HARNESSING COMPLEXITY AND DATA SCIENCE

TO DEVELOP URBAN SOLUTIONS FOR SINGAPORE

(A report on CLC's Complexity Workshop on 16 January 2017)

INTRODUCTION

“ The agents within a complex system like a city – the people, public and private institutions, markets and networks – all generate a lot of data, much of which is location-based. Combined, this constitutes what we now refer to as big data. Complexity science offers a way to marry different tools – such as agent-based modelling that is used inter alia for traffic flow dynamics, combined with insights from big data using data analytics – to gain a better understanding of the city in all its complexity.

The tools of complexity science combined with the insights from big data can help us to “see” the city differently, through new lenses. ”

***Peter Ho**, Chairman of Urban Redevelopment Authority (URA)*
Excerpt from speech “Complexity and Urban Governance”, paper delivered on Feb 2015 in Vienna

Cities are complex systems; city policy-making is typically made in complex environments with many factors covering a whole spectrum of social, environmental, economic and technological considerations.

The complex challenges that Singapore's policymakers face are compounded by the limitation of its size as a small island state of just over 700 km^2. Yet, Singapore has undergone a successful transformation from an undeveloped colonial outpost to a city that enjoys a high quality of life in a liveable and sustainable environment.

In recent years, our urban complexities have been better managed by the introduction of new tools and research streams—from data analytics and geospatial techniques, to urban modelling and simulations, to complexity science. These new developments enable government agencies to better understand complex urban issues, anticipate possible scenarios, and to make the best policy decisions.

In fact, our agencies have been leveraging on these tools and datasets to facilitate their work. For example, the Urban Redevelopment Authority (URA) has created a suite of digital planning tools such as ePlanner and GEMMA that integrates data across time and space to improve the way we plan our city; the Housing Development Board (HDB) has developed environmental simulation tools and has been using available data on the environment to identify the best scenarios and the best plans that will allow for a more comfortable living environment; the Land Transport Authority (LTA) has developed big data analytic tools to look at over 4 million daily public transport trips to better understand commuter behaviours and the transport situation on the ground to identify areas for improvement in the public transport network; the National Parks Board (NParks) has also been using GIS-enabled modelling tools to understand the behaviour of natural systems and to manage our parks and natural reserves.

Complexity science can add more possibilities to these on-going efforts through providing a scientific lens for evidence-based approaches. It calls for a more integrated approach, stitching data across silos, to discover patterns, and derive principles to address urban problems from a holistic perspective.

As what Singapore's development trajectory has shown, it is possible to increase liveability with density by taking an integrated urban systems approach. Moving forward, as we are seeing greater urban challenges such as an ageing society, a more crowded urban environment, and competition from other global cities, we need to understand the key patterns and problems in cities, policy interventions and their implications, especially in Singapore's context.

Researchers from Santa Fe Institute (SFI), a world-renowned research centre in complexity science, have been analysing many different properties of thousands of cities around the world and establishing the theory of a city as a complex system. Their work would help agencies better understand the urban complexities and the need for integration of various components which make up urban systems.

The Centre for Liveable Cities (CLC), which has been maintaining a dialogue with renowned experts and leading researchers at SFI, organised a workshop to bring together leaders and practitioners from government agencies and leading experts in complexity science. The objectives of the workshop are to discuss how we can better leverage complexity and data science as effective tools to give us better understanding of our city as a complex system, the fundamental parameters within it, the interactions and influences fundamentals have on the city's future trajectory, and to discover principles and potential solutions to guide our future planning work.

COMPLEXITY AND ITS RELEVANCE TO CITIES AND URBAN PLANNING

Urban planning in Singapore can be considered largely successful, enabling population density to increase while ensuring the provision of necessary infrastructure, housing, and amenities that have enhanced its liveability. However, going forward, it will be important for Singapore to maintain, and continue the upward trend.

In light of the need to address current and future challenges – population pressures, ageing infrastructure, climate change, changing lifestyle demands, rapid technological advances, just to name a few – there has been a concerted shift towards data-driven policymaking. Assisted by advances in technology, urban planners have increasingly sought to integrate data analytics with existing urban planning models to gain new insights and draw up plans that will be able to keep up with the rapid urban landscape changes.

Modeled on current assumptions and parameters, data analytics is still limited by current norms and perceptions. Studies by prominent researchers have indicated that there are gaps in our current understanding of the city that could potentially affect current projection methods. There are many interconnections, patterns, and linkages that need to be identified and accounted for in the urban planning process to ensure that Singapore's long-term plans are robust and effective.

Rather than seeking to isolate problems and to provide targeted solutions, thereby inadvertently creating silos, policymakers need to acknowledge that cities are complex adaptive systems and take a more holistic approach towards planning for urban growth and development. The following five characteristics of a city illustrate how a city is a complex system.

