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Considering healthy indoor environments in the development of human settlements by characterising the building indoor microbiome.

Keywords

Microbiology of the built environment, microbiome, health, spatial analytics, hospital design, Infection prevention and control, hospital, health care, risk, microorganisms

ABSTRACT

As humans we spend up to 90% of our lifes in indoor environments. Considering the rate of urbanisation in South Africa and globally, it would be prudent to consider the health quality of the indoor environments of current and future planned human settlements. The impact of the built environment (BE) on user health is widely known, with up to 15% of people contract healthcare acquired infection (HAI) in hospital environments, family members contracting tuberculosis (TB) in home environments and cost concerning workhours lost (USA). Yet we know very little of the health related characteristics of the indoor environment.

An emerging field of the microbiology of the built environment (MOBE) could unlock our understanding towards future planning and design. Characterising the indoor BE requires interdisciplinary approaches that include architecture, microbiology and engineering. The methodology adopted was applied at two case study facilities. It includes microbial sampling of indoor rooms; sensor data collection for CO2 and temperature; and spatial metrics that include occupancy, people type, room function with internal flow patterns through spatial modelling. Correlation of the data sets provided identification of environmental factors that play an influential role on the microbiome of the indoor environment brought about by the typical user type.

The findings indicated that the indoor biome varied seasonally and consisted of unique air and surface communities. Unique biomes were observed at a room space level, with similar communities at building typology level. The indoor built environment is dynamic, the need to extend these investigations into the residential and housing sphere is critical. The influence of building design decisions (operations, layout, planning, hardware and systems…) has a direct effect on the microbial composition and structure of the indoor built environment and consequently user health. This study presents an empirical quantitative approach to asses and determine what healthy indoor environment applicable in human settlements at large could be.

INTRODUCTION

Africa is poised to urbanise with an estimate growth rate of 300% over the next 40 years from 395 billion to 1.339 billion, with an expected estimated 1.3 billion people living in urban environments (Guneralp et al 2017). This rapid and expansive migration to urban environments will drive the need for housing and social services. As is evident from developement patterns, the rate of change however, will most likely result in poor human settlement development. Focussed on delivery, over built environment and indoor environmental quality. This has a direct impact on health and wellbeing of the built environment inhabitants. Higher density urban spaces has the potential to provide improved and accessible infrastructure and healthcare services as appose to rural isolated settlements. Prasad et al (2016) however suggest the opposite is more likely. Data from a comparative study of risk factors for TB in India and Korea suggest an increase TB incidence rates in some countries over others due to factors of increased poverty and poor living conditions. The authors concluded that without proper urban planning, supported services, quality social and economic conditions, the likelihood of increased adverse epidemiological conditions is a certainty, as found in the India - Korea case study. Therefore, strategic planning, health focused development of human settlements are critical in user health and wellbeing.

Considering healthy building standards for indoor built environments become paramount in shaping human settlements. Through considered policy and informed planning, health consciences design can be fostered. Transmission of healthcare associated infections (HAI) (and not limited to healthcare environments), occur in three ways: contact, droplet and airborne spread. The built environment plays a significant role in all three modes of transmission. In an era of increased antimicrobial-resistant microorganisms, two focal strategies address the occurrence and spread of antimicrobial-resistant microorganisms, 1) optimising antimicrobial use and 2) preventing the transmission of resistant organisms (Brink et al. 2006). The role of the built environment directly relates to the second strategy. Current research indicate that hospital's and the built environment as a contributor and potential incubator, in pathogen transmission that causes various illnesses through infection (Yates, Tanser & Abubakar 2016). Most studies focus on healthcare environments; with little research on human settlements. The lack of empirical data to verify and quantify health risk in the built environment has been established (Schweitzer, Gilpin & Frampton 2004; Evans & McCoy 1998). The studies suggest that more research on the Microbiology of the Built Environment (MoBE) – the study of the microbial community within the buildings - could provide such empirical data. The research work of the author and fellow MoBE researchers, have suggested a paradigm shift in understanding building ecology. Building ecology based investigations have increased in recent years, and more particularly from a microbiological ecosystemic perspective. Considering that 85 percent of our time is spent indoors (Klepeis et al 2001), and people are the leading contributors of bacteria in indoor environments (Hospodsky et al. 2012), it becomes imperative for designers and architects to understand the microenvironments in which we live and play. MoBE research combines built environment studies and microbiology, through interdisciplinary investigations in engineering, architecture, microbiology, health sciences, epidemiology and anthropology (Briere & Resnick 2017). Africa and in particular developing world environments have very little data on the building microbiome. The relationship between microorganisms and the built environment is much more significant than previously considered, as indoor ecosystems are dynamic, unique and location specific; but still strongly influenced by their outdoor environments. This paper presents, and therein postulate an investigative approach to microbiome identification for the application in human settlements, as piloted through two healthcare buildings. From the insight, gained in healthcare related investigations, human settlement typologies for housing and social settings could benefit with the characterisation of built environment microbiomes

