SCIENCE OF CITIES SYMPOSIUM

World Cities Summit 2022
Science of Cities Symposium

31st July 2022

Marina Bay Sands Expo and Convention Centre, Singapore

Abstract Proceedings

Contents Page

Welcome Message

Lee Tzu Yang
Chairman, Public Service Commission and Chairman, CLC's WCS Science of Cities Knowledge Council, Singapore

Cities are complex systems comprising unique, heterogenous agents operating at multiple scales. New and unprecedented challenges will determine the future of cities. To understand how a city works, we must understand not only the behaviour of each urban system, but also how they interact with one another, and how their collective behaviour manifests over time.

Until recently, the formal understanding of cities on a holistic level was eschewed in favour of investigating the properties of functional subjects like transport, environment, energy, public health, social dynamics and economics. The assumption is that when these parts are re-assembled, the whole will behave like the sum of its parts. However, outside the realm of the hard sciences, reductionism has not been very useful in predicting the behaviour of complex systems like cities. To deal with long-term city challenges, we need an integrated scientific framework to help us understand the relationship between human-engineered systems, both social and physical, and the natural environment, to better plan and manage our cities.

Over the last two decades, a "Science of Cities" has rapidly emerged to integrate different strands of urban research into a coherent viewpoint. Such an approach embraces an interdisciplinary approach to scientific knowledge production and application. It harnesses foresight to navigate complex needs with optionality and flexibility, to be less dependent on deterministic parameters. It thus has great potential to aid in informed and robust decision-making and development of plans and policies under conditions of incomplete information, emergent circumstances, and uncertain outcomes.

Research from the emerging Science of Cities has tremendous potential to support this by leveraging on three key enablers: 1) the combination of interdisciplinary, complex data analytics and tools on increasingly available big data, 2) the push to go beyond 'tried-and-tested' approaches to an ecosystem of adaptive experimentation and finetuning, and 3) strong partnerships among companies, government agencies and communities, to share domain expertise, grow capabilities and collaboratively carry out projects, prototypes and experiments to shape viable urban solutions.

The inaugural session of the WCS Science of Cities Symposium aims to gather the best minds in urban research, to advance knowledge creation along two themes: namely, the applications of complexity science to understand integrated urban systems, and where insights from scientific studies can inform regeneration strategies of urban systems.

I hope that this Symposium will take the ambition of understanding our complex urban environment a step forward towards creating more liveable and sustainable cities.

Introduction

The inaugural World Cities Summit (WCS) Science of Cities Symposium will be held in-person on:

Date: 31st July, Sunday
Venue: Marina Bay Sands, Level 5, Sands A, 10 Bayfront Avenue, Singapore 018956

Convening research heads, academics, as well as city and industry leaders involved and/or keen on research developments in two panels, representing two emerging yet pertinent fields:

Panel 1: Complexity Science for Adaptive and Sustainable Cities aims to spotlight research that applies complexity science thinking and/or methods in the urban domain to enhance understanding and addressing of the increasingly volatile, uncertain, complex, and ambiguous urban challenges faced today. Such scientific advancements adapt the technical principles and methods within complexity sciences to the highly interconnected, interdependent, and emergent relations and flows between the various urban systems and stakeholders of a city at multiple scales. By doing so, we may be able to improve the sustainability and/or adaptability of cities to complex issues such as climate change and adapting urban planning to changing economic and demographic patterns. Topics include the integrated urban systems, analytics and data platforms for urban management, complexity and artificial intelligence in urban planning and design.

Panel 2: Science of Regenerative Cities aims to spotlight sciences and innovations that facilitates regenerative urbanism. Through an integrative, multi-domain and multi-system understanding and application of solutions, regenerative sciences take sustainability a step further by building self-sustaining, net-positive cities that maximises ecological gains and delivers co-benefits to human and planetary health. Research under regenerative sciences encompass the physical, economic, and social regeneration of urban spaces and communities, where systematic innovations and scientific analysis was used to understand how to enhance the human-nature symbiosis.

Through the presentations, panel discussions, and posters, the symposium will serve as the academic platform of WCS, where insights from scientific knowledge and research methodologies would connect to WCS' main audience of industry practitioners and city leaders, kickstarting cross-institute and sectoral evidence-based innovations to address current and emerging urban challenges.

Symposium Programme

Time (GMT+8)	**Programme**
12.00–1.00pm	**Poster Exhibition cum Presentation**
1.00–2.00pm	**Lunch Reception + Registration**
2.00–2.10pm	**Opening Remarks**
Panel 1: Complexity Science for Adaptive and Sustainable Cities	
2.10–4.00pm	**K1.1**: How does Complexity Theory Change our Understanding of Cities *Sanjeev Sanyal* **K1.2**: Scientific Frameworks for Imaging and Creating Future Sustainable Cities *Luis Bettencourt* **K1.3**: City Laboratory, New City and Future City in the Context of Disruptive Technologies *Ying Long* **O1.1**: Vertical Cities: Complex Emergent Patterns of Movement and Space Use in High-Density Urban Context *Thomas Schroepfer* **O1.2**: Explaining Road Network Resilience using Spatial Variations of Network Topology: A case study of Singapore *Nishant Kumar* **O1.3**: The New World Order of Airports: A Population- and GDP-driven model for Forecasting Aviation Demand in 2050 *Sam Conrad Joyce* **O1.4**: Network Science-Based Analysis of Evolutionary Park Systems *Anjanaa Devi Srikanth* **O1.5**: Deciphering the Spatial Co-occurrence and Co-change of Industries at the Scale of City *Lock Yue Chew* **Panel discussion** (moderated by keynote speakers)
4.00–4.30pm	Networking tea break
Panel 2: Science of Regenerative Cities	
4.30–6.20pm	**K2.1**: Enabling the Regenerative City – from Theory to Practice *Josef Hargrave* **K2.2**: Planning Tool for Regenerative Cities *Alexander Zehnder* **K2.3**: Sponge City and Sponge Planet: Nature-based Ecological Infrastructures and their Regenerative Performance *Kongjian Yu* **O2.1**: Adapting Cities for Climate Change – A Regenerative Approach *Leonard Ng* **O2.2**: Enabling Climate-Resilient Development in Cities & the Singapore Green Plan 2030 *Winston Chow* **O2.3**: For Regenerative Urban Ecologies: Integrated Community Hubs *Chee Huang Seah* **O2.4**: The Role of Microbes in Regenerative Cities *Veera Sekaran* **Panel discussion** (moderated by keynote speakers)
6.20–6.30pm	**Closing Remarks**

Panel 1: Complexity Science for Adaptive and Sustainable Cities

Abstracts – Keynotes

K1.1

How does Complexity Theory Change our Understanding of Cities

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The crux of Complexity Theory is about the multiplicity of interactions of many moving parts. These interactions are sometimes predictable, sometimes unpredictable, and ever evolving. This describes cities well – the interactions between citizens, buildings, public spaces, government, business, cultural institutions and so on. The goal of a city manager or designer is to enhance positive interactions, minimise negative feed-back loops even while allowing for evolution to take place. This is not about a known destination, but about constant transition management.