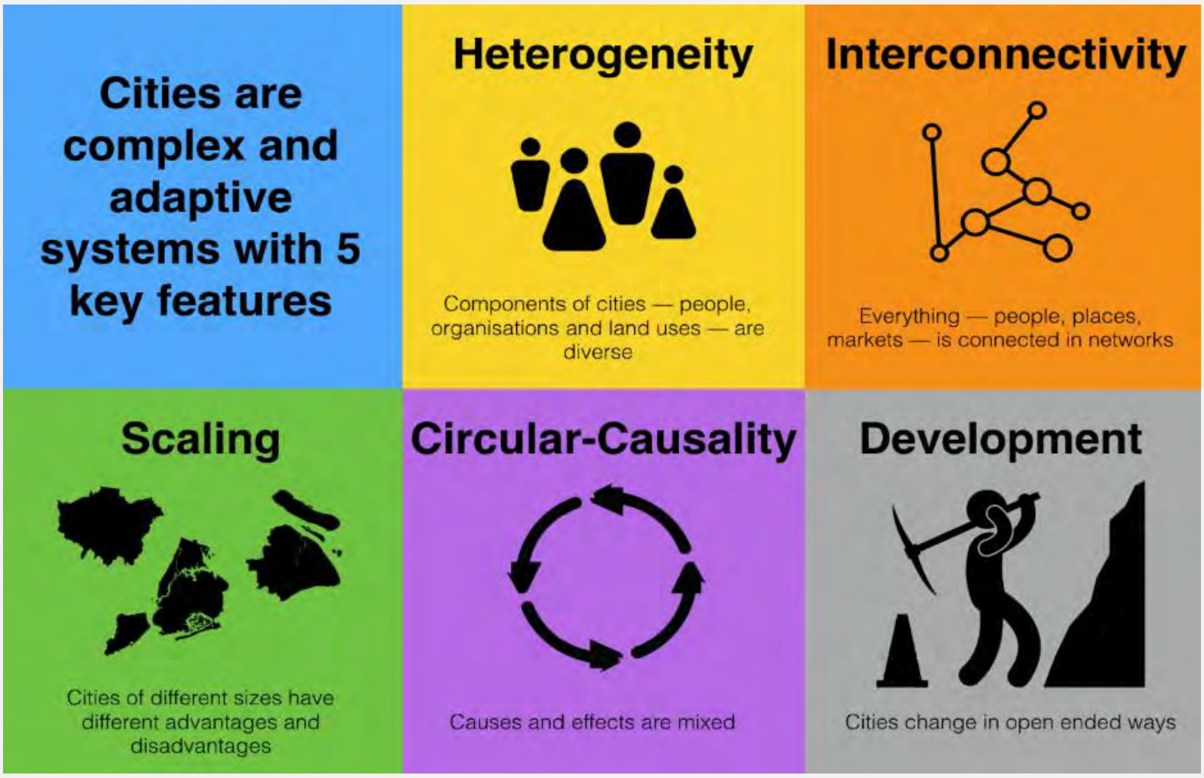

Figure 1 Complexity science research has revealed these five common characteristics and principles that all cities share (Bettencourt, 2017)

1. **Heterogeneity of its components; Diversity of people, organisations and land uses.** Cities are congregations of people and activities, all with varying needs and demands that require a whole spectrum of spaces and land uses. As a result, policymakers and urban planners are finding it increasingly difficult to ensure that land use is optimal for everyone, especially in face of rising population density. Overarching policies and parameters would have to be tailored to the specificities of each locality.

2. **Interconnectivity; Everything is connected in networks.** Recognising social interactions and interconnectivity is key to understanding the city's inner workings. Social interactions are what drive much of the city's socioeconomic processes, giving rise to innovations and economic growth, as well as crime and epidemics. Underpinning and facilitating the social interactions are not just soft structures such as safety, law, and justice, but also hard infrastructure such

as transport infrastructure, communications networks, and utilities, which play a key role in determining the cost of interactions, and its resulting consequences on the city's parameters.

3. **Scaling; Cities of different sizes have different advantages and disadvantages.** A city's size – loosely defined as its population – is related to multiple properties of a city in consistent manners, and with them comes varying advantages and disadvantages. Research by various experts, including workshop presenters Professor Luis Bettencourt and Dr. Markus Schlapfer, have identified a series of relationships between population size and indicators such as GDP, infrastructure volume, innovation, and building height.

4. **Circular-causality: Causes and effects are mixed.** Due to the interconnections amongst people and places across a wide spectrum of issues, cause and effect can be hard to distinguish, especially when there are many unknown linkages that could lead to unexpected consequences. For example, is a city rich because it has good infrastructure? Or does good infrastructure enable a city to be rich? It would be almost impossible to disentangle the numerous interconnections in a city to isolate specific causes and effects.

