LIVING STRUCTURES ACROSS URBAN HIERARCHIES: A COMPARATIVE STUDY OF FIVE SRI LANKAN CITIES

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Abstract: This study explores Living Structure, originated by Christopher Alexander and further developed by Bin Jiang, within urban settings, particularly in Sri Lanka. Utilizing building footprints as proxies for human movement, the research employs a quantitative approach to analyze and compare Living Structure patterns across Sri Lankan cities. Results demonstrate the presence of Living Structure characteristics in all case study cities, manifested through fitting power law distributions. Notably, historical cities such as Anuradhapura, Kandy, Jaffna, and Galle exhibit stronger Living Structure rankings compared to the newly developed city of Hambantota. These variations are attributed to historical backgrounds and the pace of urban development, with established morphologies supporting Living Structure patterns in historical cities. Beyond academic inquiry, the study offers practical implications for urban planners and decision-makers by illuminating the dynamics behind thriving cities and addressing identified knowledge gaps. By integrating Living Structure principles into urban planning strategies, cities can evolve sustainably over time. Through comparative analyses and exploration of Living Structure evolution within specific cities, the research contributes valuable insights into urban dynamics, guiding future planning efforts

Keywords: *Head/tail breaks, Living Structure, livingness of space, wholeness, natural cities, urban morphology*

1. Introduction

The "Living Structure" (LS) concept delves into the intricate similarities between cities and the human body, emphasizing their shared organizational patterns and adaptive qualities. Researchers like Huang and Bin Jiang have explored how both cities and living organisms manage to survive and evolve over time, with cities like Amsterdam and Venice embodying this concept through their timeless appeal and dynamic interaction with their past. Christopher Alexander, a pioneer of LS, argued that cities with a strong LS are not only visually attractive but also deeply connected to their inhabitants and environment, functioning like living organisms. He critiqued the Cartesian worldview, which he believed failed to create enduring cities, and proposed LS as an alternative framework for fostering more coherent and holistic urban environments. The concept of LS, as elucidated by Alexander, has become a focal point in the discourse of urban planning and design. Alexander's theoretical groundwork has prompted scholars like Jiang to delve into mathematical models and graphs, offering a quantitative lens to measure and visualize the theory of LS in real-world contexts. Bin Jiang's contributions, particularly in introducing various methods and studies, have paved the way for a comprehensive understanding and assessment of LS within urban environments.

The concept of "LS" represents a profound exploration into the evolution and dynamics of cities, drawing parallels between urban development and the biological processes of living organisms. Scholars such as Huang (2023) and Bin Jiang (2012) have made interesting comparisons between cities and human anatomy, highlighting shared organizational patterns and complexities. Cities like Amsterdam and Venice exemplify this concept, embodying an everlasting attraction that attracts inhabitants of all ages (Salingaros, 2015). The essence of "LS" extends beyond mere physical form; it delves into the complex functionality of cities, elucidating their purpose in serving the needs of their residents. Christopher Alexander, a pioneering figure in this field, underscores the importance of cities possessing a strong LS, characterized by a profound connection between inhabitants and their environment (Alexander, 1980).

The evolution of the LS concept traces back to Christopher Alexander's earliest works in the 1960s and 1970s. Alexander introduced the notion of a "Pattern Language," providing a framework for addressing design challenges in the built environment (Alexander, 1977). Subsequent publications such as "The Timeless Way of Building" expanded upon this idea, emphasizing the qualities of bringing life and unity to spaces (Alexander, 1980). Alexander's exploration culminated in the "Nature of Order" series, which explored the properties essential for creating LS (Alexander, 2001-2004). Building upon Alexander's foundation, contemporary researchers like Bin Jiang have developed mathematical models and graphs to visualize and analyze the LS concept (Jiang, 2012).

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Key to understanding LSs are fundamental laws such as the Scaling Law and Tobler's Law, elucidated by Bin Jiang. The Scaling Law posits that cities exhibit a prevalence of smaller structures over larger ones, while Tobler's Law emphasizes the proximity of related entities (Jiang, 2019c). These laws are underpinned by the 15 structural properties identified by Alexander, forming the basis for theoretical frameworks in urban analysis (Jiang & de Rijke, 2021). Additionally, methodologies like the Head/Tail Index offer insights into hierarchical organization within urban systems (Jiang, 2013b). Power Law Distribution further enriches our understanding, revealing the relationship between substructure size and frequency (Jiang & Slocum, 2020).

