DOI: 10.38027/N1ICCAUA2021171

Chapter 14

Network Approach to Understand the Impact of Human Settlement on Ecosystems in Cities

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Introduction

Many have previously pointed to the evolutionary outcome of cities. Gregory Bateson has written on how the flexibility of living systems are, like a tight rope, swaying from one position of stability to another to maintain balance (Mostafavi et al., 2010). A key feature of an ecological understanding of urbanism is the capacity to be reversible, evolving and provisory, owing much to the analogy of nature as a living organism (Mostafavi et al., 2010). The forces that act on an evolutionary process ultimately control patterns of settlement growth and urbanisation as well local and regional biodiversity. However, planning processes often view cities in stasis and without contemplating the system dynamics involved. This leads to one-size-fits-all approaches based on narrow subsections of available data being translated into proposals.

In increasingly urbanised contexts there is a need to understand the relationship between ecosystems capable of sustaining a diversity of animal and plant life and the city, the organism that has evolved to specialise in sustaining human life. The city has long been categorised and understood to be a barrier to the movement and rhythms of ecological elements (Hale., et.al., 2015, Beier., et.al., 2008). The origin of the word 'city' comes from the early word in Proto-Indo-European word for 'enclosure' and this has manifested itself in the walled cities of Medieval and Roman Europe which sought to remove themselves from the wilderness. Meanwhile, the Medieval Latin term 'foris', from which we get the word 'forest' refers to the areas 'outside' the civilised domain of settlement or tilled fields (Tree, 2018). This delineation between natural and urban domains exists deep into European history and culture. However, in other cultures across the world, there are different understandings about the cohabitation of human and animal species. Prevalence of attitudes based on coexistence theory in India decentralises human beings as the source of all value (Nash, 2005). In despite of this the popularity of cultivated gardens proved the determination of European colonisers to bring order and enforce rule and dominion over nature and, by implication, the native inhabitants (Mastnak et al., 2014). This view of nature is highly restrictive and prohibits the role of organic processes in daily life, making them out to be messy and uncivilised.

Kongjian Yu shows how the relationship between the prevailing human attitudes towards cosmetic beauty and gentrification have emanated from a view of the human to be transplanted to the surrounding environment (Yu and Mostafavi, 2010). Yu describes the process by which native, messy and productive shrubs are replaced with fancy flowers that bear no fruit which result in a landscape that is unhealthy, deformed and deprived of functionality (Yu and Mostafavi, 2010). Jenks and Jones summarise the research of CityForm in Sheffield on urban green spaces by suggesting that research from surveys conducted on Sheffield city parks indicate that the psychological benefits of green spaces increase with their biodiversity (Jenks and Jones, 2010). They point to the need for people-nature interactions to "contribute to the targets relating to urban liveability" (Jenks and Jones, 2010). Within this conception of liveability, the interactivity between people and nature has a positive knock-on effect within the ecosystem of the city as the conservation of biodiversity has a positive correlation with the enhancement of public health.

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How to Cite This Chapter:
Asbagh, N. B. (2023). Analysing the Divine Proportion or the Golden Ratio on the Plan and Façade of the Churches in the Walled City of Famagusta, North Cyprus. In H. A. Nia & R. Rahbarianyazd (Eds.), *Convergence of Contemporary Thought in Architecture, Urbanism, and Heritage Studies*, (pp.217-223) Cinius Yayınları. https://doi.org/10.38027/ICCAUA2023EN0024

Defining Sustainability in Systems Thinking

Sustainability is not just a consequence of passive activities. Nature is a series of overlapping cycles of energy transfers, some of which are self-stabilising while others are destabilising and chaotic (Tainter, 1990). There is a need to understand the value of self-sustaining systems when planning, and to look beyond the immediacy of rapid urban development to avoid catastrophic consequences in the natural and human environment. Looking at the design process as a "constellated reality" considers a multitude of actions and reactions between people, energies and resources (Bhabha and Mostafavi, 2010). Within these exchanges, there are synergies and relations which cannot be understood in pure separation. As cities are in a constant state of flux (Paul et. al., 2018), what we observe is a temporary moment in a fluctuating field, otherwise understood as a momentary equilibrium of forces between individuals, collectives and institutions. Within this conception, the order is emergent and not governed by overriding principles but by many complex factors (Batty and Torrens, 2005). If the land is not treated as a living system and is indifferent to flexible approaches, then planning in cities will be static and progress will remain illusory.