5. **Development: Cities change in open-ended ways.** Cities are constantly evolving. Rather than implement static designs that are unwieldy and leave no space for adjustment, urban planning and design would have to keep pace, embed flexibility, adapt by reacting and incorporating feedback in an efficient manner to keep pace.

With a clear understanding of these five characteristics, complexity science can then be used as a lens to unpack the city, allowing us to make sense of hidden dynamics and interactions as the city develops. It will also guide how urban issues are conceptualized, how available data can be used, and help to highlight unknowns that we are previously unaware of. The traditional way of solving urban problems often is to divide and conquer, inadvertently creating silos that fail to address issues that occur at an aggregated level. Cities are ultimately made up of people, and individuals face different combinations of urban problems relating to childcare, employment, recreation, health, transportation, nature, education, housing, etc.; all of which are interrelated and changing in response to circumstances. In that sense, all the urban problems are inter-connected in intricate and unexpected ways.

Figure 2 Combinations of urban problems that individuals living in cities face (Bettencourt, 2017)

Complexity science will be highly relevant in the coming decades as Singapore seeks to strike an even finer balance between liveability and density, a feat that many cities have failed to achieve. Liveability is a highly complex issue which grapples with many tangible and intangible parameters, and it is compounded by Singapore's land constraints, where population growth translates to increasing density. Complexity theories have the potential to offer insights, provide tools that help to guide data analytics, derive guidelines for urban development, and enhance the current urban planning process by accounting for the previously unknown factors and variables.

"Sometimes when you bring things together, they get simpler, not more complicated" – Luis Bettencourt, Complexity Workshop. By integrating disparate datasets, searching for patterns, and modeling behaviours, complexity science can help to identify, and potentially clarify these complex relationships. With these thoughts in mind, the next section will touch on some of the research and discussions that were shared during the Complexity Workshop.

APPLYING COMPLEXITY SCIENCE TO CITIES

ON DIFFERENT SCALES

With complexity science, cities are becoming more understandable on larger scales. Research conducted using big data have illustrated the possibility of elucidating scientific patterns and correlations on city and neighbourhood scales. More in-depth studies need to be conducted to find the causalities of these patterns, and more perspectives such as civic and practitioners' should be included in the conception of these studies to ensure its usefulness in urban planning.

As technology advanced, many avenues for data collection have arisen, creating massive data sets that track the evolution of a city as it expands physically and population-wise. This has allowed us to break down the city into more easily understandable quantifiable parts. But as discussed previously, complexity science is initiating a fundamental shift in how a city is perceived as a system. Integrating and analyzing multiple data sets have the added benefit of enabling urban planners and policymakers to observe the city as a whole. With these data, urban leaders will have more opportunities to derive illuminating connections that provide insights to guide the government as it adapts to the city's changing needs.

Scaling is one means by which researchers have used to organise and obtain findings from integrated data sets. Despite its complex nature, studies have revealed that cities, regardless of their different contexts, share certain generic spatial and socioeconomic relationships. To illustrate this scaling effect, Professor Bettencourt uses log-log graphs to control the scale of variables, and reveal relationships.

