxins in them … You worry because it's a long-term thing. (Female resident, 70, 7009)[2]

This suggests that invisible forms of legacy contaminants were more likely to be associated with an inversion of the assumed safety of an environment, as is characteristic of lifescape change (Edelstein, 2002, 2004). Several interviewees also emphasized that this was the case, even when industrial pollutants were known to pose a serious health risk:

> I used to work in the public works and everything, and I used to bite my fingernails all the time. I got lead poisoning from down there. Back in those days you used to test for lead poison all the time … The danger is when you can't see anything … it could be sterility, you could go blind or different things … I know one person, he got testicular cancer and he blamed it on there, but I don't know how. (Male resident, 85, 7001)

Contamination in Indoor Home Environments

Another reason invisible contaminants were perceived as more harmful and associated with greater environmental distrust concerned their potential to spread undetected into residents' homes. Both residents and members of official organizations reported they perceived those who spent greater amounts of time at home were more likely to be vulnerable to harm from exposure than other members of the population: "Children, the elderly, those who are already sick. Those who spend the majority of their time in the area [are more vulnerable than others]" (Female resident, 63, 7008).

Interviewees also emphasized how the risk of exposure to invisible forms of contamination within homes were especially traumatic, as well as being associated with prolonged worry and uncertainty over the health risks associated with exposure:

> Dust containing lead particles was especially worrying. Parents were encouraged to wash their children's hands and not let them out barefoot, and to wipe down surfaces to limit exposure inside. But even though they were doing this they didn't know what to do when the kids still showed high blood lead readings. (Female remediation expert, 40, 7005)

2 The four-digit number included in the bracket after the age of the participant refers to survey and interview numbers. These have been included throughout this paper.

Others described how a lack of perceived safety from domestic exposure led to several local residents deciding to move away: "If you really feel bad about this … [it's] going to destroy you. A lot did sell up and move away because … I wouldn't want children to breathe in stuff from an early age that you don't know if it's harmful" (Male resident, 68, 7000).

This reveals how the perceived presence of invisible legacy contaminants within the home was associated with a lack of trust and certainty about the safety of such environments. Both residents and remediation experts also expressed concern about domestic exposure as being associated with greater insecurity than that of outdoor contaminants:

> I think the greatest worry is a trauma; the worry that you don't know about—not know whether or what can invade your home. Old soil from the gardens was taken away, and new, clean soil brought in, but people were scared about the roof cavities and where the dust might have settled on the homes over the years and what could have crept in. (Remediation expert, 50, 7002)

Invisible legacy contaminants within homes were perceived by residents as being more difficult to control in terms of exposure than contamination from active industry during previous decades. The perceived visibility and tangibility of these older forms of pollution deemed them more controllable, as residents could take direct personal action to prevent them from entering their home environments:

> You'd do your washing at night and bring it back in, and have to do it again because it stank of whatever it was. So you did your washing at other times … If you knew there was a problem you could shut your door, whereas now you don't know; it's hidden. (Male resident, 68, 7000)

The attribution of personal responsibility to control exposure to previous forms of industrial contamination within domestic spaces also influenced if living in such affected areas became associated with any form of stigma. Residents explained this sense of shame that accompanied life with contamination from heavy industry activity during previous decades, as it meant they could not afford to reside elsewhere. As such, pollution within the home was perceptibly associated with the presence of dust, to which many felt they could control their exposure by adopting rigorous cleaning practices that were considered an expected social norm at the time:

> There was a stigma because if you lived in [place name] you didn't live there because you wanted to, you lived there because couldn't afford anywhere else. You were working class. But if your home was contaminated, it meant it was dirty. That was a stigma. You didn't want a dirty home … It's pride. (Male resident, 68, 7000)

Conversely, residents did not believe the same stigma existed for those living in the same areas today. This was attributed to the rising cost of property prices in Australian cities, the closure of heavy industry, and the gentrification of these spaces. They also described how exposure to legacy contaminants was more likely to lie beyond a resident's personal control:

> I'd say that the house prices mean there isn't the same sort of stigma nowadays … You don't know what's there or how to prevent kids ingesting it or breathing in something then. I'd say its unavoidable … it's the nature of the legacy. (Female resident, 70, 7009)

Changing Significance of Indoor Home Environments

Residents also emphasized the importance of having a clean and safe neighborhood environment, as well as living in an area marked by a close-knit sense of community. They also stressed the significance of having a safe indoor environment as being an integral aspect of their well-being: "Your home was important; it was your home. It's the place where you raised your family and stayed until you died. It's that whole security thing of being at home" (Female resident, 83, 7001).

Residents spoke about how the meaning of one's domestic space had changed since the closure of industry within these areas, particularly explaining how the majority of new residents commute to work within city centers. Many of these new inhabitants are less likely to get involved in local community activities because their lives tend to be constructed around activities that transpire across a much wider geographic area than the neighborhood in which their home is located. Others explained how longer working hours means people are more likely to keep to themselves and spend greater amounts of time indoors: "People do their own thing more now. They spend more time at home and are less involved with others nowadays" (Female resident, 70, 7009).

A number of participants also explained that changes to working patterns resulted in enhancing the significance of indoor environments for providing a sense of security to residents; hence, the indoors became perceived as increasingly meaningful for providing a sense of well-being: "I think now home is more important than before. It's where you relax, with the family, uninterrupted, almost like a kind of sanctuary—a place to recuperate from the stresses of modern life" (Female resident and remediation expert, 45, 7003).

Greater significance was also attributed to indoor home environments for the safety and well-being of children compared to previous decades:

> Children spend more time indoors. You don't see kids playing out on the street anymore like you used to. There's more of that fear of crime or accidents, or what could happen, so people keep their kids indoors more. (Female resident, 70, 7009)

Hence, considering such changes to the significance of interior domesticity, it follows that if the safety of these spaces becomes threatened due to actual or perceived contamination, it may result in greater insecurity today compared to in the past.

Changes to Daily Activities and Routines as a Result of Contamination

Answers to the second survey question (Question 6), which was designed to elucidate information about residents' lifestyle change and changes to daily activities, suggested that, despite concern about exposure to contaminants at nearby sites, few residents changed their daily habits since becoming aware of contamination. The frequency analysis revealed that only 46 of the total 496 participants (9.3%) had made changes to their daily habits, while an overwhelming 421 (84.9%) said they made no changes. The full details of the responses are provided in Table 2.

Table 2. Descriptive statistics frequency analysis of online resident survey (Question 6).

Frequency statistics Question 6: Have you changed any daily habits since becoming aware of the contamination at your site?					
	Response	**Frequency**	**Percent**	**Valid percent**	**Cumulative percent**
Valid	Yes	46	9.3	9.4	9.4
	No	421	84.9	85.7	95.1
	Unsure	24	4.8	4.9	100
	Total	**491**	**99**	**100**	**N/A**
	Missing	5	1	N/A	N/A
	Total	**496**	**100**	**N/A**	**N/A**

Changes to daily routines can be associated with lifescape change. This is because variations in one's habits can be reflective of a situation in which residents become disconnected from normal activities that provide a sense of purpose. The survey findings suggest that the majority of residents did not make any changes to their daily habits associated with lifescape change.

Changes to Assumptions About Mundane Daily Activities

While responses indicated that the majority of residents did not alter their lifestyle habits upon discovering contamination, answers to the interview and focus group workshop question "How has contamination affected or changed your livelihood or routine?" suggested that evidence of lifescape change involving disconnection from normal routines was experienced. The findings likewise imply that disconnection occurred, even in instances in which contamination did not alter participants' daily habits.

Some residents reported feelings of disconnect from the typical taken-for-granted assumptions about life embedded in daily activity, despite not altering any of their activities upon believing change would not help reduce the risk of harm from invisible forms of legacy contamination: "If you don't know how far they have actually spread, you really don't know if there is anything you can do" (Female resident, 70, 7009). Others described their awareness of the need to consider taking precautions to prevent exposure, but could not readily apply this advice to their own lives: "People … they used to come to me and say we've got to protect the children. I thought, okay, what do I need to do … I don't understand a lot of it … There was a panic" (Male resident, 85, 7001).

This suggests that although people were not actively changing their activities, they were questioning taken-for-granted assumptions about their routines due to concerns of exposure. It also reveals how the use of very technical language in official communications advice hindered residents' ability to apply guidance effectively.