Researching the potential of flexible planning processes in the Global South is considered important because of the poor availability of data and maps in these regions (Dempsey and Raman, 2009). GIS data is fundamental in the analytical modelling of cities as it can be used as the basis for advanced spatial and morphometric analysis. In Kochi, Kerala, the authors were involved in a research project gathering data for analysing Kochi's urban form, collating responses to a citizen-led survey and drawing plots and building boundaries from a variety of primary and secondary sources. The research considered the definitions of Liveability and concluded that an important attribute of the 'liveable city' is its capacity to encompass all the inhabitants of the city (Kamalaneson., et. al., 2020). One of the resultant projects explored in greater detail through this paper posits that the human development of Kochi should not be seen in isolation from the conservation of natural ecosystems. Within this conception, the human inhabitants of Kochi are seen to have a symbiotic and dynamic relationship to the native flora and fauna of the region. The threat of a catastrophe in Kochi from rising sea levels caused by climate change as well as the degradation of natural flood defences such as Mangrove forests can be seen as entangled issues relating to the human development of estuarine backwaters.

This research points to the potential of the city to be understood more holistically by integrating system dynamics. Through advances in the computer sciences, complex simulations utilising agent-driven algorithms can explore a variety of outcomes based on different variables. It is hoped that through this research tools can be proposed and developed that might aid planning processes in embracing complexity and enable evidence-based decisions to be made regarding important urban scale initiatives.

While this research acknowledges the limitations of this research is to explore in-depth the mathematics and algorithms underpinning the urban simulations. Instead, we have chosen to focus on simple visual-programming languages such as Grasshopper and Gephi to construct algorithmic explorations.

Network Theory and Complexity

Urban morphology has a considerable impact on resource consumption making it a critical factor for global sustainability. Richard Rogers conceptualised the city as a self-sustaining system. Self-sustaining systems are characterised by their openness and dynamism in consumption and production cycles, with inflows and outflows that can be conceptualised in abstract dynamic systems. This research takes their definition of complex systems from Michael Allen as one that can respond in more than one way to its environment; non-linear processes amplify microscopic heterogeneity which results in emergence (Batty and Torrens, 2005). Michael Batty chiefly advocates this sort of thinking in the field of the social sciences where modernist arguments of objectivity in answering socially important questions have been eroded by the "growing realisation that such certainty is illusory" (Batty and Torrens, 2005). Batty also draws the distinction between simulation and modelling suggesting "simulation differs from modelling in that simulations are dynamic and open-ended" (Batty and Torrens, 2005).

Cities can be understood in dynamic urban simulation models through exploring the relationships between "organisms, built structures and their natural environments" (Forman, 2013). When the city is understood as a "structural network composed of critical landscape elements and spatial patterns", the consequences of urban planning variants can perhaps be simulated (Yu and Mostafavi, 2010). To achieve this the authors attempted to reproduce the interactions between human populations and ecological networks through an agent-driven algorithmic model which explores bottom-up mathematical phenomena.

The early models used in the simulation and prediction of urban development find their origin in the work of John Conway and his influential 'Game of Life' which consisted of a two-dimensional orthogonal grid of cells (Gardner, 1970). Each cell has a possible state: dead or alive. Further to this, a set of four rules based on the neighbouring cell's state determines whether the cell is dead or alive in the next iteration of the simulation.

This very simple setup allows a wide variety of emergent patterns after the program runs for several generations. These bottom-up phenomena played out in the orthogonal grid have subsequently taken the attention and fascination of urban designers. Krawczyk describes cellular automata as "the computational method which can simulate the process of growth by describing a complex system by "simple individuals following simple rules" (Krawczyk, 2002). This relation to real-world phenomena becomes apparent when realising the development of form and land use patterns in cities are, like the cells in Conway's grid, influenced by the interaction of agents through bottom-up processes informed by simple rules.