K1.2

Scientific Frameworks for Imaging and Creating Future Sustainable Cities

Luis BETTENCOURT
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Imagining and planning future sustainable cities requires knowledge that can extrapolate to entirely new situations, where not only energy systems will be different, but also where a fundamental redesign must take place of material flows and our relationship with the biosphere. I will briefly introduce several tools for thinking about cities as sustainable complex systems, motivated by recent progress in urban science. I will show how these tools, articulated with sustainability plans with quantitative targets over the next decades are changing the way we run and design cities to create places that are at once healthier and more productive.

K1.3

City Laboratory, New City and Future City in the Context of Disruptive Technologies

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As China's urbanisation enters a new stage, the people-centred and quality-oriented urban development goals put forward higher requirements for urban research and practice. At the same time, the fourth industrial revolution, which relied on the integration of computers and communications, is changing cities with a series of disruptive technologies. Three ways to promote

urban development with emerging technologies are concluded in this paper. Specifically, the first way is to provide new data and methods for urban studies, the second is to influence urban space and urban life and eventually change the cognition of cities, and the third way is future-oriented, which introduces digital innovation into urban planning and designs to make cities smarter. This keynote aims to provide some references for urban studies, management, as well as planning and design practice.

Abstracts – Oral Presentations

O1.1

Vertical Cities: Complex Emergent Patterns of Movement and Space Use in High-Density Urban Context

Thomas SCHROEPFER[1], S. Gopalakrishnan[2], D. Wong[1], B. CHIN[3], A. Manivannan[4] and R. Boffanais[4]

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High-density liveable cities require new integrated planning and design strategies that acknowledge their complexity. Traditionally located on the ground level in land-scarce Singapore, public and common spaces and networks are increasingly also added on elevated levels in the form of sky bridges, sky parks, sky terraces, and roof gardens. Combinations of these, often applied to mixed-use (residential, civic, and commercial) developments can have complex interactions with the common spaces on the ground level within the vertical dimension, producing vertical cities that become components of larger urban systems and networks. However, these interactions, their impact on patterns of human movement in the city, their contribution to a more liveable high-density urban environment, and their scalability are not well understood. The study presents a Complexity Science-based approach to the analysis of high-density urban built environments. Buildings and their contexts were mapped as spatial networks of nodes, and superimposed with socio-spatial information derived from human movement sensor data to provide important insights into actual space use. This method was test-bedded in Kampung Admiralty, a first-of-its-kind building development in Singapore that integrates housing for the elderly with a wide range of social, healthcare, communal, commercial, and retail facilities. The pilot study successfully tested a systematic post-occupancy socio-spatial network analysis framework using: (1) qualitative architectural analysis, (2) quantitative spatial network analysis, (3) quantitative data collection, and (4) correlation analysis of actual performance with spatial network patterns. It provided early insights into the effectiveness of the combination of methods and tools for data collection, established the potential and limitations of scaling up the approach to the larger urban scale, and further validated the proposed methodology's potential to provide a scientific basis for planning and designing future vertically integrated developments that can support higher population densities, higher standards of environmental sustainability, and enhanced liveability in Singapore and beyond.

Keywords: Bluetooth localisation, Complexity science, Mobility patterns, Spatial network analysis, Socio-spatial networks, Spatial performance

O1.2

Explaining Road Network Resilience using Spatial Variations of Network Topology: A Case Study of Singapore

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The resilience of a road network refers to its ability to bounce back to the desired level of serviceability (LOS) after a disruption. Traffic congestion is the most commonly occurring disruption to a road network that reduces its LOS. A more resilient transportation network can restore the flow of traffic faster than a less resilient network. Using real incident and congestion data collected from road networks in Singapore, this paper aims to understand the relationship between the topology and resilience of road networks. We used congestion duration as a proxy for transportation network resilience and present a four-step framework to explore this relationship. First, a uniform segmentation of the urban space into spatial grids was done and eight graph-based features were extracted for each grid. Second, we used these features as independent variables in a regression model and obtained a goodness-of-fit (GOF) when congestion duration was used as the dependent variable. Feature selection was incorporated into the second step to retain the top N features. Third, we varied the size of the grids and evaluated the GOF for different grid sizes. Finally, in the fourth step, we manipulated the grids using an iterative split-merge algorithm to reallocate the segmentation of urban space into unconstrained regions, such that the GOF was maximised. Once the split-merge algorithm converged, the distribution of the unconstrained regions helped us to answer two specific research questions regarding the spatial variation of resilience. First, when using a grid-based segmentation strategy, what are the optimal grid size and feature combinations to quantify the road network resilience? Second, can a more robust segmentation of the urban space help us better segregate the low and high resilience parts of the road network? Such insights will be useful for targeted action to improve the resilience of low-resilience parts of the network.

Keywords: Congestion duration, Network topology, Road network resilience, Segmentation, Spatial variation, Urban space

O1.3

The New World Order of Airports: A Population- and GDP-driven model for Forecasting Aviation Demand in 2050

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Aviation activity has been shown to mirror the expansion of urban centre activity through increased airport-city linkages, infrastructure enhancements, and passenger numbers, all of which have accelerated over the last two decades and specifically within Asia. Aviation supports vital information flow through people and goods and is a key driver of countries' economies and business productivity despite the recent impacts of COVID on commercial travel. Our work explores how the symbiotic relationship between global aviation networks and urban centres will evolve in response to projected changes in national indices as population and gross domestic product, and thus drive new aviation

demand profiles, location links, and even new airports. This was explored using of network theory derived from computational social science as indicators for the attractiveness of airports based on global 2019 flights data. PageRank was also used as a proxy to the average desire to visit an airport and its corresponding urban centre based on access to advantageous business, touristic, or social opportunities. We combined this network analysis with Central Place Theory to capture the spatial function of the airport as a nodal gateway between cities taking part in the global aviation network. Existing volumes of flights and thus, demand for airport pairs within and between community clusters were found to be related to proximity to urban areas, GDP, network access, and how these influence the likelihood of inter-cluster travel for business and tourism. Lastly, we employed gravity models to predict significant new connections between the South and Southeast Asian regions, which used information on projections of changing international demographics, forecast future demand for airports, travel destinations and urban centres.

Keywords: Airport-to-city connections, Aviation, Mobility, Networks

O1.4

Network Science-Based Analysis of Evolutionary Park Systems

Anjanaa Devi SRIKANTH[1], C. Hablani[1], S. Gopalakrishnan[2], D. Wong[1] and T. Schroepfer[1]

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Cities are hubs for interactions of their inhabitants, which drive innovation, culture, and economic welfare. As building density in many cities increases, urban planners are increasingly prioritising parks as agents of urban vitality because of their many physical and mental health benefits. This has led to a shift in urban design and landscape architecture practice to promote 'evolutionary parks' in that the built environment 'evolves' over time. Our research proposes a novel Network Science-based methodology of spatial performance assessment for the study of evolutionary parks. In this paper, we present the case of one-north Park as an example of an evolutionary park. One-north Park is a key spatial component in one-north, a vibrant research and business district in Singapore. The linear park is in the centre of the development, providing a continuous green corridor that enables the maximisation of frontage for user access and it connects many of the one-north's research clusters. The aim of our study is to evaluate the connectivity of the park and its effect on walkability within the larger one-north planning subzone, using Spatial Network Analysis methods, which allows us to predict the effect of the park's topography on pedestrian movement patterns based on a three-dimensional pedestrian model of the subzone, and empirical sensor-based studies of pedestrian movement. The results correlated with the observations from the sensor-based investigation of our study which determined the level of integration of the park with its larger urban context. Correlating space use patterns in the multi-level model provides important insights into how users form pedestrian mobility networks. These can subsequently become the basis for more informed planning and design decisions on how to improve the park's connectivity and usage. The presented study is part of a larger ongoing research project on urban vibrancy in one-north and contributes to the development of a novel multi-disciplinary methodology for Spatial Network Analysis.