Changes to Daily Routines Within Home Environments

Forty-five of the 46 respondents who answered "yes" to having changed any of their daily habits in the online survey provided a response to the open-ended survey question "Can you briefly describe what daily habits you have changed?". Thirty-four of these responses described changes made to activities that transpired in outdoor home environments, with 27 including descriptions of avoiding exclusion zones, and not allowing children to play near affected sites. Five respondents explained that learning about contaminants affected their gardening practices, and described how they stopped growing vegetables and using bore water to hydrate their gardens. One described how they chose to cease their environmental volunteering pursuits after learning about the contaminants, while another explained how they made extra effort to actively pursue information about activities happening within their area to help manage and remediate the contaminants.

The semi-structured interview and focus group responses from participants who were asked how contamination affected their livelihoods or routine also highlighted changes to bore water use, gardening practices, and outdoor pursuits as being key lifestyle modifications made upon learning about contamination: "Some residents had filled their swimming pools with groundwater, so there was a whole lot of things they had to change" (Female resident and remediation expert, 45, 7003).

Information elicited during the interviews illuminated residents' emotional attachment to some of these activities. For example, one remediation expert (45, 7003) noted "a lot of homes had installed bores. People were upset when they lost that amenity." Another explained that having a vegetable garden in Australia has

a strong cultural meaning for some, which can be a defining aspect of their sense of home: "Veggie gardens. I think it's a cultural thing as well. It's very important to them" (Female remediation expert, 40, 7005).

A third interviewee suggested that having a garden to tend is important for a person's identity, which she thought to be rooted in Australian culture as a result of its colonial history:

> It's the whole having a house, a garden … It gives people the sense that if they have that, they have somehow made it, made a success of their lives … It's very important here in Australia … I think it's part of that old colonial idea that you build yourself up, make a home. (Remale resident, 70, 7009)

This suggests that changes to gardening routines and activities not only disrupt residents' lifestyles, but lead to emotional responses that are likely to involve questioning one's identity and embedded culturally constructed assumptions about the purpose of one's life. Meanwhile, other residents described feelings of sadness about being restricted from entering areas they had formed long-held attachments to, which, as one female resident (63, 7008) explained, "are is now fenced off. I've been here for years and you sort of have this nostalgia for the area." Again, this suggests that changes to daily practices are accompanied by feelings of loss for a sense of security associated with the maintenance of meaningful activities.

Changing Routines Within Indoor Environments

Participants also described changes to their daily practices within indoor environments. Seventeen of the 45 residents who responded to the open-ended question about changes to their daily habits explained how they had altered their indoor habits, activities, and routines after discovering the presence of contaminants. Three respondents described how they now try to keep their windows closed to prevent pollutants from entering their homes, while two changed their indoor cleaning practices. One stated they now use a mask when cleaning their house, while another described how they now boil water to wash dishes. One respondent also explained how they changed their personal care practices by no longer rinsing their mouth with tap water. Further, six participants stated how they modified their food and drink preparation and consumption practices, while another became more conscious of how they disposed of household waste.

Responses to the interview questions also revealed concern about preparing and consuming food products they perceived were contaminated. Avoidance of bringing such items into one's home was also identified as an important change to daily practices:

> They said don't fish from the area … You were going to be eating the fish and swallowing all that mercury and maybe it's doing you harm. Then, the concern was bringing back in fish caught in the bay. You aren't just eating it if you bring it indoors, whatever's there you could be spreading everywhere. (Male resident, 68, 7000)

This indicates lifescape change, in that it reflects both loss of belief that the natural environment will always support the human need for food and water, and critical questioning of "normal," taken-for-granted daily routines. Hence, another resident said many changed their normal food preparation practices for fear of exposing children to contaminants, explaining, "people were asking, is it safe to feed my kids? Is the water safe for them to drink?" (Female resident, 63, 7008). This likewise reveals evidence of lifescape change, in that routinized daily activities were replaced with a focus on risk and uncertainty.

Participants' responses also highlighted how changes to daily practices due to increased awareness of legacy contaminants differed to the daily practices used to deal with industrial contamination throughout periods of industrial activity. As residents associated these older types of pollution with visual cues (such as smoke emitting from industrial chimneys), they explained many would shut their windows and doors, and ensure their homes were clean, rather than change their food preparation practices. One resident explained that if heavy soot was visible, residents throughout that period may have increased their cleaning efforts but were unlikely to have adopted any new practices as a result: "If there was some heavy soot … maybe [I] cleaned more" (Female resident, 83, 7001).

Further, many also emphasized how daily practices performed to prevent exposure in one's home were, themselves, taken-for-granted activities that were embedded within the social norms of the time: "You'd take overalls off inside, but you'd do that anyway. It wasn't a nice area but people didn't want their houses to be dirty. You'd want to be respectful" (Female focus group participant, 63, 7014). This suggests that changes made to daily routines due to exposure from industrial contaminants in the past did not represent the same break from taken-for-granted daily routines as changes made due to legacy forms of contamination.

Discussion

Lifescape Change from Contamination to the Home Environment

The findings from the survey, interviews, and focus group suggest that residents experienced lifescape-suggestive change after being exposed to environmental contamination. The number of residents reporting a lack of personal control over exposure to such pollutants reflects a situation in which home environments, once

associated with protection and security, became associated with a sense of harm and danger (Edelstein, 2004). Changes to individuals' daily routines and thoughts about their safety reveal that normal assumptions about daily life were replaced by a focus on risk and uncertainty (see Davidson, 2018; Edelstein, 2004), and a loss of belief that the natural environment will always support the human need for food and water. This reflects a loss of connection to the predictable flows and patterns of life, which provide residents a sense of existential security (Alexander, 2012; Giddens, 1991).

The study findings also suggest the presence of ontological insecurity among residents. Feelings of a loss of control over the environments in which they reside clarify in responses to questions about ability to limit contact with legacy contaminants. Arguably, this not only indicates a loss of security, but also implies a loss of deeply embedded, taken-for-granted, Western philosophical beliefs in the human ability to control the environment (Edelstein, 2004). Responses also reflect a sense of helplessness associated with ontological insecurity (Edelstein, 2004; Herman, 1992).

The study builds upon previous research in residents' responses to contamination within an Australian context (Edelstein, 2004; Prior & Partridge, 2009). This is conveyed through participants' perceptions that the visibility of contaminants may influence the degree to which one's exposure may yield lifescape change. Resident beliefs that invisible and intangible legacy contaminants were more difficult to limit exposure to than visible contaminants associated with former industrial production suggests that legacy contaminants are more likely to become linked with perceptions of environmental distrust, regardless of specific type (e.g., heavy metal, chemical, or solvent). This lends support to studies that emphasize an association between invisible contaminants and higher levels of residential uncertainty (Davidson, 2018; Dosman et al., 2001; Freudenberg, 1997; Vyner, 1988; Whitehead et al., 2011), and those that highlight the importance of subjective perceptions of risk in influencing individuals' subsequent responses (Luria et al., 2009; Slovic, 1987; Whitmarsh, 2008).

The findings differ from previous research that suggests residents affected by contamination experience the emergence of a stigmatized identity due to such instances of chemical exposure (Edelstein, 2004; Prior & Partridge, 2009). Instead, the findings suggest that visible forms of industrial pollutants, which individuals believed they could control, were more likely to be associated with stigmatization than legacy forms of contamination. As such, the evidence reveals that shame over industrial pollutants resulted from cultural norms concerning cleanliness in one's home, rather than exposure to contaminants themselves.

Lifescape Change in Responses to Indoor and Outdoor Contamination

The findings offer an original contribution to the body of knowledge examining responses to environmental contamination within home environments. This was achieved by highlighting how residents respond differently to the presence of contamination within domestic indoor and outdoor spaces. In particular, the findings reveal that evidence of pollution within the former is more likely to be associated with lifescape change compared to outdoor contamination. Features of lifescape change were also more likely to be associated with invisible forms of legacy contaminants within indoor home environments than more visible forms of industrial impurity, particularly as the latter were linked to resident perceptions of domestic spaces. This suggests that only when such contaminants entered one's home did they become perceived as "matter out of place" (Douglas, 1966, p. 36; Eakin et al., 2010; Hinchcliffe, 2001; Loyd, 2009; Meade, 1976; Scott et al., 2012; Smallman-Raynor & Cliff, 2008). However, despite this factor, these same pollutants were perceived as easier to control in terms of exposure than invisible legacy contaminants. This lends support to previous research that suggests certain types of pollutants associated with living in a city are more likely to be accepted by residents, regardless of health risk (Cupples, 2007; Eiser et al., 2007). Conversely, invisible legacy contaminants in both contemporary indoor and outdoor environments were rendered "matter out of place" (Douglas, 1966, p. 36), and perceived to threaten the sense of safety associated with domesticity.