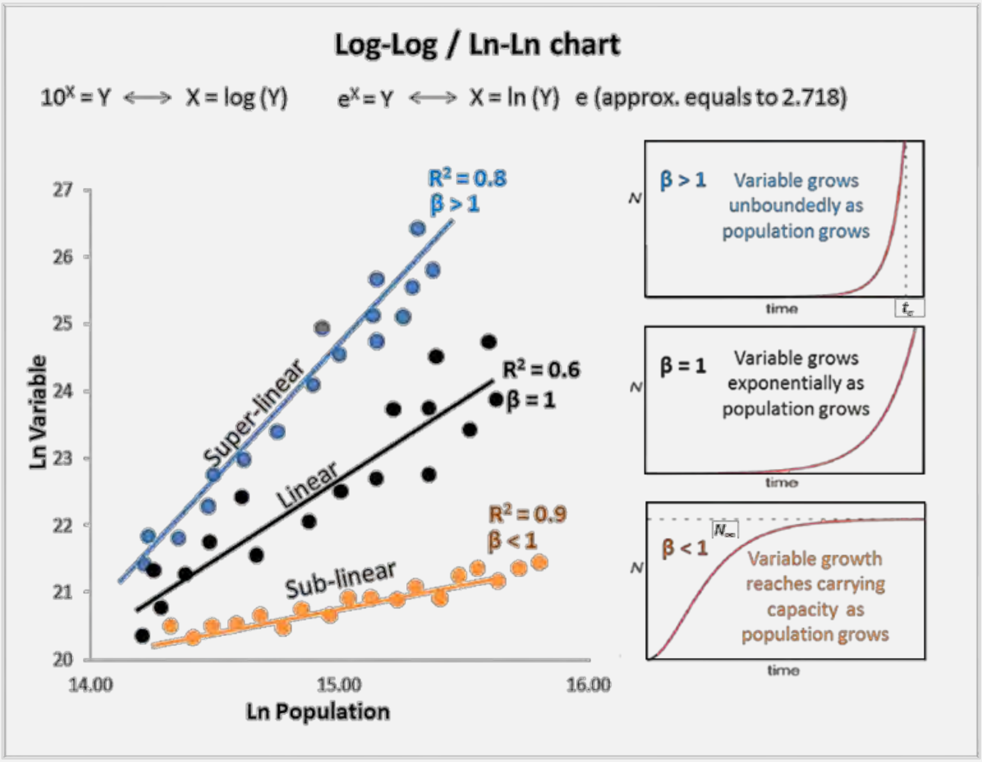

Figure 3 Log-log graphs that illustrate the influence of population increase on the growth of urban components (Centre for Liveable Cities, 2017)

His studies showed that as a city's population increases, the growth rate of a building's capacity (volume) increases at a slower rate than the population (β<1). Economies of scale are reaped as a lesser amount of infrastructure is supporting a given population size as population grows. On the other hand, socioeconomic outputs such as GDP, grow at a faster rate than population (β<1).

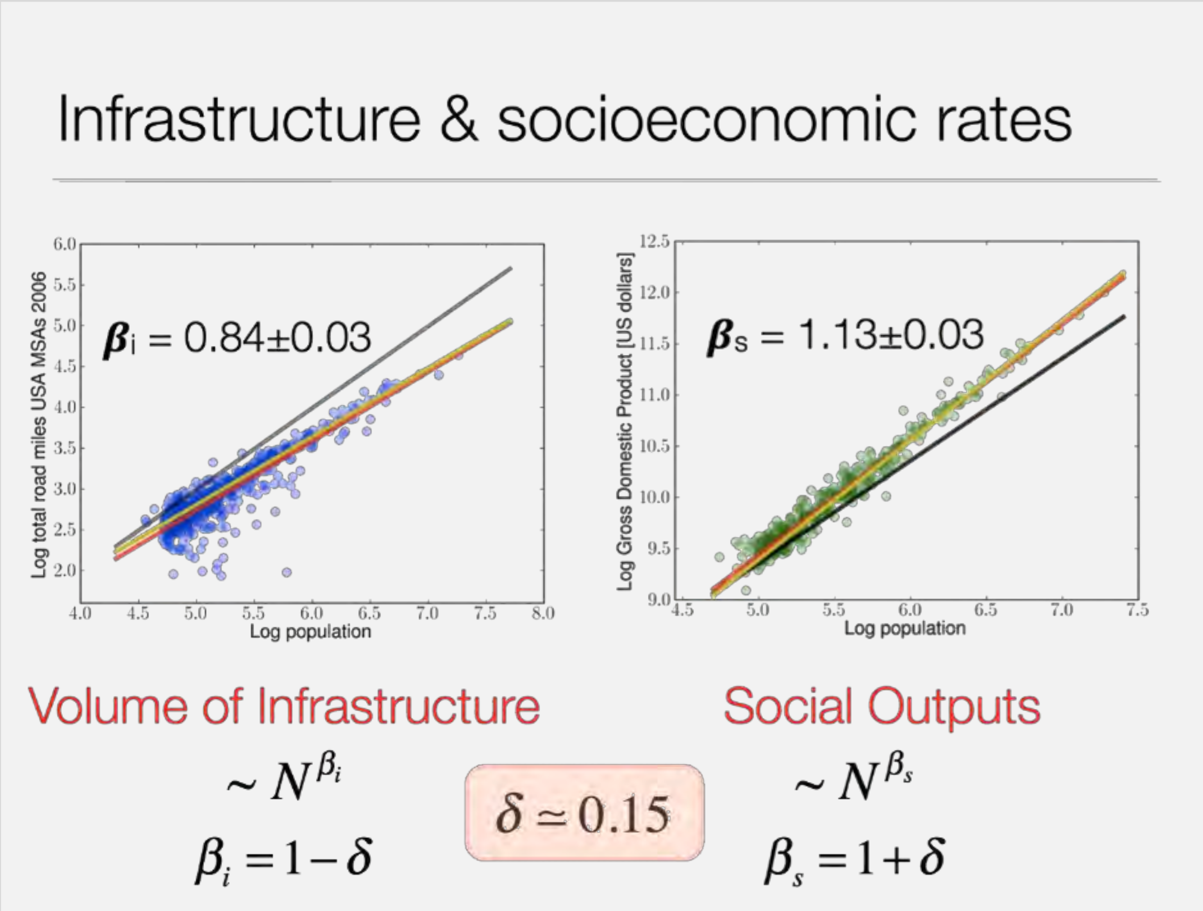

Figure 4 Scaling effect of population growth on expansion of infrastructures' volume and increase in social outputs (Bettencourt, 2013)

During the workshop, Professor Luis Bettencourt, Dr. Markus Schlapfer, and Mr. Zhou Yimin, shared some of findings where scaling theory was used to conduct comparative studies between and within cities, deriving some interesting patterns that serve as useful springboards for further investigation and validation.