Calculating LS involves synthesizing various parameters such as substructures and hierarchical levels. This quantification facilitates comparisons between different urban entities, shedding light on their relative vitality and coherence (Jiang & Huang, 2021). However, applying these methodologies at scale presents challenges, necessitating significant resources and expertise. Despite limitations, LS analysis offers valuable insights into urban dynamics and evolution.

Ongoing research endeavors continue to refine the understanding of LS and its implications. Scholars explore diverse methodologies, from analyzing connectivity patterns to leveraging geospatial big data (de Rijke et al., 2020; Ren et al., 2024). Natural cities, derived from geographic information datasets, serve as foundational units for studying urban morphology and evolution (Jiang & Miao, 2015). Novel approaches, such as utilizing nighttime imagery and location-based services, offer alternative perspectives on urban dynamics (Jiang & Yin, 2014). Moreover, methodologies like Structural Beauty analysis and Power Law Distribution enable researchers to assess LS across diverse contexts (Jiang & de Rijke, 2021).

While these studies yield valuable insights, they also face limitations. Challenges include data availability, methodological complexity, and scalability issues (Jiang, 2015c). Additionally, ensuring the representativeness and reliability of derived natural cities remains a concern. Despite these challenges, ongoing research efforts contribute to a deeper understanding of LS and its implications for urban planning and design. Incorporating previous studies on Living Structure (LS), it is crucial to measure LS across various hierarchical levels. There are two main reasons for this: First, it enables planners and practitioners to assess whether LS characteristics are present at each level of the city's hierarchy and identify where they might be lacking. Understanding where LS is missing allows for analysis of the underlying reasons for its absence. Second, by comprehending the city's LS across different hierarchical levels, planners can address disparities within the city's structure, leading to more balanced and effective urban planning.

This study aims to bridge this gap by investigating how the concept of "LS" applies to diverse urban contexts, particularly in Sri Lanka. Existing studies, rooted in concepts by Christopher Alexander and expanded by Bin Jiang (Jiang 2013a), often overlook the dynamic interplay across hierarchical levels within the same city. Consequently, this research seeks to address this oversight and shed light on the LS characteristics across various hierarchy levels (Jiang & Chris, 2023) , crucial for a holistic city assessment. Furthermore, a notable gap exists in neglecting buildings as proxies when comparing cities. Given their pivotal role in shaping urban character, this study adopts a comprehensive approach, utilizing buildings to measure LSs and rectifying this gap (Jiang,2013a). The practical implications of this research extend to urban planners in Sri Lanka to incorporate LS concepts in the planning disciplines.

2. Methodology

The methodology employed in this research focuses on assessing the LS within Sri Lankan cities, employing a comprehensive approach that integrates quantitative and qualitative analyses. The selection of case studies Jaffna, Anuradhapura, Kandy, Hambantota, and Galle was based on their unique characteristics and diverse urban contexts, ensuring a holistic comparison of LSs. Jaffna, for instance, was chosen due to its isolated nature and rich historical significance, while Anuradhapura represents a city with extensive blue-green areas and historical importance. Kandy, recognized as a UNESCO World Heritage Site, serves as a central hub in the country's transportation network, while Hambantota showcases significant infrastructure development and coastal connectivity. Galle, with its historic Dutch fort and strategic location, adds to the diversity of the selected case studies. Data collection primarily relied on building footprints (BFP) extracted from the Google Open Buildings dataset using Google Earth Engine. Various confidence levels were utilized to detect BFPs, ensuring data reliability. To ensure the reliability and validity of the building footprints extracted from the Google Open Buildings dataset using Google Earth Engine, a confidence score threshold to include only high-confidence detections. The building layer extracted to the extent of the case study area.

To assess the ranking of living structures (LSs) across all case studies, the TIN analysis will be followed by applying the "Head-Tail Rule. The methodology's strength lies in its systematic approach, combining advanced spatial analysis techniques with theoretical frameworks such as scaling law and Tobler's law. By leveraging BFP data and TIN analysis, the research achieves a nuanced understanding of LSs within Sri Lankan cities. By identifying the shortest edge, the first hierarchical level is determined. Building on this, the incorporation of power law distribution and the LS formula adds depth to the analysis, enabling both quantitative assessment and qualitative insights. To address the challenges of merging and comparing data from diverse case studies, this methodology applies a uniform approach to data collection and analysis across all cities involved. The same method can then be applied to the next hierarchical level identified in the initial step. The study focuses on three hierarchical levels: large, medium, and small cities, ensuring a comprehensive examination across different urban scales. Historical significance or infrastructure development are some of the unique aspects that need to be taken into consideration by applying the LS formula to every case study as well as spatial analysis techniques. As such, the comparative analysis will be strong, dependable and revealing for urban differences in each city that are unique and also allow constructive cross-case comparisons. Overall, this methodology sets a robust foundation for analyzing LSs, paving the way for valuable insights into urban dynamics and facilitating informed decision-making in urban planning and development contexts.