The study also highlights how the increased importance attributed to indoor home environments within contemporary city life results in greater potential for lifescape change within the context of legacy contamination (Dupuis & Thorns, 1998; Giddens, 1991). This supports the theory that perceptions of contaminated spaces are socially constructed and fluid over time (Bickerstaff & Walker, 2003, p. 46; Davis, 2005).

Conclusion

This study builds on previous research examining human responses to environmental contamination at home by revealing how differences in residents' perceptions of contaminants result in differences in lifescape change (Edelstein, 2004; Freudenburg, 1997; McIntryre et al., 2018; Prior & Partridge, 2009). It also offers an original contribution to the existing body of scholarship exploring the spatial dynamics of responses to environmental contamination (Edelstein, 2002). This is primarily achieved through an exploration of how lifescape change relates to indoor and outdoor home environments, and how changes to the symbolic value attached to such spaces affect resident responses.

From a human ecology perspective, the study offers new insights into how the presence of environmental contamination in both indoor and domestic spheres influences human behavior, as well as how socioculturally constructed norms about home environments and different types of contaminants affect the interrelationship between humans and their surrounds. It also reveals the merits of a transdisciplinary and mixed-methods approach for understanding the extent to which contaminants affect human experience.

Overall, this study presents important implications for the development and implementation of strategies for public health hazard-risk information. Awareness of the factors that contribute to lifescape change can help guide the development of strategies to improve the relevance and communication of information outputs. Given the extent to which subjective perceptions of contaminants influence resident responses, it is vital that these outputs seek to remedy incorrect assumptions to restore a sense of security. Public health information should also focus on providing specific information about the risks present within indoor environments, particularly considering the significance of such settings for human security. However, further transdisciplinary research involving multiple stakeholders needs to be undertaken to better investigate what the information outputs should include and how best to communicate these to ensure they reach different audiences, especially those most marginalized within communities. This could involve researching how demographic factors, such as age and disability status, influence responses to contamination.

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Design Philosophy and Poetic Thinking: Peter Sloterdijk's Metaphorical Explorations of the Interior

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Abstract

This article makes the argument that Peter Sloterdijk's philosophy provides a useful and thought-provoking basis for studies of contemporary indoor ecologies. Sloterdijk's philosophy is distinctively attentive to the various environments in which humans exist and of the ecological situation of beings in general. The notions of interiority explored in Sloterdijk's work, particularly the third volume of his S*pheres* trilogy *Foams* (2016), provide important tools for conceptualizing the changing nature of indoor spaces and contemporary modes of being in the world. Sloterdijk's approach to philosophical analysis exhibits a number of interrelated advantages that mesh well with the ambitions of human ecology, particularly in relation to indoor ecological conditions. These include his sustained conceptual exploration of technological and scientific developments, his distinctive use of rhetoric and philosophy in the characterization of human agency, and the close attention he pays to the relationship between being and design. This article unpacks the value of these perspectives through a sustained attention to *Spheres III: Foams* and aims to demonstrate why Sloterdijk's work provides an invaluable philosophical tool kit to foreground and unite scholarship in diverse fields exploring the relationship between interior spaces, human perception, and society.

Keywords: design philosophy, design theory, interior design, Peter Sloterdijk, philosophy of technology

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Introduction

Peter Sloterdijk is currently Professor of Philosophy and Aesthetics at Karlsruhe University of Arts and Design in Germany. Founded in 1992 by celebrated architecture scholar Heinrich Klotz, Karlsruhe is a progressive university that focuses on philosophy, design, media, art, and architecture. Sloterdijk's work has only come to the attention of the English-speaking world relatively recently, in some part due to the advocacy of Bruno Latour, doyen of Science and Technology Studies. In his keynote address at the Networks of Design meeting of the Design History Society in Cornwall, Latour (2008) suggested, in typically provocative fashion, that it ought to have been Sloterdijk in his place. Since then, Latour (2009, 2010) has continued to advocate for Sloterdijk's work in various contexts, claiming to have been "born a Sloterdijkian" (p. 139), and suggesting that Sloterdijk's foam metaphor possesses many advantages over the popular network metaphor central to the actor–network theory.

This obscurity is not matched in Germany, where Sloterdijk is arguably the most well-known contemporary philosophical figure. In 2002, he began cohosting the popular German television program *In the Glasshouse: The Philosophical Quartet*, and was for some time embroiled in a widely publicized media stoush with Jürgen Habermas, long-time leader of the philosophical orthodoxy in the country who publicly accused Sloterdijk of resurrecting the kind of thinking associated with Third Reich politics—an accusation that Sloterdijk (2011a) compellingly analyzes and evaluates as lacking nuance over a series of extended interviews.

Sloterdijk (2011a) is arguably unique among contemporary philosophers due to the emphasis he places on space as a "key anthropological category" (p. 9). In Sloterdijk's wide-ranging analysis of human civilization, he proposes a theory of human evolution through a series of interlinked yet distinct developments in the form of buildings, and the associated biological, psychological, cultural, emotional, and systemic conditions with which they are accompanied. This article presents a curation and contextualization of a series of key examples from Sloterdijk's oeuvre that are particularly relevant to the study of interior spaces, a consideration that he suggests is essential to any adequate understanding of humans. After introducing and explaining some of the distinctive elements of Sloterdjik's philosophy, a brief account of his broader history as a thinker is given, before focusing on the third and final volume in his epic *Spheres* trilogy, *Foams*, in which he proposes that technological and cultural developments in the twentieth century can be suggestively interpreted using the metaphor of foam. In Sloterdijk's work, foam is the metaphorical expression of a generalized notion of dwelling and society that accounts for the way developments in architecture and telecommunications have serviced and been served by an ideal of co-isolated living. This aspect of Sloterdijk's work, and his theory of spatial immunity, which informs his thinking about space more broadly, is

particularly germane for any program of research that attempts to interpret practices of human dwelling and sociality with a transdisciplinary orientation. It does this by demonstrating the ways in which an understanding of the metaphorical basis of language and becoming human can be used to create concepts that facilitate the successful integration of forms of knowledge from the sciences, humanities, design, and experiential ways of knowing.

This article is written according to a principle that puts sustained, in-depth attention to a particular text and author over ambitions of survey or critique in relation to other arguments. The intent is not to judge if Sloterdijk's various propositions bear out the claims they make through reference to evidence or application to further examples. Rather, the approach taken is informed by an intent to highlight the unique conceptual tools and modes of thinking employed by a thinker with deep relevance to the focus of this special issue: to integrate disparate perspectives on indoor life and ecologies. There is much opportunity for further work to be conducted using and evaluating Sloterdijk's often bold claims in relation to evidence-based sociological, scientific, and anthropological approaches.

Techniques of Language, Immunity, Space, and Ecological Metaphysics

An understanding of the rationale that informs Sloterdijk's stylistic decisions places readers in a better position to grasp the meaning expressed in the often peculiar language play evident in his philosophical analysis. Sloterdijk's style is characterized by a unique use of poetic techniques, in particular his abundant use of metaphor and hyperbole. This approach is informed by a stated commitment to exaggerating or recontextualizing the language games of other discourses. This stylistic decision is informed by an interpretation of "the human" that is mindful of the limitations of biological positivism and adequately accounts for the excessive dimension of humanity within the context of ecological history: "All the decisively human capabilities are exaggerations. Walking upright itself was already a hyperbole that could never be totally compensated for with biological advantages" (Sloterdijk, 2016, p. 31). These impressionistic but often captivating caricatures of evolutionary history are frequent in Sloterdijk's analysis. Like all caricatures, they are at once inexact and, if successful, expressive of a certain truth.

This stylistic inventiveness is further amplified by the numerous disciplinary voices that echo through his prose. He referred to the "trans-rational, trans-subjective, trans-experiential" (Sloterdijk, 2011a, p. 30) nature of the visionary thinking that informs well-rendered philosophical and poetic writing:

> All my work moves in such trans-dimensions; it wanders between disciplines, languages, aspects. It could be understood as the literary materialization of an extended conception of the Enlightenment. (Sloterdijk, 2011a, p. 30)

Understatement and notions of communicative competence are in this sense avoided in favor of exaggeration, irony (which he described as "an overreaction to the permanent annoyance of statements of facts" [Sloterdijk, 2011a, p. 31]), and metaphorical play—to this extent it is revealing that Sloterdijk (2011a, p. 204) toyed with presenting his *Spheres* project as a novel until the last minute.