Koenig et al proposes an integrated system dynamics simulation using the stocks and flows approach to represent aspects of urban systems. They propose a theoretical framework of urban metabolism as a "model to facilitate the description and analysis of stocks and flows of the materials and energy within cities... [to] provide researchers with a metaphorical framework to study the interactions of natural and human systems in specific regions" (Koenig et al. 2018). Complexity and energy are related in a helix spiral where increased complexity demands greater energy at an increasingly greater cost to human civilisation (Tainter, 1990). Although elaboration of structure and control mechanisms can occur concurrently with emergent phenomena, rapid simplification can occur when a complex system grows more complex and costly than can be sustained. Understanding these patterns of growth and collapse underpins the logic of using rules-based in the explorations of Koenig et al and was an important aspect to take forward into a dynamic urban development model.

Material and Methods

The authors are particularly interested in the interactions of natural and human systems concerning the rapid expansion and urbanisation of Kochi. The development of human settlements on the fringes where human and animal species coexist has caused severe interferences with local ecosystems that result in a loss of biodiversity. The gradual erosion of green areas in the city of Kochi due to intense densification in the Ernakulam region and the urban sprawl at its peripheral edges means that ecological corridors for biodiversity have been fragmented. It is therefore proposed that a tool for finding opportunities for greater landscape connectivity at the urban level could be beneficial to the city through improving the vitality of the population and species richness.

Through the aggregation of urban information found within a geographical area, it is possible to trace the changes in land use and make critical assumptions on the inter-relationships of land use patterns. These rules can be extrapolated through analysing the interdependencies, balances and imbalances within a network graph of the relationships between individuals, collectives and institutions found within the city network. The city network, produced through analysis of stakeholder and ecological dependencies, can be used to test empirically the results of omitting certain individuals and perceiving the resultant dominance or centrality of a different individual. Network analysis can be produced using the Gephi open-source graph tool, allowing us to understand centralities and dependencies. A spatial network is defined formally as a graph, composed of nodes and edges, where the nodes represent an individual within abstract space and the edges represent connections or interactions between nodes.

Initially, we tested this approach when trying to understand the coalescence of literature sources about liveable cities. The approach consisted of textual analysis, parsing text from literature sources through a word cloud generation script in R and then using Tableau to examine the relationships between texts. This method allowed for a decentralised analysis of the relationships between textual sources with centralities appearing as emergent as opposed to the more unreliable subjective narration of similarities. However, a shortcoming of this method was despite the cleaning of the data to purge common words that would distort the analysis, and yet we found that results were not completely reliable and needed further interpretation. The conclusion was made that for greater reliability of this method, relationships within a network graph would need to be defined based upon evidence as opposed to semantic similarity.