Keywords: Complexity science, Spatial network analysis, Spatial performance assessment, Urban design

O1.5

Deciphering the Spatial Co-occurrence and Co-change of Industries at the Scale of City

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We analysed the location of industries in two metropolitan cities to investigate how firms are spatially distributed, and identified the trends in firm location choice. By defining a "Region-Index" metric, we demonstrated how industries have concentrated in or diffused from regions of interest over time. We applied this metric to the Central Area (CA) of Singapore and London to decipher the relative tendency of industries to locate at CA as well as London. To analyse spatial co-location of industries, we constructed a community network, which revealed subtle relationships between firms. Extending this approach temporally to create a co-change network, we deduced the occurrences of industries in Singapore and London that move into or out of a spatial region synchronously. Based on this approach, we identified the possible presence of industries that not only co-change but also co-occur in space. Overall, we observed certain common patterns of industry movements in the context of Singapore and London through the analysis. Finance and insurance companies were found to have the consistent tendency of concentrating in CA and London throughout the period of the study while "other financial services except insurance" companies have the tendency to diffuse out of these regions. Conversely, opposite movement patterns were observed, where we see the proclivity of Web Portal (which is a subsector of the IT industry) to locate into London but relocate out of the CA of Singapore.

Keywords: Complex network, Complexity science, Spatial co-occurrence, Spatial analysis

Panel 2: Science of Regenerative Cities

Abstracts – Keynotes

K2.1

Enabling the Regenerative City – from Theory to Practice

Josef HARGRAVE

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What is regenerative design and how will it shape the future of our cities? This talk will explore insights from Arup's ongoing research programme on regenerative design. It will introduce the key principles of a regenerative city and possible implications for the future design, construction, operation, and experience of urban spaces, places, and systems. Principals range for a more systems-based approach to infrastructure delivery to restorative approaches to urban biodiversity. The talk will look at London to highlight examples of what a more regenerative approach to cities could look like in practice.

K2.2

Planning Tool for Regenerative Cities

Alexander J.B. ZEHNDER
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The 2000-Watt society principle was introduced in Switzerland in 1998 and has been adopted by a number of European, American and Australian cities to plan their more sustainable futures. The principle refers not only to the energy consumption of individuals or households, but to the total energy consumption of society, including embodied energy used in buildings, infrastructure, operation, and maintenance of structures. Energy is easier for everyone to understand and manage than carbon. In the end, the energy mix determines the carbon footprint. Examples from China, Europe and Singapore will be used to present the power of this tool for carbon accounting and regenerative city planning.

K2.3

Sponge City and Sponge Planet: Nature-based Ecological Infrastructures and their Regenerative Performance

Kongjian YU
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Founder and Principal Designer, Turenscape, China

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We are facing many challenges today including flood and draught that are associated with climate change, pollution, and habitat loss. The conventional solution of grey infrastructure consumes huge amounts of concrete and energy, lacks resilience and destroys nature. The alternative is nature-based ecological infrastructure which is critical for securing ecosystem services woven together with grey infrastructure. By protecting and restoring the ecological infrastructure, we are able to secure and make wise use of self-sustaining nature's services for the benefit of the planet and the welfare of people, making it a highly regenerative solution.

Abstracts – Oral Presentations

O2.1

Adapting Cities for Climate Change – A Regenerative Approach

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Sea level rise and more frequent inland flooding due to climate change are posing significant risks globally. Recent floods had occurred over large areas in China, Australia, and Europe. There had also been unprecedented scale of forest fires in the USA which had driven home the need for urgent coordinated solutions. It must be an all-of-society effort for climate change solutions to be effective.

As subject matter experts, we can play a pivotal role in offering innovative solutions to private and public sector stakeholders who are confronted with challenges like displaced population due to flooding or upgrading old assets to cope with climate change. This calls for a more resilient urban development approach to mitigate climate risks. At Ramboll, our multi-scalar approach towards flood resilience emphasises on incorporating nature-based solutions as part of the toolkit for creating future regenerative cities. As part of this presentation, I will showcase Ramboll's design approach in detail and demonstrate the outcomes through some recent leading project examples around the world.

Keywords: Adaptive design, Climate change, Multi-scalar solutions, Nature-based solutions, Regenerative coastlines, Restorative landscape

O2.2

Enabling Climate-resilient Development in Cities & the Singapore Green Plan 2030

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Using the broad context of the Singapore Green Plan 2030, this talk presents an overview of the concept of climate resilient development – a solutions framework that successfully combines proven strategies dealing with climate risks (adaptation), with actions to reduce greenhouse gas emissions (mitigation), consequently resulting in improvements for nature's and people's well-being (sustainability) – operates in cities. Recent Intergovernmental Panel on Climate Change assessment reports released earlier this year indicated that climate resilient development is a viable path forward for cities to undertake, not just only regenerating relationships between human beings and nature, but also as a blueprint for successful climate action.

Keywords: Climate resilience, Emission reduction, Global warming, Inclusive and Integrated planning, Social policies, Urbanisation

O2.3

For Regenerative Urban Ecologies: Integrated Community Hubs

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Within the past decade, the Singapore government has completed four integrated community hubs around the island. These nodal developments leverage its urban context and programmatic offerings in a bid to generate a sustainable hub ecology for the city. A manifestation of the whole-of-government, and now whole-of-society approach, these large-scale communal architecture plays a significant role in rejuvenating the heartlands, advocating citizen engagement, and advancing civil society. Drawing inspiration from natural ecosystems and breaking away from silo-ed norms, the vision behind this emergent typology is in the creation of synergistic and generative environments. This paper seeks to investigate the potential of this shared urban model of integrated communal architecture as testbeds for circular concepts, to advance policy agendas and support wider collaboration to establish and achieve district-based targets in regenerative outcomes. Using Our

Tampines Hub and Bukit Canberra as case studies, the complexities of synergistic operations, and specific design strategies and the participatory approach to support a circular economy framework were analysed. It examined not only economic value in land and space optimisation, but new synergies produced for circular mindshift, closed-loop environmental outcomes and social impetus.