METHODS

The MoBE research methodology combines architectural, engineering and microbiological factors that can produce insight to architectural design, planning and potential transmission risk management. In a recent hospital, ward study by Lax et al (2017), it was found that the user patient defined the indoor microbiome, were the ward resembled the microbial signature of their patients up to 24hours after discharge. The author postulates utilising a matching methodology to investigate human settlements, as conducted in a recent doctorate investigation that performed microbiome characterisation of two hospital environments. This study considered and correlated spatial analytic findings, environmental measures and microbial sampling. The study sites were two public hospitals in the Western Cape South Africa, (MPH) and (KDH).

Spatial analytics, engineering and microbial sampling

Spatial analytics: This requires data from on-site observations, collected and processed following a methodology derived from Space Syntax principles and visualized through the Depthmap™ program. The Space Syntax methodology for spatial analytics employs various observation techniques as described in the Space Syntax methodology guide (Grajewski and Vaughan 2001; Al-Sayed et al. 2014). For the healthcare investigation, two observation techniques were elected and applied: Firstly, a mental snap shot and secondly a movement tracer technique. Effective determination of the most beneficial and representational time a pre-study questionnaire was circulated to staff at both hospitals. This determined the low and high peak times, patient load and active spaces, personnel perception of personal safety and healthcare associated infection, as well as perceived cleaning regimes. Data area processed through GIS and modelled in Depthmap™ for analysis and user flow correlation. The data on flow patterns (human movement) and space use (function) compared with the original planned design use (or potential space usage). This provides insight to design -versus actual space utilization. From the data, graphical axial representations and percentage flow, which indicated the user spatial distribution within the building spaces versus the 'planned/designed' user distribution were, derived (Al-Sayed et al. 2014). The study requires multi-seasonal investigations due to varied ecological conditions. Field researchers conducted systematic observations at each facility following a predetermined route, over a continuous twelve-hour period and for four consecutive days from Friday to Monday, as determined by the pilot questionnaire. (Nice, 2019)

Engineering data: Utilising sensors, CO2, temperature, lighting (LUX), humidity are collected. Continuous sensing and sampling of CO2, Temp and RH were gathered to correlate with user and occupant flow findings, and microbial sampling. Full characterisation of the mechanical system is required to determine air source, airflow, direction flow and pressure drop between spaces within the various facilities. (Nice, 2019)

Microbiology: This microbiology methodology was developed from a broad literature review that included sampling, equipment, analysis, sequencing techniques, database selection and the selection of bioinformatics platforms. To ensure comparability of this study reference was made to similar previous studies that included Meadow et al. (2014), Kembel et al. (2014) and a classroom study at Oregon University, USA by Adams et al. (2015). The healthcare investigation performed culture analysis with selected media to detect growth of identified HAI indicator organisms, i.e. Staphylococcus aureus (from surfaces), Pseudomonas aeruginosa (from surfaces), Pneumocystis carinii pneumonia (PCP) (air) and Mycobacteria tuberculosis (air). Further colony identification via the MS VITEK™ mass spectrometer was performed. DNA-extraction and PCR (using 16S rRNA gene V3-V4 primers) were performed on both the air and surface samples. A p-value of 0.05 and lower was accepted. 113 6275 sequences were received, with 6493 sequences per sample (175). It is important to note that both culture and 16S Rrna sequencing or pyrosequencing is required, to determine both presence and viability of organisms. (Nice, 2019)

Human settlement hypothesis

To improve our understanding of indoor environments and the factors that influence the microbiome of various built environment typologies this paper suggest utilising a closely matched methodology as utilised by the author in healthcare settings. The following variations should be considered. 1) Seasonal investigations, in matching housing typologies in different regions within a metropole. 2) Comparing high-rise housing typologies typically associated with urban environments to low rise typologies typically single free standing dwelling in suburban environments. 3) Time related investigation, considering both occupancy and in unoccupied times, that will provide insight into the microbial community fluctuation and potential space 'flushing' 4) Considering room comparison between typologies and lastly 4) Increased number of microbial samples per space due to potential low biomass.