The value of an interpretive or analytical approach grounded in hyperbole or exaggeration is advocated by a range of scholars for its potential to provide new epistemological and ontological insights (Ettenhuber, 2007; Ritter, 2012; Stanivukovic, 2007). Hyperbole, literally meaning to "throw beyond," is a mode of thought or a form of philosophical inquiry (Ritter, 2012). It is used variously in situations when language or thought must transcend epistemological and ontological boundaries to undermine or "throw beyond" literal meanings. In this sense, Sloterdijk's exaggerated and metaphoric portrayals of phenomena are intended not to capture empirical detail, but to enable us to think beyond the constraints that would usually inhibit our thinking.

In the context of this special issue, Sloterdijk's expanded use of the concept of "immunity" is a particularly instructive and relevant example of his metaphorical and hyperbolic play, which connects directly with the emphasis on space in his work. Sloterdijk's approach to thinking through concepts such as immunity demonstrates neither the indifference nor hostility shown by many humanist philosophers toward techno-scientific developments, nor any of the naive reverence for innovation and truth that informs hard-line advocates for salvation through such means. Instead, Sloterdijk practices philosophy as a way to express the broader cultural and historical implications of techno-scientific knowledge. Regarding the notion of immunity, he begins by emphasizing the distinctive paradox expressed through the idea, and the interpretative demands it puts on the various institutions that seek to shape what it means:

> One must acknowledge that there are occult battles between pathogens and "antibodies" in the human organism whose results are responsible for the state of our health. Many biologists describe the somatic self as a besieged terrain defended by endogenous border troops with varying success. The users of this hawkish terminology are opposed by a fraction of biological doves who paint a less martial picture of immune processes; in this version, the self and the foreign are so interwoven at deep levels that overly primitive strategies of definition are more likely to have counterproductive effects. (Sloterdijk, 2016, p. 185)

Sloterdijk (2016) summarized the broad conceptual field associated with the immune concept, as defined by tendencies to assign more or less significance "to the presence of the foreign amidst the own" (p. 186). However, the discursive tensions between biological, political, legislative, and social dimensions that the idea of immunity brings into relation are accompanied by a further interpretive demand for a philosophy that attempts to *think with* the innovative ideas of modern science:

> It is not only through their complexity that the immune systems confuse their owners' longing for security; they cause even more perplexity through their immanent paradox, as their successes, if they become too thorough, are perverted to become their own kind of reasons for illness: the growing universe of auto-immune pathologies illustrates the dangerous tendency of the open to win itself to death in the battle against the other. (Sloterdijk, 2016, pp. 185–186)

In this sense, biochemical understandings of immunity are accompanied by degrees of complexity and paradox that enable the concept to function as a useful metaphor for interpreting a range of different systems and technological developments that play a defining role in modern societies. For example, Sloterdijk (2016) suggested that the development and dissemination of knowledge itself in techno-scientific cultures can have paradoxically adverse effects with regard to what he described as "the mental immune status of 'enlightened society'" (p. 186). By this he means to suggest that there is a perverse side to the view that more information will deliver greater degrees of immunity from risk, and that increases in knowledge—while delivering undeniable benefits for securing the ongoing safety of humans—can also trigger something comparable to a kind of autoimmune response at a psychocultural level. Smithson (1985) made compatible arguments with regard to utility—or in Sloterdijk's terms, the immune function—of ignorance in the conditions of uncertainty that are common to knowledge-abundant societies. In this sense, levels of mental stresses relating to risks or threats become impossible for individuals or collectives to adequately manage and begin to have adverse effects as the body politic begins to attack itself. The metaphor of autoimmune overreaction could also be aptly applied to contemporary concerns about "helicopter parenting," by which parental attempts to protect one's children from harm constitute an overreaction, which can lead to children becoming less resilient and lacking in the forms of mental and embodied knowledge required to develop necessary coping strategies for life.

Sloterdiijk follows this unpacking of the modern scientific notion of immunity with a broader historical account of the field of meanings, institutions, and practices associated with the word. While contemporary understandings of immunity are largely informed by scientific and medical understandings of the concept, Sloterdijk (2016, p. 500) points out that the older usage can be traced back to Roman law, when the term described a situation in which various entities, including cities, groups, and individuals, were granted exemption from obligations to the state or to a community—a meaning still retained in the current legal usage of the word. Sloterdijk's philosophical approach involves bringing together multiple meanings of this word across different fields of knowledge to think *with* language in a way that exploits its dynamic, rather than exclusively semantic possibilities—an approach that is common to poetry and literature. He allows the different but related definitions of immunity to ramify through his analysis such that an understanding of social and architectural contexts can be interpreted in a subtly changed way that reveals

new light on notions of personal or shared immunity. This approach suggests a new way of thinking together across biology, architecture, ecology, anthropology, and sociology (Sloterdijk, 2016, p. 498).

Sloterdijk frames the historical, technological, and cultural developments associated with modernity as facilitating a distinctive kind of immune experience. He suggested that the religious and legal immune systems of the past are less pertinent to interpreting the modern condition than the architectural and technological systems that support routines of self-care and leisure:

> The dwelling of the modern person is the body extension that provides a specific representation of their habitualized self-concern and backgrounded defensiveness. It renders explicit that living organisms do not exist without ensuring enclosure in themselves. Thus dwelling gains a share in the core process of modernization: it articulates the emergence—or the becoming-explicit—of immune systems as well as the experimentation of self-referential units with larger associations (in which even the largest will still be far smaller than the "whole."). (Sloterdijk, 2016, p. 504)

The terms "emergence" or "becoming-explicit" are Sloterdijk's alternatives to the notions of national, technological, or scientific revolutions. In this sense, "becoming-explicit" or "explication" is the unfolding of forms of knowledge evident in religious and mythological practices, or otherwise vaguely known intuitions, through more precise and interwoven technological and systemic approaches. The promise of the architectural and technological realization of the immune function is "the basic right to ignore the outside world" (Sloterdijk, 2016, p. 501) so daily routines of self-care and self-expression (Sloterdijk emphasizes the interweaving of the two) can be performed and perfected.

While the archetypal architectural situation echoed in the above description is the solitary, narcissistic apartment dweller, it would be wrong to equate Sloterdijk's account of modern living as individualistically oriented in any simplistic sense. As he made clear in a feature for *Harvard Design Magazine*:

> [a]ll being-in-the-world possesses the traits of coexistence. The question of being so hotly debated by philosophers can be asked here in terms of the co-existence of people and things in connective spaces. That implies a quadruple relationship: (1) Being means someone (2) being together with someone else (3) and with something else (4) in something. This formula describes the minimum complexity you need to construct in order to arrive at an appropriate concept of world. Architects are involved in this consideration, since for them being-in-the-world means dwelling in a building. A house is a three-dimensional answer to the question of how someone can be together with someone and something in something. In their own way, architects interpret this most enigmatic of all spatial pre-positions, namely the "in." (Sloterdijk, 2009, p. 6)

The question of being *in* is among Sloterdijk's primary and most sustained philosophical focuses and explains his concern with examples of intimacy and interiority. This ranges from primitive interhuman and interspecies notions of intimacy such as bodily gestation, kissing, and biophilic relations with trees, to increasingly large-scale and complex modifications of interiority, such as air-conditioning, gas warfare, popular music, and various paradigm-setting architectural examples, including the stadium and the modern apartment. Sloterdijk's metaphor of foam describes the architectural and social situation in which humans are at once enclosed within spatial extensions of themselves and in mediated relationships with larger, often weakly connected associations or collectives. This is a significantly different situation to the simple intimate relations such as those between mother and child, or smaller collectives—the focus of Sloterdijk's (2011b) first *Spheres* volume, *Bubbles*—which, nonetheless, still endure as crucial enabling layers within the more complex and transformed interiors and systems peculiar to the modern period.