In addition to sharing his work on American cities, Bettencourt put together a city-level analysis that compares the GDP growth trajectory of Chinese cities with Singapore and Hong Kong from 1996 to 2015.

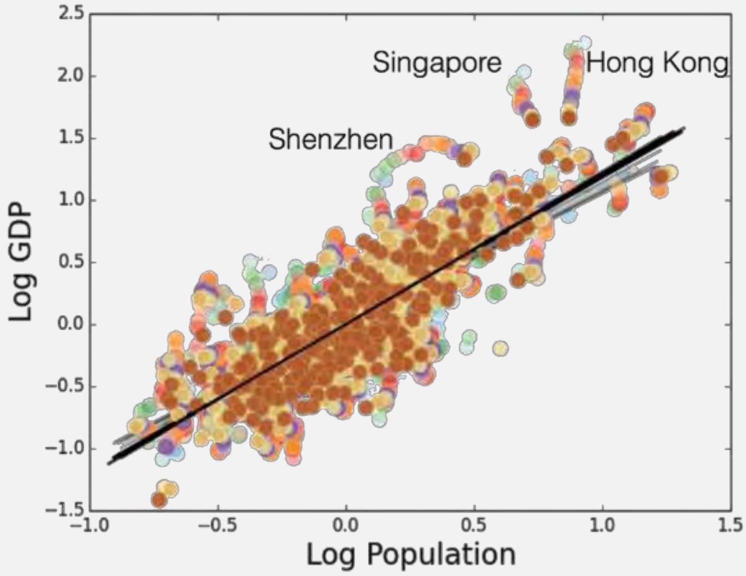

Figure 5 GDB growth trajectory of Hong Kong, Shenzhen and Singapore from 1996 to 2015 (Bettencourt, 2017)

As top-tier Asian cities, Singapore and Hong Kong are way above the trend line with significantly higher GDP, however it is evident that Chinese cities are catching up as GDP grows along with population increase. These results, coupled with prior studies done on American and European cities, prove that cities scale rather uniformly across countries and culture. It also forms the basis for conducting further trend analysis to identify more relationships in the city.

Given their similarities as city-states, Bettencourt also compared Singapore and Hong Kong with regards to three broad indicators of liveability in a city, namely, GDP, CO_2 emissions and life expectancy, from 1960 to 2015. By plotting the cities against each other, it is immediately apparent that although Singapore was the weaker performer of the two in the past, in recent decades, Singapore has caught up and surpassed Hong Kong, especially with regards to CO_2 emissions, prompting thoughts on the reasons behind the drastic improvements. A possible explanation could be that it corresponded with increased policy efforts to clamp down on industrial emissions in Singapore, but more research needs to be done to corroborate the link from policy to the trend shown by the graphs.