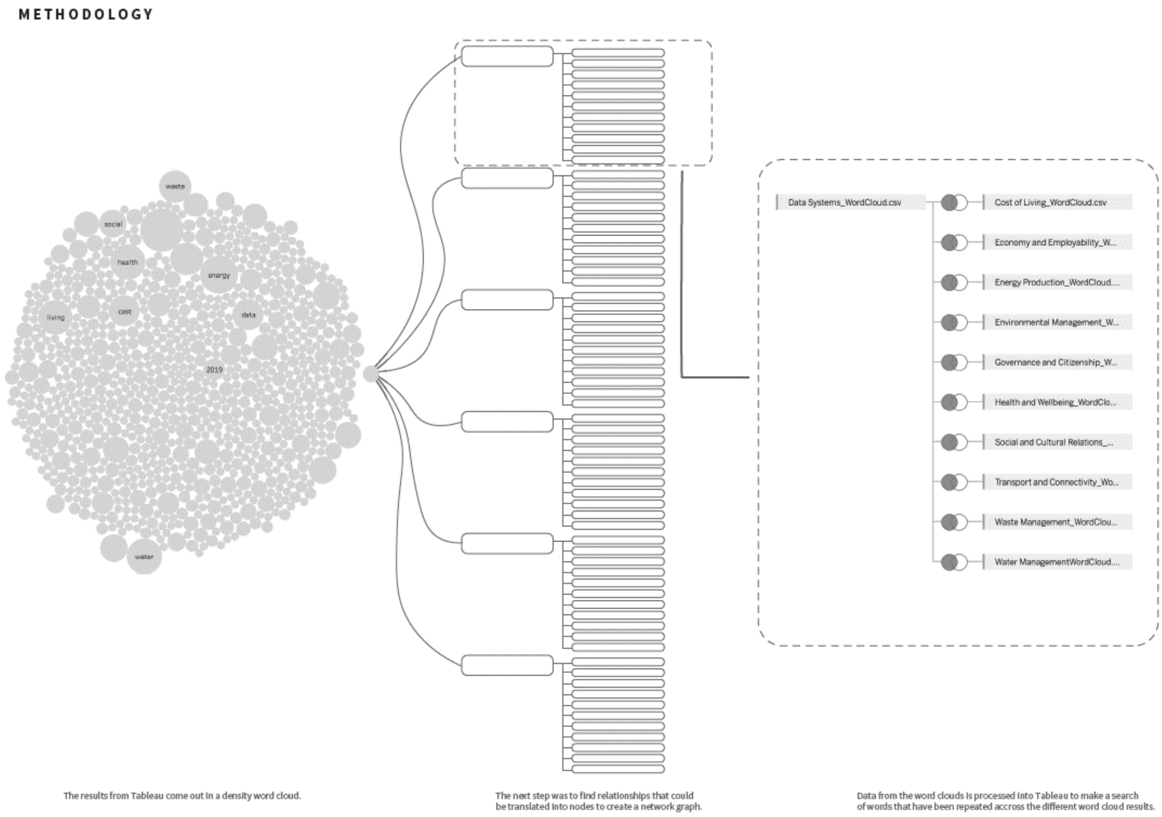

Figure 1. Textual analysis using network theory.

In the next step, we decided to take this approach forward by creating a network model for the stakeholders of Kochi through interpreting the ecosystem threats and opportunities of Kochi (Rode and Balasubramanian, 2018) and connecting a variety of stakeholders within an ecosystem related to their common threats and opportunities. Through a network analysis of the resultant centralities, it was possible to understand the emergent issues of most importance to the city which clustered around the agricultural and fishing industries. Understanding the relationships between human agencies in the city of Kochi goes some way in exploring, through systems thinking, how the city might be approached by an urban designer. However, by abstracting the network of human actors within the complex system of the city from the other life forms and their networks there is the danger, as Capra describes, "of viewing humans above or outside nature" (Capra and Luisi, 2014). In order to understand the interconnectedness of species in Kochi, it was assumed that a species audit would form a strong comparative analysis of what was achieved in the stakeholder network.

Collating data for the species network for this research was achieved through tabulating the 231 species found in several surveys of the Mangalavanam, an ecologically sensitive site in the heart of the Ernakulam region of Kochi. The surveys were produced by ornithology and natural history institution, SACON. Through linking the species based on predation information found on the India Biodiversity Portal, IBP, a network graph was produced. The results of this network graph allowed us the ability to have greater insight into ecological scenarios through understanding that the Mangrove species *Bruguiera gymnorrhiza* is the most interconnected species through the measure of Betweenness Centrality, the measure of centrality based on the shortest path. Mangrove flora also scored highly on Eigenvector Centrality, the measure of influence on a network.

Gathering Datasets

In order to understand the dynamics of human and natural populations, we identified a need for datasets capturing human population density as well as green space density in an area of Kochi. Trying to gather data of this description in the global south, where access to data is poor and often not openly accessible lead the researchers to use novel methods of data gathering. For the population data authors used WorldPop, an open-source demographic dataset that spatially aggregates census data into a GIS dataset with a resolution of 30m (Bondarenko et al., 2020). A similar resolution was derived from remote sensing datasets from Landsat-MODIS satellites monitoring seasonal evapotranspiration which is the cooling effect of green infrastructure in cities (Bhattarai et al. 2015). The resulting raster datasets were processed in QGIS and densities were transcribed to land parcels using the zonal statistics function. This allowed the researchers to have visualised datasets of the city with 'live' values for biodiversity and population densities in each land parcel of the city.