Keywords: Synergies, Density with enhanced capacities, Adjacencies and dependencies, Harmony of systems, Whole-of-society, City as second nature

O2.4

The Role of Microbes in Regenerative Cities

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A regenerative city needs to develop its internal vitality to find the seeds of its own regeneration. It is an urban development based on an environmentally enhancing, restorative relationship with the natural systems that sustain the city. The term "regenerative" includes actions that lead to the continuous renewal and restoration of the ecosystem which allows the circular existence of the city's urban systems. A regenerative city sustains a mutually beneficial relation of resources and actions by minimizing its environmental impact by actively enhancing the city's ecosystems. The macro representation of regenerative cities must also consider the micro impacts made by the natural restorative mechanisms of soil science. The microbial world is just as important and plays a crucial role in restoration of the natural ecosystem services of the urban environment. The importance of the microbial world is often overlooked as we almost always see ecosystems and ecology from a macro perspective as they have the most immediate visible impact on the human species. Soil microbes restore the biocapacity of ecosystems. Artificially created landscapes do not have the biocapacity to nourish the microbiomes created using degraded soils reused within the built environment. We must embrace technology to counter these imbalances. Consortium of beneficial microbes together with sensors can give us the data and assist us in understanding the health of the ecosystems. There is an important role played by microbes in Carbon Fixing in the Urban Built Environment that we must uncover. Using Green Intelligence (GI) networks with the Internet of Trees (IoT) sensors, we seek to understand natural ecosystems in small microcosms that will allows us to substantiate the value of the microbial world and ensuring regenerative cities can become resilient in the long run.

Keywords: Consortia, Green Intelligence, Internet of Trees, Microbiome, Restorative

Poster Abstracts

P1

Urban Planning in the Digital Age – The Singapore Perspective

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This position paper describes a mandate and the corresponding approach to transform the urban planning process in Singapore from a human intensive practice into one that is "digital to the core".

We outline the state of land use planning and urban design workflows as well as the driving forces behind a recent shift towards scenario-based methods in view of the need for flexibility and optionality. As cities are enormously complex, more so now in a pervasively interconnected and interdependent world, our ability to understand each urban system and the interactions between urban systems is critical for allowing planners to understand cities holistically and deliver good planning outcomes. The proliferation of data and advances in technology allows us to assess and simulate planning problems innovatively and quickly, in a way hitherto too prohibitive to enact. We posit that a transformative approach is necessary and inevitable in the way we plan our cities and provide a framework to normalise the digital throughout the planning life cycle. We discuss how digital planning projects such as "joint lab" studies, "planning data hub", "AI and urban design technologies" chart a sustainable way forward-- for the planning ecosystem as well as the future urban landscape. Ultimately, this paper intends to create a dialogue on how urban planners, architects and policy makers should get on the front foot for the digital age.

Keywords: Complexity, Digitalisation, Urban planning

P2

Sensitivity Analysis for Urban Design Optimisation

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This project puts forward methods of sensitivity analysis for complex urban design models. These methods are intended to support designers' ability to understand trade-offs among objectives for sustainable, resilient urban design and identify optimal results. Computational urban design models are taking on a growing range of objectives, as city planners seek to find good solutions for overlapping challenges of economic development, sustainability, and resilience. Urban design objectives addressed in this research include not only the economic performance of a development and its sustainability in terms of lifecycle carbon costs, but also metrics for a well-performing urban environment. These metrics increase the complexity of the models, driving a need for better analytic tools and methods to identify, understand and validate insights useful to city planners. Multi-objective optimisation and statistical analysis methods have increasingly been deployed for generating best results. However, multi-objective optimisation for conflicting objectives results in a solution space with no single best outcome, but rather sets of equally good pareto-optimal results. In cases with more than two conflicting objectives resulting in a weak pareto-optimal solution, it is unclear how a designer could objectively identify the best possible solution set. The complex relationships among objectives require deeper analysis to navigate the complexity of the optimisation process. To manage the complexity of multi-objective urban design optimisation, replicable methods are needed to understand interactions between objectives and model parameters. Collectively these techniques are known as sensitivity analysis and while widely used for larger-scale models in public health or climate studies, they have been deployed with only limited frequency for the smaller scale and three-dimensional problems of urban design optimisation. In this conference presentation we tested sensitivity analysis on a demonstration model and illustrate how the results of sensitivity analysis can inform the set-up of an optimisation problem.

Keywords: Complexity, Computational urban design, Design space exploration, Multi-objective optimisation, Sensitivity analysis, Sustainable development

P3

Vertical Cities: Complex Emergent Patterns of Movement and Space Use in High-Density Urban Context

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High-density liveable cities require new integrated planning and design strategies that acknowledge their complexity. Traditionally located on the ground level in land-scarce Singapore, public and common spaces and networks are increasingly also added on elevated levels in the form of sky bridges, sky parks, sky terraces, and roof gardens. Combinations of these, often applied to mixed-use (residential, civic, and commercial) developments can have complex interactions with the common spaces on the ground level within the vertical dimension, producing vertical cities that become components of larger urban systems and networks. However, these interactions, their impact on patterns of human movement in the city, their contribution to a more liveable high-density urban environment, and their scalability are not well understood. The study presents a Complexity Science-based approach to the analysis of high-density urban built environments. Buildings and their contexts were mapped as spatial networks of nodes, and superimposed with socio-spatial information derived from human movement sensor data to provide important insights into actual space use. This method was test-bedded in Kampung Admiralty, a first-of-its-kind building development in Singapore that integrates housing for the elderly with a wide range of social, healthcare, communal, commercial, and retail facilities. The pilot study successfully tested a systematic post-occupancy socio-spatial network analysis framework using: (1) qualitative architectural analysis, (2) quantitative spatial network analysis, (3) quantitative data collection, and (4) correlation analysis of actual performance with spatial network patterns. It provided early insights into the effectiveness of the combination of methods and tools for data collection, established the potential and limitations of scaling up the approach to the larger urban scale, and further validated the proposed methodology's potential to provide a scientific basis for planning and designing future vertically integrated developments that can support higher population densities, higher standards of environmental sustainability, and enhanced liveability in Singapore and beyond.

Keywords: Bluetooth localisation, Complexity science, Mobility patterns, Spatial network analysis, Socio-spatial networks, Spatial performance

P4

Network Science-Based Analysis of Evolutionary Park Systems

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Cities are hubs for interactions of their inhabitants, which drive innovation, culture, and economic welfare. As building density in many cities increases, urban planners are increasingly prioritising parks

as agents of urban vitality because of their many physical and mental health benefits. This has led to a shift in urban design and landscape architecture practice to promote 'evolutionary parks' in that the built environment 'evolves' over time. Our research proposes a novel Network Science-based methodology of spatial performance assessment for the study of evolutionary parks. In this paper, we present the case of one-north Park as an example of an evolutionary park. One-north Park is a key spatial component in one-north, a vibrant research and business district in Singapore. The linear park is in the centre of the development, providing a continuous green corridor that enables the maximisation of frontage for user access and it connects many of the one-north's research clusters. The aim of our study is to evaluate the connectivity of the park and its effect on walkability within the larger one-north planning subzone, using Spatial Network Analysis methods, which allows us to predict the effect of the park's topography on pedestrian movement patterns based on a three-dimensional pedestrian model of the subzone, and empirical sensor-based studies of pedestrian movement. The results correlated with the observations from the sensor-based investigation of our study which determined the level of integration of the park with its larger urban context. Correlating space use patterns in the multi-level model provides important insights into how users form pedestrian mobility networks. These can subsequently become the basis for more informed planning and design decisions on how to improve the park's connectivity and usage. The presented study is part of a larger ongoing research project on urban vibrancy in one-north and contributes to the development of a novel multi-disciplinary methodology for Spatial Network Analysis.