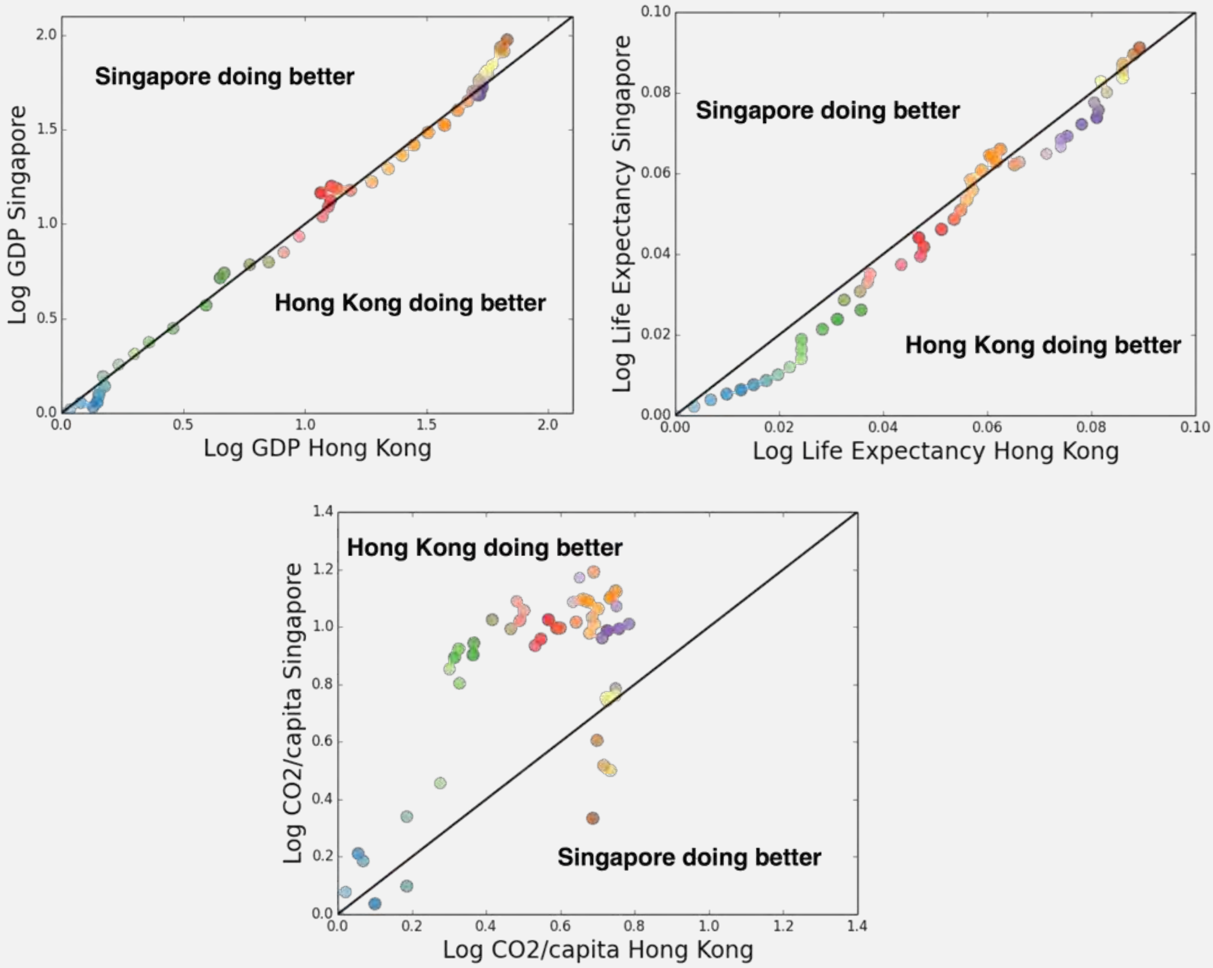

Figure 6 Scaling of cities with regards to 3 liveability indicators - GDP, CO_2 emissions and life expectancy in Singapore and Hong Kong from 1960 to 2015 (Bettencourt, 2017)

Schlapfer elaborated on two more specific examples, 1) building heights and 2) quantifying attractiveness of locations. In the first, Schlapfer correlated American data on building height and volume with city size, showing that as population increased, the height and shapes of buildings increased and became more needle-like nearer to the city centre.

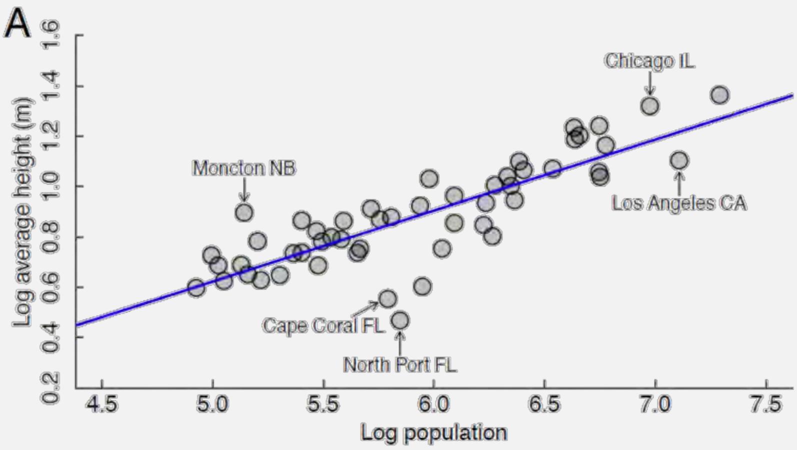

Figure 7 Scaling effects in American cities with respect to building heights and population (Schläpfer, 2017)

An interesting finding was that with artificially imposed height restrictions, as in the case of Washington D.C., building volumes remained the same as cities without height restrictions despite lower average heights.

For the second, Schlapfer used mobile phone data to analyse social interaction networks and track how people move within the city. Data from Boston, Portugal, Senegal and Singapore were used to answer three questions.