Among the key antecedents for Sloterdijk's philosophy, and what makes his work such a good fit for the focus and ethos of the present journal, is the making explicit of the notion of the environment as a key focus in the biological and social sciences. He makes several references to, and his thinking is clearly influenced by, the work of the Estonian biologist Jakob von Uexküll (1992), who, writing in the first half of the twentieth century, used the metaphor of a soap bubble to express his concept of the microworld, or *Umwelt.* According to Sloterdijk (2016), Uexküll's theory and the broader notion of living creatures each inhabiting a specific ecology had a decisive effect on the way space and social life are conceived and demands a renewed approach to metaphysics:

> When Jakob von Uexküll formulated the thesis that it had been a mistake to view the human world as a shared stage for all living creates, he was not only drawing the life-scientific from the deflation of the world soul-idea; he was also taking the step from monological metaphysics, which interprets the world as mono context and projects it onto a single eye, to a pluralistic ontology that estimates as many worlds as there are eye types and other sensors to see and feel them, without resorting to the hypostasis of an eye of all eyes (or a sensor of all sensors). (p. 230)

Uexküll's interpretation of the world as "countless millions of narrowly bounded bubbles that overlap and intersect everywhere" (cited in Sloterdijk, 2016, p. 230) is taken up into Sloterdijk's thinking as the metaphor of foam and extended to the point of rupture in his various conceptual and rhetorical acrobatics. Unlike the different religious and metaphysical conceptions of a unifying spiritual or perceptual force—whether in the form of the gods in monotheistic religions, ancient conceptions of heavenly spheres, or nostalgic reiterations of these ideas in naive forms of holism—Sloterdijk's ecologically informed use of the foam metaphor emphasizes a complex, contingent, and irregular field of relations produced by diverse gatherings of beings.

Sloterdijk's further contribution to the program set out by Uexküll is to characterize human spheres in a manner that is adapted to their specific properties. While he is clearly sympathetic to a decentered notion of ecological agency, Sloterdijk (2016) also argued that the human species possesses attributes that are not captured in Uexküll's biological conception of space, relationality, and perception:

> The human households described here as cells in the social foam make use—beyond merely defensive provisions—of manifold expansion mechanisms extending from the setting-up of a living container, via the establishment of a personalised traffic system, to the creation of a customized world picture poem. Such observations provide a concept of immunity with aggressive qualities: starting from the biochemical layer of meaning, it moves up to an anthropological interpretation of the human *modus vivendi* as self-defence through creativity. (p. 232)

The notion of immunity as defensive force might be adequate for an understanding of biologically interpreted living things. However, in Sloterdijk's view, this lacks the scope to account for the exemplarity of humans with regard to creativity, in particular the technologically realized expressions of creativity that in modernity go by the modern name of "design."

Sloterdijk (2016) argued that attentiveness to creative excesses and multiple spatial environments of modern humanity sets his foam theory apart from other conceptions of the social:

> The familiar suggestions for solutions offered by such concepts as division of labour (Smith, Durkheim), capital context (Marx), imitations and somnambulism (Tarde), interdependency (Simmel), sacrifice (Girard, Heinrich) or progressive differentiation and communication (Luhmann) all suffer from the same deficit: they do not adequately address the spatial qualities of social cells or the immune system character of primary spaces. (p. 235)

Sloterdijk is clearly influenced by all the thinkers listed in this critique, and makes regular and highly nuanced use of them in his work. For example, his notion of spatial immunity, or what he described as "the exemption from service to society" (Sloterdijk, 2016, p. 275), whether serviced by architecture or media, captures and emphasizes the latent indication in thinkers such as Simmel, Tarde, and Luhmann in particular, that "'societies' are composed of beings that must simultaneously stand inside and outside of their association" (p. 278). However, he nonetheless maintains the argument that their various conceptions of society proposed by the thinkers listed lack a rich enough metaphorical grasp of the spatial diversities, excesses, and commitments of humans and their technological extensions.

Sloterdijk's unique attentiveness to finding the right image to describe this highly nuanced conception of the psychosocial spaces inhabited by humans is recognized by Bruno Latour (2010)—arguably the contemporary thinker who, in his

popularization of the network metaphor in actor–network theory, has done the most to advance a conception of the social that is most compatible with Sloterdijk's notion of foam:

> As you may know, one of the criticisms often made about networks (particularly by Peter Sloterdijk) is that they are extremely poor metaphors since they remain entirely made of nodes and edges to which is often added some conveniently drawn potato-like circles … To say that something is a network is about as appealing as to say that someone will, from now on, eat only peas and green beans, or that you are condemned to reside in airport corridors: great for traveling, commuting, and connecting, but not to live. Visually there is something deeply wrong in the way we represent networks since we are never able to use them to draw enclosed and habitable spaces and envelopes. (p. 5)

In contrast to the spatially impoverished notion of networks connecting in simple geometric space, Sloterdijk's psychoanalytically, poetically, and architecturally informed interpretation of human psychosocial space aims to give an account of the complex interweaving of physical and psychic space. In this sense, Sloterdijk's approach to philosophy is particularly compatible with the often unanswered promise of the discipline of design, which conceives humans as beings motivated by aesthetic desires that perpetually ramify in their level of nuance. The importance of the personalization of interiors as spaces that reflect multiple creative, protective, and connective urges is evident throughout his works. The next section will focus on a segment of *Foams* that gives sustained attention to the routines of apartment living as a platform for more abstract philosophical and poetic analysis.

Immunity Practices and Apartment Life

Sloterdijk (2016, p. 529) regarded the creation of the solitary apartment dweller as one of the key sociopsychological phenomena of the twentieth century. He employs a range of rhetorical and conceptual resources to animate a vision of this lifestyle as practiced by a relatively wealthy subject living in an advanced industrial democracy. The value of this approach comes from the simultaneous gathering of theories about contemporary media, quasi-physiological analysis of metabolic and sensory activity, and phenomenological-type descriptions of how this might be experienced by a hypothetical subject. Sloterdijk (2016) described the apartment as "at once stage and cave" where a "self-care cycle" is performed, which might include "a morning grooming session consisting of emptyings, washings, acts of cosmetic self-attention and clothings" (p. 650). The "universe of differentiations that are assigned great intrinsic value in the consciousness of users" are crucial in this stage of the practices of getting ready for daily life performances: "here combination becomes the duty of design, while selection becomes a self project" (Sloterdijk, 2016, p. 650). Next, the analysis moves to breakfast, which is also an occasion for the development of "self-care from a nutrition-critical perspective" (Sloterdijk, 2016, p. 551). According

to Sloterdijk (2016), these "elementary gastrospheric standards" are, along with sanitary standards, the defining "concept of comfort in a modern housing unit" (p. 552).

Sloterdijk (2016) then turns his attention to the role of media in the unfolding of morning routines, which he describes with the characteristically enigmatic phrase the "anti-*silentium*," indicating the entry of sound into the "nocturnal soundfast":

> This anti-*silentium* shows how the solitary apartment dweller takes their daily resocialization and attainment of worldliness into their own hands by having a say, through the choice of media, in the content and dosage of the reality influx. (Sloterdijk, 2016, p. 552)

He is keen to point out that while in the past this outcome was achieved through reading, now it is more likely to be practiced through immersion in sound or (increasingly) audiovisuals, which, once released into broader public spaces, can be compared to "cells in sonorous foams; with reference to the countless competing listening collectives" (Sloterdijk, 2016, p. 554). The combined function of different media in the apartment space, whether paper, radio or television, allows for remote "world content" to enter into the space of the cell while it still "performs its defensive functions as an insulator, an immune system and a supplier of comfort and distance" (Sloterdijk, 2016, p. 555).

The three final focal points of Sloterdijk's account of apartment life include the role of the telephone, the elaboration of self-serving sex practices, and the maintenance of knowledge levels. Each of these points has implications for how apartments function as immune structures, and the psychological, cultural, and biophysical states that develop within indoor spaces. Sloterdijk (2016) regarded the key effect of the telephone as the introduction of a "two-way media" that enjoys the "double ontological privilege" of connecting the apartment dweller with the "domain of the real" and puts them into a "state of simultaneity" (p. 555) with the caller. This function is continued in contemporary Internet technology, which Sloterdijk (2016) suggested is "merely the continuation of the telephone by visual means" (p. 556). Telephonic technology is "an ambivalent innovation" with regard to maintaining the immune function of the apartment space: "it directs a canal for dangerous infections from the outside into the dwelling-cell, while conversely expanding the inhabitants radius—in the sense of larger alliances and opportunities for action—in an explosive fashion" (Sloterdijk, 2016, p. 556). This has significant consequences that are distinct from religious practices, which Sloterdijk compellingly characterizes as a kind of telecommunications technology, and print-based cultures. He argued that "modern telephone supported apartment lifestyle" represents a significant shift from the premodern era, in which "the most interesting messages came from a strong sender known as 'God'," to a phase in which such messages are to some

extent trivialized, as individuals attempt to maintain a requisite level of interest in themselves, or that, failing, "focus on the lives of the stars" (Sloterdijk, 2016, p. 558).