Keywords: Complexity science, Spatial network analysis, Spatial performance assessment, Urban design

P5

The Planning and Design of Resilient Spatial Networks

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A high level of connectivity is one of the key objectives in the planning and design of many urban developments. Events and policies that result in access controls and the spatial reconfiguration of activity hubs affect the connectivity of these urban spaces, i.e., the movement restriction of people between places to mitigate the risk of disease spreading. Therefore, the evaluation of the development layout and the resilience of its spatial network with the consideration of both connectivity and separation becomes an important task. To understand how the connectivity of spaces affects the resilience of its spatial network, this paper proposes an analytic framework based on the spatial mapping of human movement at the urban and architectural scale. This approach allows for the evaluation of the effects of isolating spatial nodes on the disease spreading process in a spatial network. We explored how the connectivity of nodes affects people flow and identifies the morphological and typological features of a spatial layout that relates to that connectivity. Next, we evaluated the dynamic effects of altering the network structure on movement and clustering of people through a series of link removal analyses. Our findings suggested that for the scale of our case study, a compact university campus in Singapore, alternatives to zone-separation and isolation measures, such as increasing spatial separation while reducing physical interactions and close contacts helped to maintain resilience of its spatial network. By framing the spaces of such a built environment as a

complex adaptive system, the results provide important insights into human-centred design and interventions for public health at the building and urban scale.

Keywords: Architecture analysis, Human movement, Lockdown, Post-pandemic, Spatial connectivity, Urban design and planning

P6

Identifying Urban Functional Zones by Analysing the Spatial Distribution of Amenities

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Understanding urban form and functions is crucial in the urban planning and redevelopment process. Given the complexity of urban entities in a city, identifying the boundaries of urban functional zones is an important but challenging task. Functional zones are subsections of urban areas that provide a similar set of services. This study proposes a general analysis framework to delineate urban functional zones and reveal the composition of amenities using point-of-interest (POI) data. Since POI data is a set of geocoded user-generated content, it can capture the spatial structure of underlying human activities. Three study sites in Singapore---Queenstown, Jurong East, and Punggol---were used for the demonstration of the analysis framework. We identified the shapes of functional zones and analysed the composition of amenities at the three sites. The results revealed the spatial configuration and makeup of amenity clusters within the urban area. Many of the identified urban functional zones were observed to differ from planned land uses. This not only implies that the emergent composition of amenities is more diverse than planned land uses but also indicates that the urban living experience is complex and non-uniform within an urban area---i.e., the degree of mixed uses can vary in areas with the same land-use type. The results of urban spatial configuration can be used to reflect on planned uses and guide further urban renewal. The presented framework is generally applicable in cities where POI data is available. The approach can be used as a basis for further analyses, such as understanding accessibility and assessment of urban vibrancy and vitality.

Keywords: Geodemographic segmentation, Mixed use, Points-of-interest, Spatial partitioning, Urban planning, Zoning

P7

Spatial Structure of Places in Singapore from a Complexity Perspective of Public Transit Network

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As cities become increasingly developed, inclusive and equal provision of public services and affordable housing is essential in achieving sustainable growth and development. In Singapore, with much of the population living in public housing and taking public transport, there is a great need to understand their landscape across the country. In this study, using tools from Complexity Science, we investigated the spatial organisation of places in Singapore through the public transport connectivity and linked such pattern to its social counterparts, including the distribution of the population age groups and property price, to gain insight into the characteristics of different places. From the spatial network of the public transit services, we probed the places' scale using the continuum percolation approach to uncover their spatial pattern. After that, we employed an information-theoretic measure of complexity to quantify the spatial organisation of the system. It was found that there is a critical distance embedded with the public transit system at which the structure of the places in Singapore emerges. In many areas, the places mapped well to the official planning boundary, yet the non-alignment in others suggested a more organic pattern on the ground. The places' structure also revealed a larger-scale regional pattern, which maps remarkably well to the distribution of age group and property price. In particular, the well-connected areas in and around the central region of Singapore were associated with a higher property price and an older population. In contrast, the peripheral less-connected areas tend to see a lower property price and a younger population. The findings can contribute to understanding the existing pattern of physical and social form within an urban system, which in turn could act as guidance for future planning by highlighting the areas where more attention is needed to reduce the socio-economic polarisation within the system.

Keywords: Complexity measure, Public transport, Spatial organisation, Urban percolation

P8

Deciphering the Spatial Co-occurrence and Co-change of Industries at the Scale of City

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We analysed the location of industries in two metropolitan cities to investigate how firms are spatially distributed, and identified the trends in firm location choice. By defining a "Region-Index" metric, we demonstrated how industries have concentrated in or diffused from regions of interest over time. We applied this metric to the Central Area (CA) of Singapore and London to decipher the relative tendency of industries to locate at CA as well as London. To analyse spatial co-location of industries, we constructed a community network, which revealed subtle relationships between firms. Extending this

approach temporally to create a co-change network, we deduced the occurrences of industries in Singapore and London that move into or out of a spatial region synchronously. Based on this approach, we identified the possible presence of industries that not only co-change but also co-occur in space. Overall, we observed certain common patterns of industry movements in the context of Singapore and London through the analysis. Finance and insurance companies were found to have the consistent tendency of concentrating in CA and London throughout the period of the study while "other financial services except insurance" companies have the tendency to diffuse out of these regions. Conversely, opposite movement patterns were observed, where we see the proclivity of Web Portal (which is a subsector of the IT industry) to locate into London but relocate out of the CA of Singapore.

Keywords: Complex network, Complexity science, Spatial co-occurrence, Spatial analysis

P9

The New World Order of Airports: A Population- and GDP-driven model for Forecasting Aviation Demand in 2050

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Aviation activity has been shown to mirror the expansion of urban centre activity through increased airport-city linkages, infrastructure enhancements, and passenger numbers, all of which have accelerated over the last two decades and specifically within Asia. Aviation supports vital information flow through people and goods and is a key driver of countries' economies and business productivity despite the recent impacts of COVID on commercial travel. Our work explores how the symbiotic relationship between global aviation networks and urban centres will evolve in response to projected changes in national indices as population and gross domestic product, and thus drive new aviation demand profiles, location links, and even new airports. This was explored using of network theory derived from computational social science as indicators for the attractiveness of airports based on global 2019 flights data. PageRank was also used as a proxy to the average desire to visit an airport and its corresponding urban centre based on access to advantageous business, touristic, or social opportunities. We combined this network analysis with Central Place Theory to capture the spatial function of the airport as a nodal gateway between cities taking part in the global aviation network. Existing volumes of flights and thus, demand for airport pairs within and between community clusters were found to be related to proximity to urban areas, GDP, network access, and how these influence the likelihood of inter-cluster travel for business and tourism. Lastly, we employed gravity models to predict significant new connections between the South and Southeast Asian regions, which used information on projections of changing international demographics, forecast future demand for airports, travel destinations and urban centres.