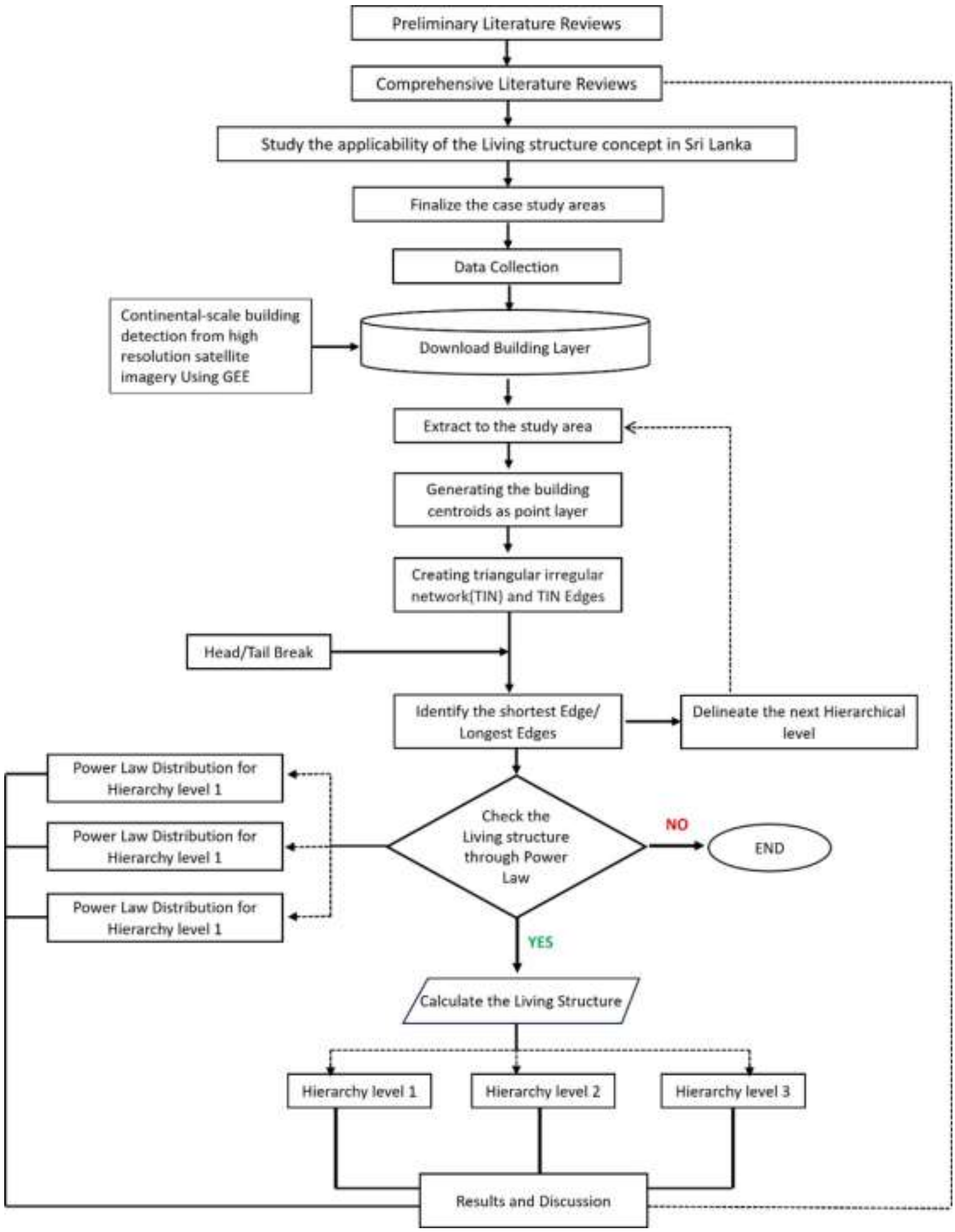

Figure 1, Formulated methodology of the research

3. Analysis

The analysis part started after collecting and processing the building data from the Google Earth engine. TIN analysis needs to be applied to ensure Tobler's law (Jiang,2015). Triangular Irregular Network (TIN) analysis facilitated the identification of natural cities based on the proximity of buildings, reflecting their organic connectivity rather than rigid rules. The TIN edges formed the basis for head/tail breaks analysis (figure 2), aligning with the scaling law principle, which emphasizes the prevalence of smaller structures over larger ones. The head/tail breaks classified natural cities based on the shortest edges, highlighting the fundamental principles of LSs.