The following section on sexuality adds a further notch to Sloterdijk's account of apartment lifestyle and the broader cultural trends through which it is informed. This is a world where sexual activity is now to a large extent released from its biological and social obligations as a force in the creation of offspring, and becomes a means by which individuals explore and experience erotic possibilities. Sloterdijk (2016) suggested that while biochemical contraceptives had a significant and "over-discussed" role in this change, it is also "inseparably connected to the gain in discretion through apartment culture, or at least to the securities of one's own room" (p. 559). Sloterdijk (2016, p. 560) cites the American feminist and masturbation activist Betty Dodson, who, in awarding herself a PhD in masturbation, offers an unimprovable characterization of the release of individuals into spaces and time to conduct research into their own erotic desires. However, such trends are not unidirectional, and Sloterdijk (2016) lent further nuance to his claims by alluding to recent literature on singles and by citing Dodson again, who admitted that she "intermittently resorted to penises" to avoid the onset of weariness associated with "auto-monogamy" (p. 561). Nonetheless, Sloterdijk (2016) suggested that studies have "shown beyond doubt" that such needs are not enough for singles to "accept the disturbance of their cellar peace through a permanent partner" (p. 561).

Lastly, Sloterdijk describes the role of modern telecommunications technology and its place in apartment lifestyle as supplying isolated individuals with the means to ensure adequate levels of knowledge are maintained. In light of the relatively small gains individuals make in self-education in comparison with the rate by which levels of knowledge increase at a systemic level across society, Sloterdijk (2016) preferred to call this "enlightened ignorance management" (p. 562). Knowledge in such contexts functions by affording individuals "the license to choose and have say" or in a manner comparable to "fashion items and markets," such that "people carry isolated particles of knowledge the same way they wear sunglasses, expensive watches or baseball caps" (Sloterdijk, 2016, p. 562).

Sloterdijk's hyperbolic characterization of a particular kind of modern interior life offers a thought-provoking and wide-ranging account of humans as beings shaped by complex cultural, environmental, and technological forces. The presence of exaggeration in the absence of any uniform, clearly identifiable, critical, or salutary perspective makes the reader more keenly aware of the not always enlightening role of totalizing or minutely detailed explanatory theories of social life. In this regard, Sloterdijk's approach can offer unique insights when compared to caricatured critiques of what is often given the misleadingly anodyne name "consumer culture,"

particularly those in the influential traditions of the Frankfurt School and Thorstein Veblen (see Denniss, 2017; Horowitz, 1985), and more broadly across sociology, cultural studies, economics, and consumer studies.

Studies of consumer culture have undoubtedly become more nuanced and inclined to detailed and situated ethnographic accounts of how and why people "consume" resources in different ways, particularly those investigating the "inconspicuous consumption" of resources that accompanies everyday activities, unrelated to symbol or status (Christensen, 2015; Eckhardt et al., 2015; Shove & Warde, 2002). However, Sloterdijk's use of exaggeration and metaphor offer additional tools for critique that literal accounts of the minutia of daily life cannot. As noted in the above section "Techniques of Language," exaggeration and metaphor can serve to extend literal meanings to new fields of thought. Ritter (2012) further articulated the value of such techniques to multiple scholarly pursuits in his statement that exaggeration and hyperbole are:

> a figure of thought that can highlight the limits of figuration and representation (Bloom, 2003), operate as a vehicle for the sublime (Marvick, 1986), destabilize norms and conventions, and encourage active reflection on "the different ways in which meaning is constructed and communicated" (Ettenhuber, 2007, 210). (p. 410)

Hyperbolic accounts can complement the rigorous and detailed observations of reality by offering a way of playing with the meanings offered at "the extreme boundaries of thought" (Stanivukovic, 2007, p. 20), thus, enabling an interruption of the language and logic of the existing argument, which can shift "one level of meaning to another, re-invented meaning" (p. 20). An argument for the value of this approach can be made through an analogy to similar arguments created for the use of different media in the sociological studios of scientific practices. For example, Peter Galison (2014) made a compelling case that the medium of film can reveal unique things about scientific practice, specifically the visceral, atmospheric, and particular dimensions of the everyday that are not captured using the standard conventions of academic publication. Likewise, through different techniques of rhetoric rather than media, Sloterdijk evokes an image or story of humans that is not reducible to the genres of novelistic, poetic, historiographic, and philosophical writing from which it borrows. The work is too philosophically conceptual in its explorations of technology for novelistic writing, far more attentive to the description of everyday life than is permissible in philosophical analysis, too thesis driven for poetry, and too impressionistic for history. Yet, in this rag-and-bone approach, Sloterdijk evokes a uniquely post-human account of humans, which demonstrates the subtle dynamics that animate the relationship between routine and dwelling, media and psychology, and the historical and futuristic dimensions of technology. The concluding section of this article will discuss in a more explicit fashion how Sloterdijk's philosophical

exploration of the "in" extends to an analysis of how broader conceptions of climate, atmosphere, and environment have become increasingly important at a subjective level during the modernization processes of the twentieth century.

Air Design

The difference between Sloterdijk's technologically informed approach to philosophical analysis and the phenomenological approaches that have been so influential in descriptions of human subjectivity is marked out in a particularly pronounced fashion when approaching the topic of air. Unlike phenomenological advocates of air, such as Luce Irigaray (1999), Sloterdijk (2016, p. 196) stressed that the air cannot be adequately understood without reference to the technical and environmental changes inflicted on the atmosphere over the course of the last 200 years. Phenomenological accounts, particularly those that call for greater attention to be paid to the air (such as Irigaray's), ignore all the crucial ways in which the air has already been made explicit, and been explicitly utilized, for various aerotechnic practices. Some of these include colonizing the air with gas in warfare to make the atmosphere uninhabitable to opponents, and researching the possibilities for larger scale atmospheric terrorism.

By contrast, using his characteristic blend of poetic and conceptual thinking, Sloterdijk explores the philosophical implications of significant air-related events over the twentieth century, including "atmoterrorism" practices evident in gas and aerial warfare; the interaction between the weather, science, the media, and subjectivity expressed in the convention of the weather report; and the hugely influential, continuously evolving "aerotechnic" practices that service the increasing demands for comfort, which are characteristic of indoor life in the modern period. These and other grouped-together technological and conceptual developments in air design are, according to Sloterdijk (2016), compelling expressions of the view for which anyone attempting to understand the originality of the twentieth century must account: "the practice of terrorism, the concept of product design and the environmental idea" (p. 85).

Gas warfare is a forceful example of the explication or highlighting of the atmospheric (a word it is worth remembering literally means "vapor ball") conditions human subjects and collectives must persist. Sloterdijk (2016) described the first "large-scale use of chlorine gas as a warfare agent" on April 22, 1915 (p. 86) as a decisive event in the development of both terrorism and environmental thinking:

> This is, in fact, the point at which traditional war becomes terrorism, assuming the latter is based on a rejection of the old crossing of blades between equal opponents. Current terror operates beyond the naive exchange of armed strikes between regular troops. Its concern is to replace classical battle forms with attacks on the enemy's environmental preconditions for life. (pp. 91–92)

These distinctive martial conditions are supported by a staggering set of statistics cited by Sloterdijk (2016):

> When one learns from military history that between February and June 1916, the responsible field depot supplied almost five and a half million gas masks and 4,300 breathing apparatuses (mostly taken from the mining industry) with two million litres of oxygen to the German troops at Verdun alone, it becomes evident in numbers how far "ecologised" war, a war brought into the atmospheric environment, had become a battle for the respiratory potentials of hostile parties. Combat now incorporated the biological weak points of the conflict partners. (p. 95)

The first environmental attack of gas warfare provoked a rapid and large-scale design response to augment the human body with the technological means to persist in an atmosphere hostile to life. In this sense, gas warfare "introduced the operative criteria of the twentieth century—terrorism, design-consciousness, and an environmental approach—in close union" (Sloterdijk, 2016, p. 96).