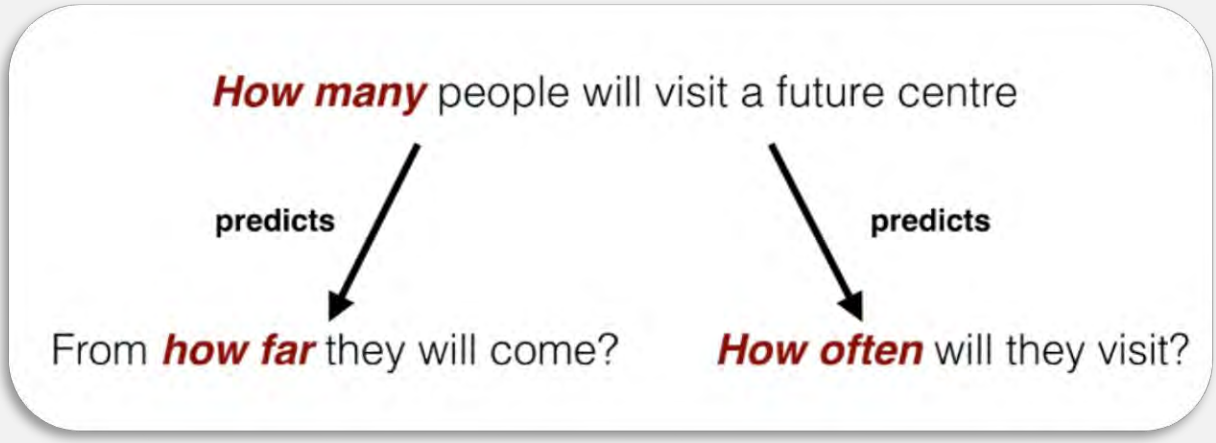

Figure 8 Analysis of social interaction networks using mobile phone data (Schläpfer, 2017)

Figure 9 Derived relationship between travel distance and visiting frequency (Schläpfer, 2017)

As illustrated in the images above, the further away, the fewer the visits; the further away, the lesser the visits. While the findings sound rather unsurprising at first glance, time and distance are factored into a single dimensional equation relating the number of visitors, travel distance from home and visiting frequency. This allows datasets for various locations to be easily plugged in for quantifiable results that might be useful in planning for space capacity.

Applying scaling to Singapore, CLC researcher Zhou Yimin shared some of the centre's preliminary research findings using HDB towns as a unit of analysis. By plotting all the HDB towns and estates on the same graph, some trends emerge (e.g. as our towns get bigger, the less facilities they would require, hence achieving certain economies of scale; the bigger a town is, the higher proportion of residents working farther away from the town), raising questions for further exploration.

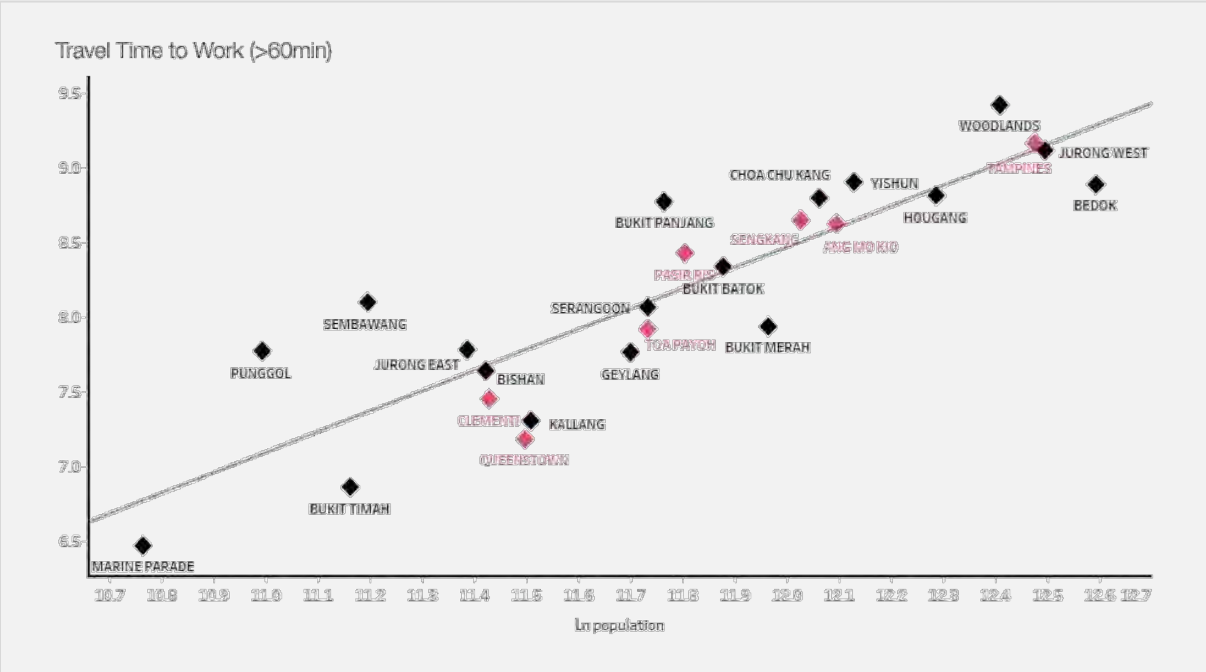

Figure 10 Planning areas with more residents tend to have a more than proportionate number of people that takes more than an hour to travel to work (Centre for Liveable Cities, 2017)

During the workshop, it was acknowledged that extracting the data out of the cultural context and planning paradigms that govern the variables, and purely focusing on correlations and patterns ran the risk of oversimplification. However, simplification enables researchers to take an analytical perspective and identify broader trends (network effects) that might otherwise not be obvious to the naked eye. Subsequently, trends must then be examined within the local context. As cautioned by Mr. Peter Ho, the focus of any research should be on how to make use of the correlations to produce a more complete and accurate reflection of our urban settings.