Power law distributions were generated using head/tail breaks calculated in the preceding section. Figure 2 displays the head/tail classification of the larger city of Jaffna, serving as the basis for plotting the power law distribution. The x-axis and y-axis represent the "size of substructure" and "number of substructures," respectively, derived from Tin edges data and the aforementioned head/tail distributions.

#Data	#head	%head	#tail	%tail	mean
541905	132762	24%	409143	76%	68.12875902
132762	23296	17%	109466	83%	172.243206
23296	3835	16%	19461	84%	516.7014596
3835	702	18%	3133	82%	1802.69818
702	158	22%	544	78%	6016.19342
158	44	27%	114	73%	16673.48413
44	15	34%	29	66%	33453.55813

Figure 2, Head/Tail break classification table of Larger city in Jaffna (Source: Compile by author)

The power law distribution graph provides insights into the relationship between the size of substructures and their frequency in the larger city of Jaffna. The logarithmic transformation aids in visualizing patterns that may follow a power law distribution. By analyzing this graph, the research can assess whether the living structure pattern is evident and, if so, to what extent. The (L*H) formula , where L represents substructures and H denotes the head/tail index, has been applied to assess and rank living structures across all case studies at multiple levels.

Living Structure (LS)= Substructures(S) × H-T index(H) (1)
Living Structure (LS)= 541905 × 8
= 43335240

This approach provides a detailed evaluation by considering both the size and distribution of substructures. The resulting Living Structure values, alongside power law distribution analyses, will be discussed to offer a comprehensive understanding of how living structures vary across different cities. This combined quantitative and qualitative analysis sheds light on the dynamics of living structures in diverse urban settings.

4. Results

As discussed in the previous chapter, the comparison of LSs among the five main cities in Sri Lanka provides valuable insights into urban organization and development. These cities, namely Jaffna, Kandy, Anuradhapura, Galle, and Hambantota, each exhibit distinct characteristics and historical significance. The analysis in this chapter aims to elucidate the findings through two primary approaches. Firstly, the comparison is conducted across different hierarchy levels within each city, examining variations in LS patterns. Secondly, the focus shifts to inter-city comparisons within the same scale level, highlighting disparities and similarities.

Beginning with Jaffna, a city renowned for its unique heritage and cultural identity, the examination reveals a consistent adherence to power law distributions across large, medium, and small scales. The calculated alpha values of 1.4799, 1.7753, and 1.8234 (figure 3) respectively, underscore a well-organized living pattern across different city sizes. The H-T index further corroborates these findings, with the large-scale city exhibiting a significantly higher LS compared to its medium and the ranking order remains consistent, emphasizing the scalability of the LS pattern within Jaffna.

Moving on to Anuradhapura, a city steeped in historical significance and sacred sites, similar trends in LS patterns emerge across all three scales. The power law distributions highlight the dominance of large-scale cities in terms of LS, with medium and small-scale cities exhibiting proportional decreases. The ranking order reflects this trend, with the large-scale city boasting significantly higher LS values compared to its counterparts. The underlying factors, including the number of substructures and H-T indices, contribute to these variations, further validating the observed patterns. compared to its counterparts. The underlying factors, including the number of substructures and H-T indices, contribute to these variations, further validating the observed patterns.

In Kandy, renowned for its rich history and cultural traditions, a striking power law distribution characterizes the LS across all scales. The pronounced disparities in LS values among large, medium, and small-scale cities underscore the hierarchical nature of urban organization. Factors such as the H-T index and the number of substructures elucidate the underlying mechanisms driving these variations, highlighting the intricate interplay between urban morphology and spatial organization. Transitioning to Hambantota, a city known for its well-developed infrastructure and coastal location, deviations from expected LS patterns become apparent. Despite following power law distributions, medium and small-scale cities exhibit lower alpha values, indicating a departure from the norm observed in other case studies. The disparity in LS values between large-scale and medium/small-scale cities underscores the hierarchical nature of urban development, with large-scale cities commanding significantly higher LS values.