Sloterdijk (2016) traced developments in atmoterrorism from these initial uses of gas warfare in World War I, through the industrial-scale extermination camps used in World War II, to gas chambers used sporadically in United States (US) for executions, and the "explication of radioactive matter through nuclear power," which resulted in a "reordering of 'environmental' awareness towards the invisible milieu of waves and rays" (p. 130). He concluded this focus with reference to a paper presented to the US Department of Defense on June 17, 1996, which bears the chilling title, *Weather as a Force Multiplier: Owning the Weather in 2025* (House et al., 1996), and the following, equally chilling, strategic ambition:

> A high-risk, high-reward endeavour, weather modification offers a dilemma not unlike the splitting of the atom. While some segments of society will always be reluctant to examine controversial issues such as weather modification, the tremendous military capability that could result from this field are ignored at their own peril. (cited in Sloterdijk, 2016, p. 139)

Exactly 110 years on from the first large-scale uses of atmoterrorism in World War I, these intentions to develop weather-modification technology and the rationale that supports them signal the potential of a new era in advanced military combat. Details on the contemporary progress of such research are notoriously difficult to access. However, in light of the increasing commonality of nonmilitary climate-design technologies, such as cloud seeding and the evident strategic advantages of large-scale climatic attacks, it seems entirely plausible that this is an area the military will continue to explore. Further, with spending on military research and development in the US (or any other world power) unlikely to dip in the near future, the nonmilitary spin-offs of these large-scale climate manipulations will have significant and unforeseen consequences for industries around the world, from agriculture, to tourism, and the ever-expanding indoor biomes that populate these regions.

Sloterdijk (2016) proposed that the large-scale environmentally destructive potentials of modern military technology is one expression of "a progressive subjectification of the weather" (p. 161). This subjectification is also occurring at meso and microscales, for which he contended humans have become "weather clients" (p. 161) through the performance of weather reporting, associated weather travel or tourism (Sloterdijk mentions vacations for Northerners in the winter months to Morocco and Mallorca), and air-conditioning developments in shopping malls and homes designed to sustain thermal comfort for the ongoing presence of human users. Both these macroscale militaristic and mesoscale comfort-inspired developments represent a subjectification of the weather through both the rhetorical and performative techniques used in the reports, and the technological adaptations of climate to the body evidenced in air-conditioning.

Sloterdijk's (2016) amusing characterization of the modern weather report as "a performance given by a nature for society" by which "meteorologists gather people to form an audience of connoisseurs under a shared sky" (p. 160) provokes a renewed consideration of this perhaps taken-for-granted, everyday convention. Like other significant natural events such as birth and death, the weather is no longer the domain of God or nature, but a context for the "nuancing activities" (Sloterdijk, 2016, p. 787) of modern humans, whether the calculations of meteorologists or the intersubjective planning programs of kinetic elites who escape their colder northern locales to warmer countries in the winter months. At a more local level, the weather report and its digital equivalent, the weather app, functions as a permanently accessible discussion-generating tool through which users "compare their personal perception with the briefing and form an opinion about ongoing events" (Sloterdijk, 2016, p. 159).

The notion of air design, or what Sloterdijk (2016) also called "atmotechnics" (p. 165), is realized in micro and meso levels in the air-conditioning technology and associated practices that increasingly shape public and private spaces over the course of the twenty-first century. Sloterdijk suggested that various air-conditioning and climate-control technologies have both enabled and testify to the "addiction to dwelling" (Sloterdijk, 2016, pp. 169–170), expressed as a preference for conducing all manner of activities indoors. As with his discussion of the "greenhouse effect" in the second *Spheres* volume *Globes*, Sloterdijk (2014) reinvigorates the interpretative potential of the otherwise inconspicuous notion of air-conditioning by grounding it in significant historical examples and extending the metaphor to culture more broadly. Following the insights of Hermann Broch and Elias Canetti, he suggested that the "mood modification" techniques used in air-conditioning practices of commercial shopping centers, offices, and private residences are metaphorically interpretive of the personal media ecologies and mass communication technologies that are among the defining features of life in the twentieth century and beyond: "Broch had realized that after the intentional destructions of the atmosphere in

chemical warfare, social synthesis itself took on the character of gas warfare in some respects, as if atmoterrorism had turned inwards" (Sloterdijk, 2016, p. 174). Similar ideas have been suggested by the French philosopher of science Michel Serres, who suggested that the new metaphysics of the information ages is "more liquid than solid, more air like than liquid, more informational than material" (Serres & Latour, 1995, p. 121), and demonstrated a comparative appeal, with efforts by Stokols (2018), to expand the study of social, or human, ecology into the digital realm.

Conclusion

This article has made the argument that Sloterdijk's philosophy is a distinctively thought-provoking resource for scholars whose work focuses on investigating indoor ecologies from different perspectives. It proposes that Sloterdijk's work provides a basis for integrating perspectives from natural and social scientific disciplines, which is particularly attentive to the spatial, physical, and experiential manifestation of knowledge as architecture and design. Sloterdijk's commitment to practicing philosophy according to multiple logics and stylistic devices allows him to explore the boundaries of human thinking by approaching language as something that has a dynamic, rather than static or simply definitional, relationship with meaning. In this regard, the hyperbolic and metaphorical techniques Sloterdijk employs allow him to evolve diverse yet cohesive understandings of concepts such as immunity, the cell, foam, and the atmosphere, which are often dulled through exclusive usage in their disciplinary sites. The elaboration and curation of his ideas evidenced in this article are intended to prompt scholars from different disciplines to further explore his work, and use it as a reference point in research into indoor ecologies that requires framing in relation to broader sociotechnical trends and the futures to which they may give rise.

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Book Review

Social Ecology in the Digital Age: Solving Complex Problems in a Globalized World

By Daniel Stokols

London, UK: Academic Press, 406 pp., 2017
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Reviewed by Robert Dyball[1]

Social Ecology in a Digital Age is a comprehensive overview of the theoretical development and application of social ecology to understanding the wicked problems humanity faces today and in the future. It chronicles author Daniel Stokols's personal journey, including his joining the Program in Social Ecology in the early 1970s at the then relatively newly founded University of California Irvine, and his development as a teacher and scholar within that program. It is also a narrative of the emergence of social ecology as an approach to the changing problems of the world, including the development and consequences of novel phenomena, such as digital technology. *Social Ecology in a Digital Age* makes a valuable contribution to all students, researchers, and policy-makers who are grappling with transdisciplinary approaches to socioecological situations that are both unsustainable and unjust, and demand interventions to transform them for the better. Consequently, this book is highly relevant to human ecologists, as demonstrated by it being awarded the Society for Human Ecology's 2018 Gerald Young Book Award.

Chapter 1, "Discovering Social Ecology: A Personal Journey," sets out Stokols's own academic background and what drew him to social ecology. It culminates with the analytical framework of social ecology as a tool for mapping the interconnections between the natural, built, sociocultural, and cyber dimensions of human communities. Chapter 2, "Historical Origins and Conceptual Foundations of Social Ecology," next details how this approach developed over time and what Stokols perceives as its unique and distinguishing features, specifically what sets it aside from its very close cousin in human ecology. These characteristic features are elaborated in Chapter 3, "Deriving Core Principles of Social Ecology." These principles include that social ecology understands human environments as multifaceted, with natural, built, sociocultural, and virtual cyber-based dimensions, and recognizes that these spheres need to be analyzed across multiple scales. A second principle is that the interactions between people and these spheres form feedback systems, and, thus,

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need to be understood from a systems-thinking perspective. Third, social ecology commits to methodological plurality, as different problems at different scales need to draw on different concepts and methods to adequately propose solutions for them. Finally, and arising necessarily from the previous principles, social ecology is transdisciplinary and translational, in that it seeks to apply its research findings to improve a situation under study.

Having established the conceptual framework of social ecology across the first three chapters, Stokols then moves to demonstrate their application in a number of contexts and scales. In Chapter 4, "Rise of the Internet: Navigating Our Online and Place-Based Ecologies," Stokols focuses on the subtitle of the book as a whole with the emergence of a new dimension in human-environmental systems, cyberspace, and with it the digital age.2 Its psychological, health, social, and environmental effects are addressed along with its mixed blessings. Personally, I am grateful to have had the term "Google Knowledge" introduced to me to indicate the narrow and uncritical knowledge one can gain about absolutely anything, and will definitely be adding it to my QuickMark options for grading student papers in the future. Nevertheless, digital literacy is a functional requirement for modern society, and Stokols rightly describes the situation that nearly half the global population does not have access to the digital world as an "epistemic injustice." The challenge is to provide that access and simultaneously harness the benefits of the digital age while minimizing its burdens and harm.