Keywords: Airport-to-city connections, Aviation, Mobility, Networks

P10

Limits to Adaptive Capacity of Airports using Aerial Imagery and Machine Learning

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Due to exponential aviation demand in the last two decades, and conversely due to COVID19 and environmental pressures, airports have seen pressure to undergo unprecedented levels of transformation which includes upscaling, downscaling, and reconfiguration. For instance, the new Beijing Daxing airport designed to handle over 100 million passengers, the complete relocation of Istanbul airport to a new site away from the congested city center, the Jewel in Changi Airport combining airport functions into mixed-use spaces that mirror central business districts, and Anchorage Airport's development as a logistics hub due to reduced East Asian passenger flights and recent Russian aerospace closing. These are just a sample of the range and extent of recent global changes that have and will impact airports and thus cities land use. Responding to this global change, our study investigated the 'adaptive capacity' of airports in a novel data-driven way. We explored the spatial relationship between the world's top 500 cities and their airports using machine learning techniques to perform automatic land use classification on aerial imagery, sourced from the Sentinel-2 satellite data set, using a bespoke trained U-Net based image segmentation approach. These images were analytically compared at scale to derive relationships between airport-city land usage pairs, comparing airport network metrics including centrality, size, against the complex land usage, level of development and ability to expand or contract. Based on this unique dataset, we explored the future adaptive capacity of airports, as a result of spatial pressures from the city, airport demand driven by changes in local population, and passenger footfall. Identifying the cites that are the least and most able to adapt to future changes.

Keywords: Aviation, Aerotropolis, Aerial Analytics, Machine Learning, Urban Planning, Adaptive

P11

Sentiment Analysis of Social Media Response on the Government's Handling of COVID-19

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The outbreak of the Covid-19 pandemic in 2019 has posed a severe threat to the world. In response, governments around the world introduced various measures and policies. These policies are posted on social media (e.g., Facebook and Twitter), and people can reply and comment on them. Applying the artificial intelligence technique of sentiment analysis to these comments could promptly help the government understand the public's perception and opinions on the measures and policies. However, it is noted that the number of policies and comments is very limited, in particular at the early stage of the Covid-19 pandemic. Such a small dataset is difficult to train a reliable artificial intelligence model for sentiment analysis. To address the training data shortage problem, we propose a novel data

augmentation technique named Tailored Text Argumentation (TTA) which generates synthetic data to enlarge the original dataset. It has two main operations. The first operation is the probabilistic word sampling for synonym replacement based on the discriminative power and relevance of the word to sentiment. The second operation is the identification of words irrelevant to sentiment but discriminative for the training data, and application of zero masking or contextual replacement to these words. The first operation expands the coverage of discriminative words, while the second operation alleviates the problem of misfitting. Both operations tend to improve the model's generalisation capability. In our experiment, TTA was applied to public sentiment analysis on measures against Covid-19. The over 8% improvement in prediction accuracy proves the effectiveness of the new data augmentation algorithm. Then, the well-trained model was employed to predict sentiment over 10,000 comments from social media. The results showed how public's perception and opinions vary on different types of measures and policies across time.

Keywords: Artificial intelligence, Public's perception, Text augmentation

P12

Smart Cities and Crime: Mapping the Impact of Urban form on Crime occurrences

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The idea that cities are like machines is not new. Borrowing the concept of cities as machines in the context of security in smart cities leads us to think about which variables in cities, in addition to social ones, can impact urban crime. The current research seeks to understand this relationship through statistical modelling, simulation and mapping of urban crimes. There seems to be a gap in the research on the influence of the physical attributes of the urban form on the occurrence of crimes using statistical methods coupled with simulation and mapping techniques in GIS. This investigation consists of three main parts. The first part consists of examining how the theoretical principles associated with urban form can be seen in terms of their influence on the distribution of crime patterns. This will involve using the principles of environmental criminology to help explain the relationship between crime patterns and the urban environment in which these patterns form. The second part includes the development of tools that can be used to model elements of urban form and measure the relationship between these elements and crime patterns. The third part comprises determining the extent to which managing the physical attributes of the urban environment can contribute to reducing crime. Understanding the relationship between urban form and crime patterns will help to highlight the influence that city planning has had so far on the crime problems; and how effective urban planning can contribute to crime reduction, bringing new contributions to the field of smart cities.

Keywords: Building energy, City information, Energy resilience, Planning support, Urban energy systems

P13

Hybrid Art Places: Exploring the Relationship between Social Media and Art Venues in Singapore

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This study explores emerging art production and consumption in connection to the use of social media, and in relation to locations of art production and consumption in global cities, focusing on the case study of Singapore. The methodology uses geographic, temporal and social metadata, which has created an abundant (big) data source waiting to be explored and put to use for planning of responsive cities. The emergence of virtual social media, be it Twitter, Instagram or Weibo, has stimulated many new kinds of social interaction. This has had an important effect on traditional public places in the city where conventional face-to-face and collective social interaction would take place. Increasingly, the two kinds of social interaction intersect, and new hybrid physical-digital places are emerging as a result. Such new hybrid 'pixel-places' support many new kinds of interactive phenomena and effects. The possibilities of such hybrid places in the city are still not well understood, and new methods and approaches are required to analyse and harness them for sustainable and vibrant future cities.

Keywords: Computer vision, Cultural planning, Hybrid art places, Natural language processing, Spatial-temporal planning metrics

P14

New Launch: International Journal on Smart and Sustainable Cities

Centre for Liveable Cities and **World Scientific Publishing Co Pte Ltd**

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The International Journal on Smart and Sustainable Cities is a newly launched biannual publication which aims to provide a platform for global inter-disciplinary research that is at the nexus of urban science and technology, sustainable development, urban planning, and resilience, with a focus on the Asia-Pacific region. It accepts high-quality research papers, review papers, insights, and opinions from practitioners and policy makers in a wide range of topics, from complexity science for cities, application of digital humanities and citizen science to address city challenges, use of emerging technologies to enhance liveability in urban systems, adopting multi-stakeholder approaches to anticipate and tackle emerging urban challenges, enhancing sustainable and/or regenerative development in cities, and more. The Journal aims to connect theory and practice, share innovative thoughts and experiences from policymakers, academics and industry leaders that would be useful to shed light on the practical applications of science and technology in advancing the liveability, and sustainability of cities. The Journal's aims and scopes in terms of discipline, regional focus, and article type may be further adapted to address specific gaps in researchers' publication needs.

Keywords: Complexity sciences, Human-centric cities, Net-zero carbon cities; Smart cities, Sustainable city development, Technology

P15

Adapting Cities for Climate Change – A Regenerative Approach using Nature-Based Solutions

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Sea level rise and more frequent inland flooding due to climate change are posing significant risks globally. Recent floods had occurred over large areas in China, Australia, and Europe. There had also been unprecedented scale of forest fires in the USA which had driven home the need for urgent coordinated solutions. It must be an all-of-society effort for climate change solutions to be effective. As subject matter experts, we can play a pivotal role in offering innovative solutions to private and public sector stakeholders who are confronted with challenges like displaced population due to flooding or upgrading old assets to cope with climate change. This calls for a more resilient urban development approach to mitigate climate risks. At Ramboll, our multi-scalar approach towards flood resilience emphasises on incorporating nature-based solutions as part of the toolkit for creating future regenerative cities. Ramboll's design approach will be showcased through some recent leading project examples around the world to demonstrate regenerative outcomes.