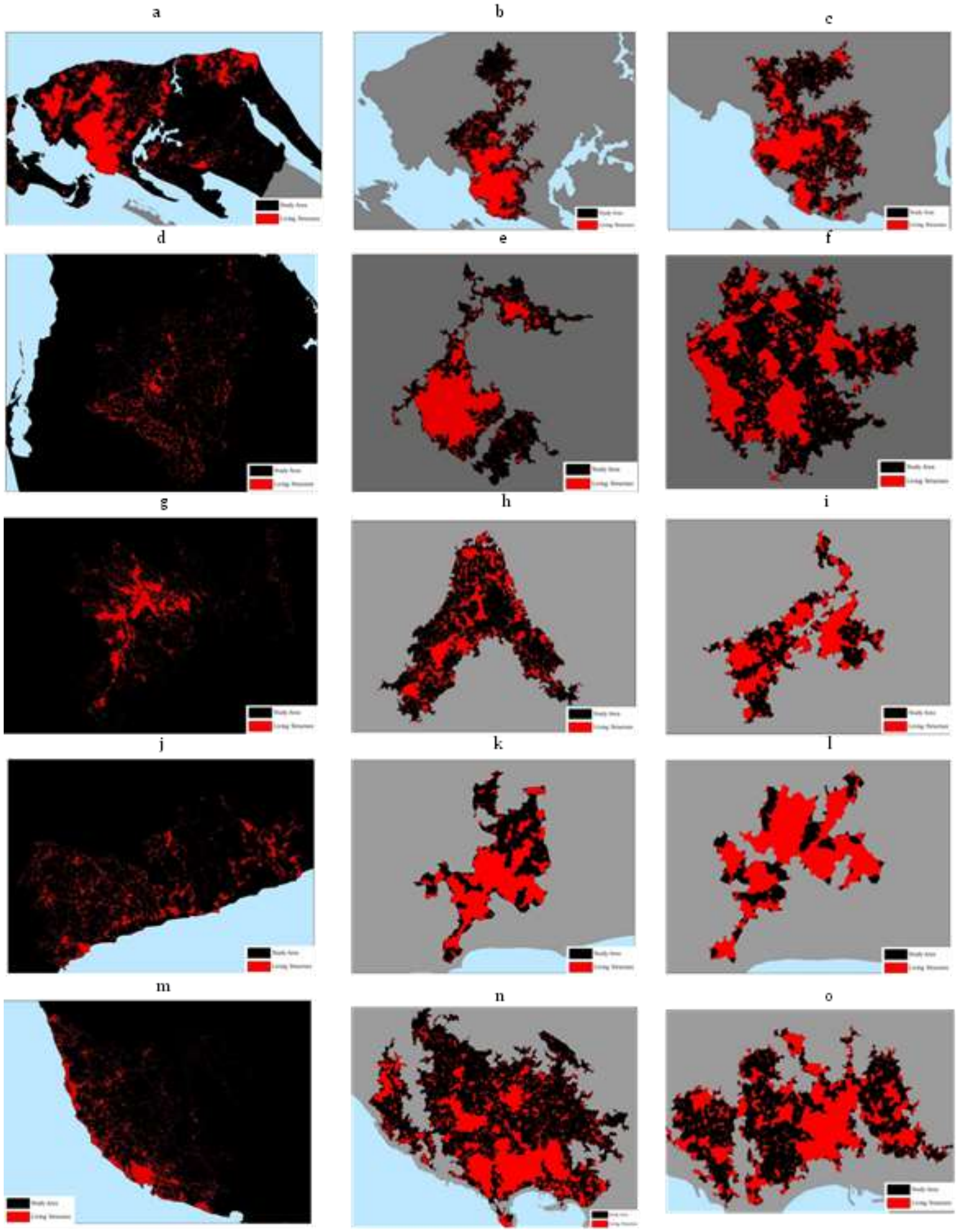

Figure 3,Visualization of Living Structure (See the below matrix for more information)

City	Large Scale	Medium scale	Small Scale
Jaffna	a	b	c
Anuradhapura	d	e	f
Kandy	g	h	i
Hambantota	j	k	l

In Galle, characterized by its coastal charm and rich cultural heritage, consistent power law distributions underscore the LS patterns across all scales. However, disparities in LS values among large, medium, and small-scale cities highlight the hierarchical nature of urban organization. The nuanced interplay between natural sites and urban morphology elucidates the observed patterns, emphasizing the importance of context-specific factors in shaping urban form and function. In conclusion, the comparative analysis of LSs among the five main cities in Sri Lanka provides valuable insights into urban organization and development. Despite variations in geographical context and historical significance, consistent patterns emerge, highlighting the hierarchical nature of urban development and the influence of contextual factors on urban morphology and spatial organization. Further research into the underlying mechanisms driving these patterns is warranted to inform more effective urban planning and development strategies in the region.