Figure 4. Visualised datasets of population density (left) and Evaporative Stress Index (right)

Constructing a Simulation

After going some way to understand the interdependencies and relationships between species and stakeholders, we turned their attention to enacting these relationships spatially within the geography of the city. This process aimed to dynamically generate spatial potentialities on an urban level if population dynamics were to follow a simple mathematical model. The statistical model that was selected for the simulation was the Wolf-Sheep predation model, accessed through NetLogo, an open-source repository of agent-driven simulations (Wilenksy, 1997). The appropriateness of this statistical model was appraised based on its prevalence in the natural world but was reconfigured by a novel way to represent human dependency on nature through consumption of natural resources and the inverse threat of extinction through habitat destruction. The integration of this statistical model into a spatial exploration was aided greatly by the prior explorations of Koenig et al with the Decoding Spaces Toolbox. Similar to Koenig et al, we sought to integrate the land parcels of the urban area as areas of differing attractivity for different populations. It was anticipated that the interactivity of these populations would point spatially towards areas of the city that, based on their centralities, would be attractive for consumption by humans and nature.

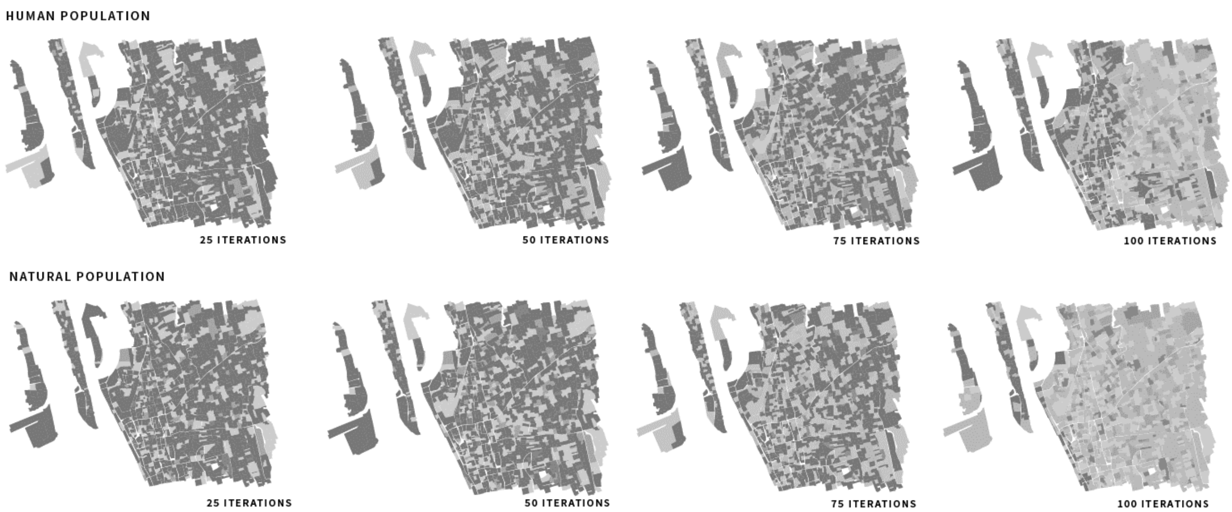

Figure 5. Simulation across 100 iterations (Developed by Author).

Discussion and Conclusion

The results of the simulation showed that after 100 iterations of the simulation natural and human populations had clustered in different neighbouring patterns across the urban area of Ernakulam. Whereas the natural populations seemed to be evenly dispersed through the city the human population densities seem to reinforce the existing datasets. This shows that in areas where humans had vacated, such as the Mangalavanam, natural populations had a stronger selection factor. This reinforces the justification for allowing areas of low utility for human occupation to be left fallow for natural populations to rebuild and disperse in the spaces between human occupation.

The shortcomings of this simulation are that the vectors for movement for both human and animal species were based upon the street network. We do acknowledge that the movement of animal species is not restricted to streets and footpaths in the same way that it is for humans. Further development of this model would be to enable vectors of interaction not confined to the street network to better analyse the evolution of biodiverse spaces in cities. Further development is needed to embrace the complexity of species movement, growth and predation in cities, but it is hoped that the research described forms a basis for future conversations between researchers. The more data that is fed into these simulations the greater the chance of accurately justifying bottom-up interactions between agents. These methods are flexible and can assist different researchers from different backgrounds to work collaboratively on solutions in cities with an emphasis on systemic thinking as a response to ecological issues. There's a need for these tools to be open and democratic as well as being able to be used effectively by planners without technical expertise. This will require further development in order to integrate the complex algorithmic explorations into a user-friendly platform.

Acknowledgement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interests

The author declares no conflict of interest.

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