Keywords: Adaptive design, Climate change, Multi-scalar solutions, Nature-based solutions, Regenerative coastlines, Restorative landscape

P16

Cooling Singapore 2.0 and Climate Resilient Development

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An important element for enabling climate resilient development in cities is having relevant information on what policies can effectively adapt and mitigate urban climate risks. To this end, accurate scientific information that is relevant in the urban context is essential. Research obtaining valid urban climate observations is required for developing environmental models that can help stakeholders decide on which risk-reduction approaches can be most effective. In Singapore, reducing urban heat is a key part of the Green Plan 2030 pillar on "Resilient Future", and the Cooling Singapore Initiative has been contributing to this since 2017. In its current iteration (2.0), the project is developing a Digital Urban Climate Twin (DUCT), in which several interacting energy, transport, building and climate models simulate Singapore's thermal environment. To ensure model validity, environmental data of how cities affect temperature and outdoor thermal comfort are being obtained and analysed by the Singapore Management University CS2.0 research team, and we can see that reducing urban heat via urban greenspace (on average by +1°C in small urban parks during night-time periods) and building design (such as by utilising shade structures) can significantly lower urban temperature risks and can be accurately identified and modelled in the DUCT system.

Keywords: Climate adaptation, Climate resilience, Urban climate

P17

Mitigating Urban Heat Islands by High-fidelity Modelling and Climate Sensitive Planning

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Anthropogenic heat is a key factor to intensive Urban Heat Island (UHI). Stagnated airflow due to closely packed tall buildings causes weak dilution and removal of anthropogenic heat. Consequently, research is critically needed to investigate the effect of urban morphology on anthropogenic heat dispersion and provide effective planning strategies to reduce UHI intensity. This study provided scientific understanding and developed a Geographic Information System (GIS)-based modelling tool to support decision-making in urban planning practice. Based on energy conservation within urban canopy layers, we developed semi-empirical models to estimate spatially averaged in-canopy air temperature increment. Model performance was validated by cross-comparing with Computational Fluid Dynamics (CFD) results. By applying new models, the impact of anthropogenic heat on air temperature was mapped in residential areas of Singapore for annual-averaged and short-term extreme low wind speed to improve urban climate sustainability and resilience.

Keywords: Anthropogenic heat dispersion, CFD, GIS mapping, Semi-empirical model, Urban planning

P18

Enhancing Urban Planning in Singapore using Supercomputers

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To mitigate the Urban Heat Island (UHI) effect, the Urban Redevelopment Authority (URA) performs environmental simulations at the upstream planning phase where there is greater opportunity to optimise urban design guidelines and policies. Using High Performance Computing (HPC) via the National Supercomputing Centre (NSCC) and an integrated computational fluid dynamics (CFD) software that is embedded with NSCC's supercomputer, URA saw an approximately 8–12 times increase in efficiency and was able to scale up on the environmental modelling and simulations.

Keywords: HPC, Modelling, NSCC, Simulations Urban heat effect, URA

P19

HPC to address Singapore's Rising Temperatures

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Developing an urban microclimate model for the local Singapore environment presents challenges, including developing complex environmental simulations of surface material properties, climate, integration of the buildings, structures, tree canopies and terrain. National Supercomputing Centre (NSCC) provided High Performance Computing (HPC) resources that allowed the team of the test-bed site at the Kent Ridge campus of the National University of Singapore to carry out multiscale modelling with an approximately three times increase in efficiency in their local research workstations.

Keywords: Building energy, City information, Energy resilience, Planning support, Urban energy systems

P20

Urban System Resilience through a Digital Twin-enabled Approach

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With the increasing frequency and magnitude of disruptive events in urban areas, the resilience of the built environment has received increasing attention in recent years. A digital twin-enabled approach would allow planners and system operators to assess system performance in real time and understand the effects of past events and future scenarios on urban system resilience. We propose a methodology for creating a digital twin for the simulation and evaluation of the energy performance of a district-scale urban area. The case study area is a university campus comprising around 300 buildings in a 170 ha area. The digital twin used comprises a user interface for real-time data visualisation along with physical models for the evaluation of future scenarios. The digital twin dashboard was developed through a web map application and combined visualisations of the 3D campus, real-time data from sensors, and energy demand simulation results. The district-scale building energy demand model was calibrated with measured building electricity and cooling demand data, and building occupancy patterns were extracted from campus-scale WiFi connection data. To test the possibilities of the digital twin platform for resilience evaluation, different scenarios were defined to explore the long-term effects of the COVID-19 pandemic and climate change on building system performance. The results stress the importance of rethinking building system operation to support the transition to flexible work arrangements while minimising energy consumption and increasing system resilience. Ongoing work focuses on formulating a resilience assessment metric to measure the robustness of networks and buildings to these disruptions. This district-scale digital twin demonstration can help in facilities management and planning applications.

Keywords: Building energy, City information, Energy resilience, Planning support, Urban energy systems

P21

Can Demand-side Management Save Space for Solar PV Installation? A case study within the NUS campus, Singapore

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The transition towards solar energy is one of the strategic cornerstones in Singapore's Green Plan 2030. Unfortunately, solar photovoltaic (PV) has significantly higher land-use requirements than conventional power generation systems (e.g., coal and gas). As space is a key and limited resource in high-density urban systems, land-use saving should be considered as a priority for solar PV expansion planning in Singapore. With demand-side management, a certain portion of the energy demand is shifted from peak hours to off-peak hours, thus reducing the total solar generation needs and, as a consequence, the corresponding land-use requirements of solar PV. This study aims to identify the optimal demand-side management scheme for reducing land-use requirements in a community energy system. We first differentiated the hourly building energy demand into different end-use categories, e.g., lighting, air-conditioning, water heating, and electric vehicle (EV) charging. The energy consumption and demand shift potential of each end-use category were estimated based on multiple data sources, e.g., real historical building data, simulations, and surveys. Then, a mixed-integer linear programming model was developed to identify the optimal solar PV expansion and operation plan with demand-side management for the minimization of land-use requirements. Results were validated with a case study of a building cluster in the Faculty of Engineering at the National University of Singapore. Two different scenarios were designed, i.e., solar PV expansion scenarios with and without demand-side management. The costs, land-use requirements, and solar PV installation and operation plans under the two scenarios were compared and analysed. The results of the model can provide valuable insights to decision-makers, for example how much land-use saving the demand-side management strategy can generate, and how to manage buildings energy demand when considering the trade-off between cost and land-use saving.