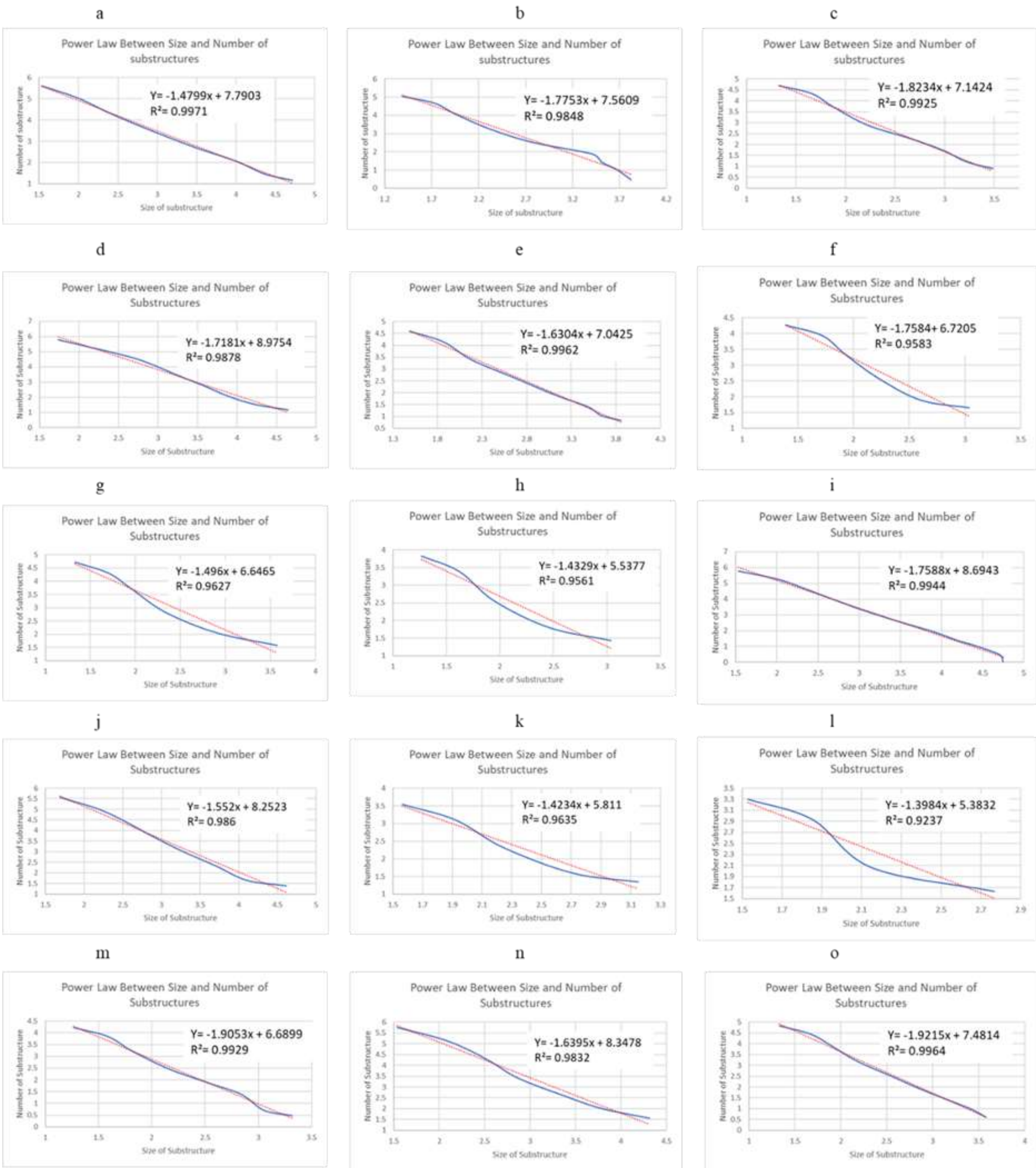

Figure 4, Power Law Distribution of the case studies(See the below matrix for more information)

City	Large Scale	Medium scale	Small Scale
Jaffna	a	b	c
Anuradhapura	d	e	f
Kandy	g	h	i
Hambantota	j	k	l
Galle	m	n	o