In addition, some suggestions on possible research directions were raised, including:

1. Using complexity science findings to track the KPIs of agencies for different densities;
2. Benchmarking of different cities and different localities;

3. Establishing and integrating a key set of variables that affect how Singapore develops as a city and a nation; and
4. Construct a platform of matrices, constituted by the variables, to better understand the interconnections among them and test scenarios.

In summary, Chair of the workshop Peter Ho concluded that while past methods have sufficed thus far, the problems that Singapore encounters will only get more complex, requiring more advanced methods of processing and analyzing to make informed decisions. By taking a holistic perspective, planners and policymakers avoid the danger of reducing large problems to small isolated issues. Complexity science comes in useful as it provides a lens and means to identify the links amongst a myriad of seemingly unrelated components, supplementing efforts to populate future scenarios with more accurate information and predictions.

A GUIDE TO CREATING URBAN SOLUTIONS

THROUGH COMPLEXITY SCIENCE APPROACH

How can we harness complexity science to complement data science and create new urban solutions? What are the key concepts that we should always bear in mind? How should we approach future developments in this field?

Complex ≠ complicated The issues that a city faces can be broadly divided into two types, complex, and complicated. First, there are complicated problems which can be addressed by engineering solutions and models. MRT system operations, electricity grids management, building construction, and utility and service deliver can all be classified as complicated engineering problems. Second, there are complex problems, which involve an immense number of causal factors and interdependent components. Using engineering solutions to tackle these complex problems would not be adequate. For example, building more roads in the city does not necessarily alleviate congestions or create better mobility flows, there are social dimensions that would also influence traffic flows such as individual's preferences to the types of transport modes and varying perceptions on walkability.

While cities appear to be shaped by the planning interventions (e.g. land use planning and zoning system), emerging data science is giving us a better way to understand the processes of the city. Analysed through the lens of complexity science, hidden principles that govern the city's spatial and temporal evolution are being revealed and thus, adding a more holistic perspective. After all, cities are planned and developed for its people, who will encounter a whole combination of urban issues that are dynamic and inter-connected.

Adopting this lens implies not only the use of data science, but also the integration of data collected across different agencies in order to appreciate the various implications that a policy can have on society, economy and environment directly, and indirectly. Apart from integrating urban systems, complexity studies would also complement agencies' on-going efforts to create a more robust understanding of urban complexities—by considering the whole urban system and the interactions of its parts—for better planning and provision of urban solutions.

With this in mind, a multi-year collaboration will be worked out between Singapore agencies and experts in Complexity Science to further explore how we can better leverage complexity science and data as effective tools to gain better understanding of complex issues in our city, and discover principles and potential solutions to address those issues.

APPENDIX

The slides presented by the three speakers during the workshop are appended for your information.

Workshop Presentation	Materials
"Discovering the Science of Cities as Complex Systems" by Professor Luis Bettencourt, Santa Fe Institute As an expert and leading researcher on complexity theories and urban development, Professor Bettencourt will be sharing about the ideas and concepts behind the theories and applying them to explain the growth of cities. He has a key part to play in establishing the theory of a city as a complex system and his work has largely been focused on examining the city at an aggregate level to identify patterns of scaling as cities expand. For example, he has established a pattern of non-linear scaling between population growth and a range of indicators, from GDP and housing to transport infrastructure and HIV prevalence.	Cities as Complex Systems_Luis Betten
"From Hidden Patterns to Predictive Models" by Dr. Markus Schlapfer, Future Cities Lab Markus Schlapfer will be presenting on some of his research where he applies complexity theories of urban scaling to various aspects of the urban landscape. Some of his work includes using cell phone data to predict the travel patterns (frequency and travel distance) within and between urban areas. Another area of research examines the relationship between building volume, typology, and height with city size, potentially offering insights into the relationship amongst population density, land rent, housing affordability and liveability.	New insights from big data_Markus Scl
"Complexity in the City, Benchmarking Singapore" by Zhou Yimin, Centre for Liveable Cities CLC's presentation helps to set the context for discussion on how to scope research using data science and complexity tools, to help practitioners develop a scientific approach to complement experience and know-how for planning and development of future projects.	Experimenting with Singapore's Data_Zl

Complexity Workshop 2017 is organised and hosted by Centre for Liveable Cities.

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