Keywords: Electric mobility, Energy systems design, Integrated energy systems, Land use, Mixed-integer linear programming, Renewable energy

P22

For Regenerative Urban Ecologies: Integrated Community Hubs

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Within the past decade, the Singapore government has completed four integrated community hubs around the island. These nodal developments leverage its urban context and programmatic offerings in a bid to generate a sustainable hub ecology for the city. A manifestation of the whole-of-government, and now whole-of-society approach, these large-scale communal architecture plays a significant role in rejuvenating the heartlands, advocating citizen engagement, and advancing civil society. Drawing inspiration from natural ecosystems and breaking away from silo-ed norms, the

vision behind this emergent typology is in the creation of synergistic and generative environments. This paper seeks to investigate the potential of this shared urban model of integrated communal architecture as testbeds for circular concepts, to advance policy agendas and support wider collaboration to establish and achieve district-based targets in regenerative outcomes. Using Our Tampines Hub and Bukit Canberra as case studies, the complexities of synergistic operations, and specific design strategies and the participatory approach to support a circular economy framework were analysed. It examined not only economic value in land and space optimisation, but new synergies produced for circular mindshift, closed-loop environmental outcomes and social impetus.

Keywords: Synergies, Density with enhanced capacities, Adjacencies and dependencies, Harmony of systems, Whole-of-society, City as second nature

P23

The Role of Microbes in Regenerative Cities

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A regenerative city needs to develop its internal vitality to find the seeds of its own regeneration. It is an urban development based on an environmentally enhancing, restorative relationship with the natural systems that sustain the city. The term “regenerative” includes actions that lead to the continuous renewal and restoration of the ecosystem which allows the circular existence of the city’s urban systems. A regenerative city sustains a mutually beneficial relation of resources and actions by minimizing its environmental impact by actively enhancing the city’s ecosystems. The macro representation of regenerative cities must also consider the micro impacts made by the natural restorative mechanisms of soil science. The microbial world is just as important and plays a crucial role in restoration of the natural ecosystem services of the urban environment. The importance of the microbial world is often overlooked as we almost always see ecosystems and ecology from a macro perspective as they have the most immediate visible impact on the human species. Soil microbes restore the biocapacity of ecosystems. Artificially created landscapes do not have the biocapacity to nourish the microbiomes created using degraded soils reused within the built environment. We must embrace technology to counter these imbalances. Consortium of beneficial microbes together with sensors can give us the data and assist us in understanding the health of the ecosystems. There is an important role played by microbes in Carbon Fixing in the Urban Built Environment that we must uncover. Using Green Intelligence (GI) networks with the Internet of Trees (IoT) sensors, we seek to understand natural ecosystems in small microcosms that will allows us to substantiate the value of the microbial world and ensuring regenerative cities can become resilient in the long run.

Keywords: Consortia, Green Intelligence, Internet of Trees, Microbiome, Restorative

P24

Intelligent Platform for Urban Farm Design

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Today more than 50% of the world's population lives in cities. Projection from United Nation shows that there will be two thirds of the population on earth in 2050 to live in urbanized metropolitan areas. The needs of fresh and healthy food for megacities cannot be met by traditional agriculture anymore. One potential solution is urban farming: growing crops in the midst of big cities. The advantages offered by these urban farming concepts have already made their way in modern cities. In recent years, the creation of urban farming technologies has been seen in big cities of the world including Singapore. To increase the resilience of the food supply chain, Singapore has developed its approach as "three food baskets": diversifying food sources, growing locally, and growing overseas. To “growing locally”, the city state has formulated a "30 by 30" plan: to build up Singapore’s food industry's capacity and to have 30% of Singapore's nutritional needs produced locally by 2030. In this project, a crop growing cycle simulation based intelligent platform for urban farm design was developed. The intelligent platform includes a smart lighting simulation engine for natural and artificial lights, an AI module for continually lighting recipe optimising in dynamic environment, a crop growing cycle and yield simulator, and a layout-based farm design module. It can help design a farm with its layout in optimal way that takes into consideration crop growing cycle and yield, optimal lighting recipe for different stages of crop, the light distribution and uniformity in the layout, and potential to extend to other environmental conditions such as CO2 concentration, humidity and temperature distribution. The developed technologies can equip the farmers to best utilise the limited natural resources such as land and space in the urban environment to increase crop production. In addition, with better yield and using lesser energy by applying optimal lighting recipe, it results in lower carbon footprints.

Keywords: Crop growing cycle simulation, Lighting recipe, Urban Farming

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Influence of Complex Adaptive Systems Theory on Urban Resilience Approaches

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The theory of complex adaptive systems has captured the imagination of many scholars as a means of analysing, understanding, and modelling urban systems but to a much lesser extent designing or planning them. One of the positive characteristics attributed to complex adaptive systems in nature and society is their resilience. The notion of resilience itself has become a ‘buzzword’ in multiple disciplines and sectors including economics and urban planning. This paper presents a scoping review of four areas where the theory of complex adaptive systems has found relevance in urban theory and practice with repercussions for resilience. The first area is within the spontaneous self-organisation of

the city as a whole and in its physical subsystems of regions, districts, and neighbourhoods. This spontaneous self-organisation is currently diminishing in many city systems and subsystems, with consequences for their social, and economic service provision and resilience. The second area is complex adaptive system mimicry. Mimicry has been successfully used to improve urban agriculture and stormwater management as a means of optimizing urban ecological service delivery. The third area is building resilience in the access systems of the city via redundancy and modularity. This includes connectivity, and adaptability and choice within transport modes. The fourth area is the application of principles of complexity into urban governance systems. This has been advocated in theory, and occasionally applied in practice, as a means of applying collective intelligence, codesign and fairness into urban projects and policy formulation. The intention in this regard has been to optimizes intersectoral benefits from projects and policy formulations and implantation. It also has the potential to build system resilience. The task of this paper is to review ways complex adaptive systems theory can inform urban governance, projects and policies that effect urban system functions, dynamics, and resilience.

Keywords: Complex adaptive systems, Ecosystem mimicry, Governance structures, Redundancy, Urban adoptability

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NUS Cities - An Open and Inclusive Collaborative platform for Education, Research, and Advisory Services to Address Complex City Challenges

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NUS Cities is a unique multi-disciplinary, open, and inclusive collaborative platform for Education, Research, and Advisory Services. It aims to train and unite urban systems professionals to learn, research, and offer strategic advice about cities and corresponding complex urban challenges. For Education, NUS Cities is running a module called 'Liveable Cities' at the undergraduate level and plans to roll out more programmes that utilise an interdisciplinary systems approach to train future leaders in the governing, planning, and managing of cities. Its research arm focuses on urban sustainability and resilience through a systems approach, with various projects on the Science of Cities that are underpinned by social science, climate science, systems, and complexity science. Through the study of cities as Complex Adaptive Systems, our research members continue to unravel some of the most pressing urban challenges of today, and seek to tackle them systematically. Finally, on the advisory front, NUS Cities aims to offer strategic advice drawing from diverse expertise and research on urban systems challenges that call for interdisciplinary solutions. Embedded within our framework is a pipeline of talents—NUS Cities aim to build one connecting NUS to the industry, non-governmental organisations, and intergovernmental organisations. We plan to offer students an opportunity to undertake further studies with us while serving as Teaching/Research Assistants working across the three pillars. This develops them to become multi-functional, interdisciplinary urban systems experts—the changemakers of tomorrow.

Keywords: Liveability, Multi-disciplinary, Science of cities, Systems approach, Urban sustainability, Urban resilience

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