5. Discussion and Conclusion

Our comparative analysis reveals that all selected case studies exhibit distinct LS patterns across various scales. The application of the LS (LS) formula, combined with power law distribution analysis, confirms that each city adheres to the concept of LS, with power-law exponents falling within the expected range ($1<\alpha<3$). This finding suggests that while the cities may not perfectly meet ideal standards, they fundamentally align with the principles of LS, particularly the prevalence of smaller structures over larger ones (Scaling Law) and the principle that "everything is related to everything else, but near things are more related than distant things" (Tobler's Law). These results demonstrate that the cities are capable of evolving to better serve their inhabitants, even amidst ongoing development.

Upon comparing cities within the same hierarchical level (Tabel 1), it was found that large-scale cities consistently ranked higher than medium and small-scale cities in terms of LS. This ranking is primarily influenced by the number of substructures and the head/tail (h-t) index. Large-scale cities, such as Kandy and Anuradhapura, display a more robust power law distribution, indicating a higher probability of following fundamental urban laws. Conversely, the small-scale cities, often impacted by recent developments, show a reduction in LS, which contributes to their lower ranking. When comparing large-scale cities across the case studies, Kandy, Anuradhapura, Galle, and Jaffna ranked highest, while Hambantota ranked lowest. Interestingly, the medium and small-scale cities of Hambantota display a significantly lower degree of LS compared to their counterparts in other cities. This deviation is reflected in a poor power law fit, with alpha values closer to one, indicating a weaker alignment with the principles of LS.

Table 1: Overall Comparison of Living Structure

Case study	City Level	Living Structure	Rank(LS)	Alpha Value of Power Law Distribution
Anuradhapura	Large scale	6907419	2	1.7181
	Medium scale	451464	10	1.6304
	Small scale	178344	12	1.7584
Kandy	Large scale	9330585	1	1.7588
	Medium scale	475752	9	1.496
	Small scale	47345	13	1.4329
Jaffna	Large scale	4335240	4	1.4799
	Medium scale	1725680	6	1.7753
	Small scale	605240	8	1.8234
Galle	Large scale	6355360	3	1.6395
	Medium scale	1048020	7	1.9215
	Small scale	202224	11	1.9053
Hambantota	Large scale	4111784	5	1.552
	Medium scale	25300	14	1.4234
	Small scale	11936	15	1.3984

The long-evolved urban context of these cities plays a significant role in these findings. Cities such as Kandy, Anuradhapura, Jaffna, and Galle have undergone organic development over extended periods, resulting in established urban patterns that contribute to their strong LS. In contrast, Hambantota, a newly developed city, faces structural challenges commonly associated with artificially planned urban environments. This distinction aligns with existing research suggesting that cities with organic, long-term growth maintain more resilient LSs, while newer, 'artificially' developed cities tend to encounter structural issues.

The findings of this study have significant implications for urban planning in Sri Lanka. By analyzing LSs across different hierarchical levels, planners can better understand the dynamics of urban environments. This understanding enables more informed decisions that can strengthen the resilience and sustainability of cities. For instance, preserving the established morphological patterns of historical cities like Anuradhapura and Kandy can help maintain their LSs, while careful planning is needed to address the structural issues in newly developed cities like Hambantota. Incorporating the principles of LS into urban planning can lead to cities that not only survive but thrive over time, offering enhanced liveability and sustainability for future generations.

6. References

Alexander, C. (1980). *The timeless way of building.* Oxford University Press.
Alexander, C. (2002). *Notes on the synthesis of form.* Harvard Univ. Press.
Alexander, C. (2003). *The nature of order : an essay on the art of building and the nature of the Universe. 1, The phenomenon of life*. Center For Environmental Structure.
Clauset, A., Shalizi, C. R., & Newman, M. E. J. (2009). *Power-Law Distributions in Empirical Data.* SIAM Review, 51(4), 661–703.