RESULTS

Healthcare investigations

Key findings included: 1) the designed plans spatial analysis indicated integrated and connected environments that were spatially intelligible1; similarly, it predicted spaces of clustering. 2) comparing the global user flow patterns of the MPH and KDH to the design layouts as planned in both summer and winter seasons, higher correlation were achieved in one facility over the other seasonally (R2 0.38 vs R2 0.30 vs R2 0.58 correlation to potential design) 3) The variation between the facilities could be attributed to the utilisation of function and layout. In addition MPH had measured a 30% increase in occupancy in winter. At the KDH the Central Nurse Station (CNS) measured a 120% increase in summer. 4) From the microbial sampling the CNS of the MPH also indicated an increase in the number of Operational Taxonomic Units (OTU), i.e. a larger number of identified microorganisms compared to other rooms for both hospitals. The data indicated that there is a correlation with the change in flow patterns, occupancy and the quanta of organisms. 5) Occupancy counts varied seasonally and

[1] The level of spatial connectivity and integration with neighbouring spaces is termed spatial intelligibility (SI), it provides insight into potential social interactions. The functional use of spaces impacts the required level of integration and connectivity. Clustering of core functional spaces theoretically provides a high level of connectivity and correlates strongly with spatial integration. The level of intelligibility represents how easy it is to comprehend local position within a global structure. (Al-Sayed et al. 2014)

social factors influenced facility preference. 6) When considering occupancy rates and the variation in summer and winter in the microbial sampling of surface and air total OTU's, an increase was observed in indicator species related to an air source. This can be attributed to an increased illness rate in winter as reflected in the increase occupancy in winter. 7) Microbiome changes between the MPH and KDH in winter versus summer is noteworthy as it infers a variable indoor environment and a variation in species presence and abundance. 8) Room types such as the clinical service provision spaces per season, the MPH indicated a 60% biome variation in most zones when grading activity rates; one can attribute this finding to the clinical needs variation between two seasons. Lastly, in many respects, the gate counts and flow measures were strongly associated with the potential predicted simulations of where one would expect to find congregation or low occupancy. (No clinical data was collected during this study)

Human settlements hypothesis

As per the healthcare typology findings, it would be expected to find variations based on season and typology and even microclimate. The emergence of niche areas is likely. Spatial layouts and room configuration will influence the microbial community and be evident in OTU counts. The external environment will be of critical importance as large quanta of outdoor air is present indoors. The successful outcome of predictive space use as per the space syntax model and the observed measures presents an opportunity for accurate future design planning. Furthermore, when considering the environmental and microbial indicator factors identified in the healthcare study, combined with spatial modelling design guidance for heath conscience design can be achieved.

CONCLUSIONS

Core findings that would benefit from further typological investigations within the field of human settlements include: The indoor air and surface samples, which were sequenced and analyzed, the majority of organisms were found indoors where humans interacted. Furthermore the study found that human sourced organisms amount to 65%, and 35% of organisms come from outdoor sources in both hospitals. To note - the majority of organisms in any indoor environment are not pathogenic (it is estimated that less than 1% off all known organisms are pathogenic to humans (Nature, 2011)) but yet the 1% has a significant effect on our immune system especially in impoverished environments with malnutrition, lack of social and healthcare services etc. This is significant when one considers that people spend most of their time indoors, up to 85% (Evans & McCoy 1998; Klepeis et al. 2001). The study of how people use space and specifically programmed space is essential to the understanding of the indoor microbiome. The research findings gathered from the healthcare study provide guidance on infection prevention decision making for example: mechanical systems and services selection, localised filtration, policy implementation versus building design program, efficacy of planning design through user flow reducing potential cross contamination and lastly identifying core cluster development and spatial interrelationships to reduce cross infection and contamination. Spatial layout is a significant contributing factor in the microbiome composition. Spatial analytics and indoor microbiome dependencies (common sources, ventilation etc.) found in the healthcare study demonstrated that the modelling techniques can be applied for risk grading in hospital environments. (Nice, 2019).

Applying MoBE research methodologies to human settlement investigation will provide empirical data that could support decision-making tools and policies. The data will inform (as found in other studies) planning selections, environmental awareness, material selection, user health, and support the characterisation of building typologies and appropriate building system selection for improved user health.

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