Chapter 5 is on "Promoting Personal and Public Health" and provides a history of the development of the biomedical approach to health and disease, and the later emergence of a biopsychosocial model. The latter is conducive to socioecological analysis, which is better able to understand the biophysical and sociocultural context within which choices are made. An example is the broader contexts that constrain which decisions are made concerning what to eat as well as the health consequences, such as incidents of obesity, that follow. Stokols presents examples of such issues across scales, from the individual, to family, to neighborhood, and city region and above, demonstrating the nested contexts within which health and well-being issues arise. The chapter closes with a brief discussion of digital technologies' contribution to future health care—for example, in online health services.

Chapter 6, "Confronting Complex Social Problems," further applies a socioecological framework, initially through an analysis of a low socioeconomic status community and their struggle with a waste tip located within proximity. Lessons drawn from this example include the need to address contextual scope—meaning the often contested boundaries placed on the spatial, temporal, sociocultural, and virtual aspects of a problem—and that different stakeholders in a problem's situation identify different objective and subjective dimensions of that problem itself. In the

2 In his contribution to this issue, Stokols discusses these effects at the scale of indoor environments.

waste tip example, the council's emphasis was on objective elements, such as if the tip conformed to environmental standards, while the community's emphasis was on the subjective dimension of living near a tip and the social justice dimension that the tip was where it was because the community in question was politically disempowered. This last lesson overlaps with the need to view problems both from an individual perspective (concerning statistical estimates of the health risk to an individual), and an aggregate or community perspective, such as the community stress of distributive and process injustice. A final lesson drawn in understanding social problems is the distinction between the partitive component, or the narrow cause and effective relationship (here, between the immediate effect of such tips on individuals' health), against the composite component, being the broader physical, mental, and emotional dimensions of individual and community well-being. The second half of the chapter concerns examples of narrowing the digital divide with socioecological approaches, featuring an overarching message about the limited contribution individual disciplines can make to solving complex human-environmental problems.

Chapter 7, "Managing Global Environmental Change," then applies the social ecology approach at a larger scale. A contrast is drawn between the relative success of international efforts to control chlorofluorocarbons and their damage to the Earth's ozone layer, alongside the less successful international effort to limit greenhouse gas emissions and climate change. The chapter further engages with other planetary thresholds, of the kind identified by Rockstrom et al. (2009), and discusses how collectively we can reduce our environmental effects while allowing the under-consuming and developing world greater justice and access to the Earth's resources. Stokols notes that achieving this turnaround will require both top-down policies, such as those forged through international negotiations, as well as bottom-up steps taken at much more local levels of city mayors and communities. Chapter 8, "Designing Resilient and Sustainable Communities," picks up on the closing sentiments of the previous chapter, being that we need to collectively redesign our human-environmental systems to be both just and sustainable, and usher in a new Anthropocene, which can be celebrated rather than feared (Anthropocene 2.0). As with all previous chapters, Stokols emphasizes the nested scales at which action is needed, and the importance of synergistic outcomes for both environmental health, and the health and well-being of people and communities. The chapter emphasizes that a "good Anthropocene" will require a much broader set of measures of human values than mere economic indicators. According to Stokols, it will also require concerted and collaborative efforts from policy areas and knowledge bases that do not typically view themselves as having common cause:

> Social ecological analyses and solutions to these problems require transdisciplinary approaches that draw not only on the macroscale views of earth system science, society–nature relations, economics and international governance but also insights derived from urban planning, environmental design, public health, informatics,

> psychology, and social behavior—fields that address meso- and micro level (e.g., municipal, organizational, behavioral) facets of people's relationships with their surroundings. Transdisciplinary conceptions of social and human ecology must bridge these disparate perspectives if they are going to be able to provide multiscale, comprehensive solutions to today's challenges. (p. 296)

This is no easy challenge, but as Stephen Boyden noted back in 1986:

> the whole question of the dynamic interrelationship in the modern world between human populations and their environments really is a complicated one, and the subject is very difficult. It is very much easier to be a good specialist in one of the traditional academic disciplines than it is to be a good human ecologist. (p. 3)

Having established the need for comprehensive solution-oriented approaches to complex problems, Chapter 9 completes the book with an important discussion of how we can educate more people to think this way. In "Educating the Next Generation of Social Ecologists," Stokols sets the core learning outcomes of social ecology as being "to train students to analyze scientific and policy questions from a broad social ecological and interdisciplinary vantage point, and to apply basic theory and research toward resolving complex societal problems" (p. 321). Stokols also sets out the four Ts of social ecology as being transdisciplinary, translational (turning findings into outcomes), team-oriented, and transculture. He also emphasizes the need to work across knowledge bases, including with communities, practitioners, and policy-makers in off-campus collaborations. These are all sentiments and goals that human ecologists can readily agree on, but, of course, the issue remains that most large-scale universities are structured along traditional disciplinary lines. Further, major grant applications favor narrow, discipline-based projects, academic promotional rounds are often vetted by disciplinary specialists who place premiums on mono-authored papers in prestigious disciplinary journals, and the main entry certificate to an academic career is a solo-authored PhD. If we are to generate graduates with the skill sets necessary to address the major problems of their times, we need many more programs (such as social ecology and human ecology), and institutional reform to accommodate and encourage them, in turn. Stokols seems to concur, writing that the grand challenges we face demand a comprehensive redesign of universities around the world to replace "traditional academic departments organized around arbitrary (and increasingly 'ossified') disciplinary boundaries with problem-oriented … schools and institutes" (p. 340). I could not agree more.

Stokols finishes *Social Ecology in the Digital Age* with a short epilogue reflecting on his intellectual journey in writing the book, and on some of the social and political changes that occurred in that time. Given that he started the work in 2014 and completed it in 2017, those changes in the political landscape have been significant. I can only imagine and sympathize with the amount of rewording Stokols had to do to his manuscript after November 2016. Still, approaches to understand human-

environmental problems that are not merely descriptive but are also change-oriented and morally concerned, much like social ecology and human ecology, are needed in these times arguably more than ever.

Overall, Stokols's book is an important and timely contribution with lasting value; however, I am not without some criticism. For example, I do not agree with Stokols's claim that human ecology only deals with macroscale events, as any issue of *Human Ecology Review* will demonstrate. In fact, I would argue that providing a framework for decomposing macroscale and general principles to microscale and specific contexts is one of human ecology's important contributions (see Dyball & Newell, 2015). I neither think human ecology is particularly challenged upon including cyberspace as a significant variable that affects flows of energy, material, and information in the modern era. Essentially, I really cannot see anything that distinguishes social ecology from human ecology, but potato, potato, as they say (which makes more sense said out loud than in writing). Beyond that, I feel that Stokols's association of human ecology with the work of Park and Burgess in Chicago in the 1930s is something of a straw man argument, which does not do justice to significant developments in the field taken since (see *Human Ecology Review*, vol. 23, no. 1, for an overview). Finally, there are some contributors to human and social ecology that I am a little surprised were omitted. Notably, Stephen Boyden pioneered much of the ideas around the co-benefits of healthy environments for healthy people, as acknowledged by *The Lancet* (Horton, 2015). In a pre-digital 1969, in his book *Design With Nature* Ian McHarg forged many concepts around urban design approaches that work with natural forms and processes. Ulrich Beck, Peter Checkland, Gerald Midgley, and Ray Ison are all systems-thinkers who have contributed a great deal of work around inclusive problem-solving and boundary setting. Finally, while Stokols acknowledges Val Brown et al.'s (2010) work to advance Rittel and Webber's "wicked problems" in *Tackling Wicked Problems*, it seems an oversight that Functowicz and Ravetz do not receive mention in relation to working on urgent, value-laden problems in democratic partnership with communities. Their "post-normal science" (Funtowicz & Ravetz, 1993) seems very much the model of what social ecology so advocates. However, I am guilty of starting to review a book I would have written had I penned *Social Ecology in the Digital Age*, which I did not. Dan Stokols wrote it, and a very fine piece of work it is. I highly recommend it to anyone working in the field, whatever they have chosen to name their department.

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