De Rijke, C. A., Macassa, G., Sandberg, M., & Jiang, B. (2020). *Living Structure as an Empirical Measurement of City Morphology*. ISPRS International Journal of Geo-Information, 9(11), 677.
Jacobs, J. (1961). *The Death and Life of Great American Cities*. Vintage Books.
Jayasinghe,A.B,,Munasinghe,J.N. (2014). *A Study of the Urbanizing Pattern in Kegalle District, Sri Lanka with Connectivity Analysis*. ISSN International Journal of Scientific Knowledge, 2(1), 2305-1493.
Jiang, B. (2013a). *The Image of the City out of the Underlying Scaling of City Artifacts or Locations*. Annals of the Association of American Geographers, 103(6), 1552–1566.
Jiang, B., & Sui, D. Z. (2013b). *A New Kind of Beauty Out of the Underlying Scaling of Geographic Space*. The Professional Geographer, 66(4), 676–686.
Jiang, B. (2013b). *Head/Tail Breaks: A New Classification Scheme for Data with a Heavy-Tailed Distribution*. The Professional Geographer, 65(3), 482–494.
Jiang, B., & Yin, J. (2013). *Ht-Index for Quantifying the Fractal or Scaling Structure of Geographic Features*. Annals of the Association of American Geographers, 104(3), 530–540.
Jiang, B., & Miao, Y. (2014*). The Evolution of Natural Cities from the Perspective of Location-Based Social Media*. The Professional Geographer, 67(2), 295–306.
Jiang, B. (2015a). *Wholeness as a hierarchical graph to capture the nature of space*. International Journal of Geographical Information Science, 29(9), 1632–1648.
Jiang, B. (2015b). *Head/tail breaks for visualization of city structure and dynamics*. Cities, 43, 69–77.
Jiang B. (2015c), *Axwoman 6.3: An ArcGIS extension for urban morphological analysis*, https://livablecitylab.hkust-gz.edu.cn/binjiang/Axwoman/, University of Gävle, Sweden.
Jiang, B. (2016). *A complex-network perspective on Alexander's wholeness*. Physica A: Statistical Mechanics and Its Applications, 463, 475–484.
Jiang, B. (2017). *A Topological Representation for Taking Cities as a Coherent Whole*. Geographical Analysis, 50(3), 298–313.
Jiang, B., & Ren, Z. (2018). *Geographic space as a living structure for predicting human activities using big data*. International Journal of Geographical Information Science, 33(4), 764–779.
Jiang, B. (2019a). *Living Structure Down to Earth and Up to Heaven: Christopher Alexander*. Urban Science, 3(3), 96.
Jiang, B. (2019b). *Natural Cities Generated from All Building Locations in America*. Data, 4(2), 59.
Jiang, B. (2019c). *A Recursive Definition of Goodness of Space for Bridging the Concepts of Space and Place for Sustainability*. Sustainability, 11(15), 4091.
Jiang, B., & Slocum, T. (2020). *A Map Is a Living Structure with the Recurring Notion of Far More Smalls than Larges*. ISPRS International Journal of Geo-Information, 9(6), 388.
Jiang, B., & de Rijke, C. (2021). *Structural Beauty: A Structure-Based Computational Approach to Quantifying the Beauty of an Image*. Journal of Imaging, 7(5), 78.
Jiang, B. (2021). *Geography as a science of the earth's surface founded on the third view of space*. Annals of GIS, 28(1), 31–43.
Jiang, B., & Huang, J.-T. (2021). *A new approach to detecting and designing living structure of urban environments*. Computers, Environment and Urban Systems, 88, 101646.
Jiang, B., & Chris de Rijke. (2022). *Representing geographic space as a hierarchy of recursively defined subspaces for computing the degree of order*. Computers, Environment and Urban Systems, 92, 101750–101750.
Jiang, B., & Chris de Rijke. (2023). *Living Images: A Recursive Approach to Computing the Structural Beauty of Images or the Livingness of Space*. Annals of the American Association of Geographers, 113(6), 1329–1347.
Jiang, B. (2023, January 1). *Chapter 3 - A new kind of GeoInformatics built on living structure and on the organic view of space* (N. Stathopoulos, A. Tsatsaris, & K. Kalogeropoulos, Eds.). ScienceDirect; Elsevier
Lynch, K. (1960). *The image of the city*. The MIT Press.
Mehaffy, M. W. (2019). *Assessing Alexander's Later Contributions to a Science of Cities*. Urban Science, 3(2), 59.
Ren, Z., Jiang, B., & Seipel, S. (2019). *Capturing and characterizing human activities using building locations in America*. International Journal of Geo-Information, 8(5), 200
Ren, Z., Seipel, S., & Jiang, B. (2024). *A topology-based approach to identifying urban centers in America using multi-source geospatial big data*. Computers, Environment and Urban Systems, 107, 102045.
Salingaros. (2015). *Living Structure Comes from (Living) Patterns, Parts 1 and 2*. Journal of Urban Design, 4.