

Computational Analytical Methods for Buildings and Cities: Space Syntax and Shape Grammar

Michael J. Ostwald  and Ju Hyun Lee 

School of Built Environment, Faculty of Arts, Design & Architecture, The University of New South Wales, Sydney, NSW 2052, Australia; m.ostwald@unsw.edu.au

* Correspondence: juhyun.lee@unsw.edu.au

1. Introduction

During the first century BC, the famous Roman architect, Vitruvius, defined architecture as encompassing three essential properties: *firmitas* (firmness), *utilitas* (utility), and *venustas* (attractiveness or beauty). These principles have been debated and promulgated in the field of architecture for many centuries, and more recently, they have been reconceptualised by architectural computing researchers as ‘grammar’, ‘syntax’ and ‘style’, respectively [1]. Grammar refers to ‘form’, representing the physical presence and stability (‘firmness’) of a building. Syntax refers to the interface between people and space, which has parallels to the types of functional needs encapsulated under ‘utility’. The last property, ‘style’, pertains to the distinctive way architecture and urbanism employ language to express or communicate formally and spatially. The classic computational design approaches utilised to study and define the first two properties are Shape Grammar and Space Syntax, the combination of which has also been linked to the creation and generation of style [1].

Space Syntax, theorised by Bill Hillier and Julienne Hanson [2], examines the correlation between spatial logic and social behaviour by identifying the syntactic attributes of spatial configurations within the constructed environment. Introduced by pioneers such as George Stiny and James Gips [3], Shape Grammar is a computational and generative method for identifying and understanding the design principles that define the formal properties of a building or style. In this regard, ‘syntactical’ methods focus on the spatial or topological configurations of a building, while ‘grammatical’ methods address the shape rules responsible for a building’s formal or geometric properties. Collectively, this Special Issue, “Computational Analytical Methods for Buildings and Cities: Space Syntax and Shape Grammar”, presents advanced research findings using two widely recognized computational methods to analyse and model architectural and urban spaces.

2. Contributions

This Special Issue comprises 14 articles, with 11 original research articles and one systematic review on the applications of Space Syntax methods and 2 on Shape Grammar research. The 14 articles were authored by 41 international scholars, with a research focus on buildings and cities in Australia, Brazil, China, Denmark, Greece, Germany, Hungary, France, Sweden, South Africa, and the United States. The eleven original research articles on Space Syntax explore a range of built environments—courtyard houses [4], laboratories in history [5], art museums [6], mega-shelters [7], public libraries and their surrounding areas [8], a subway station [9], historic streets [10], rural settlements [11], and urban districts [12–14].

Zolfagharkhani and Ostwald [4] present a quantitative and computational study of the spatial topology of 37 historic courtyard houses in Yazd, Iran, using a conventional justified plan graph (JPG) method. By demonstrating how the JPG can rigorously examine socio-spatial characteristics of architecture over time, they provide illustrations and arguments to challenge traditional assumptions surrounding the Yazd courtyard house. In addition



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to a comprehensive overview of the historical, cultural, and climatic context of this iconic architectural type, their research offers insights into its spatial logic and diversity, which can inform future conservation and adaptation plans.

Zhang and Cui [5] studied the diversity and complexity of scientific laboratories in history, identifying the spatial topology of their JPGs. By reflecting changes in scientific paradigms, they observe the evolution of spatial genotypes in historic laboratories. In addition to conventional properties such as *integration*, new syntactic measures are presented in the study, such as *distributedness index* and *space link ratio*, which can be applied to examine the topological network and flexibility of building plan layouts.

Lee and Kim [6] present an in-depth syntactic analysis of four international art museums to explore the ways their auxiliary paths influence visitors' experiences and behaviours. Developed using convex graph identification, spatial sequences and possible trails are identified and compared with syntactic and isovist properties. The combination of JPG and visibility graph analysis (VGA) is used to reveal a hidden socio-spatial logic shaping human perception and engagement in architecture.

Kim et al. [7] conducted a comparative analysis of the spatial configuration of four mega-shelters for disaster refugees in Australia, Japan, and the U.S., using a comprehensive combination of axial line analysis (ALA), VGA and JPG. Space syntax is valuable in conducting a rigorous analysis of significant but sensitive environments. Their research highlights spatial cognitive abilities and communications to develop guidelines for the planning and management of disaster shelters.

Zhao and Hong [8] examine the correlation between the accessibility and utilization of public libraries in Seoul, analysing the syntactic and behavioural (usage) data from 783 public libraries and their surrounding areas. In terms of spatial analysis, two accessibility indicators are measured using axial maps and topological connections between public libraries and subway stations. The degree of utilization activation is then calculated based on the number of visitors over five consecutive years, which allowed the quantitative examination of the socio-spatial relationships using correlations and regression results.

Kim and Kim [9] statistically reveal pedestrian movements in a subway station predicted using agent-based modelling (or agent-based simulation or ABS) drawing on Space Syntax theory. It is evident in this research that a moderate correlation exists between simulated movement and specific pedestrian patterns in the station area.

Xu, Rollo, and Esteban [10] measure the experiential qualities of historical streets in Nanxun, China, which is a Beijing–Hangzhou Grand Canal town. They use a combined method of ALA, VGA, and ABS and derive four factors, complexity, coherence, mystery, and legibility, from environmental psychology and urban design theories, the knowledge of which is intended to help designers and policymakers understand and improve cognitive experiences in historical streets.

Zhao et al. [11] explore the characteristics of 18 typical rural settlements along the Grand Canal in Tianjin, China, using field investigation and GIS analysis. Their research uses a special Space Syntax modelling tool, called “spatial design network analysis (sDNA)”, measuring *proximity* and *through-movement degree*. In addition, the categorisation of historical rural settlements and on-site phenotypes is valuable for the conservation, development, and management of this cultural heritage type.

Wang et al. [14] also use the GIS-sDNA method to examine the liveability and vitality of Qingdao's historical city in China, providing a detailed spatial interpretation of the city. The authors specifically developed a composite measure of 16 built environment variables, which they call a “JANE index” (derived from Jacobs' theory of urban vitality), and then analysed the spatial distribution and correlation of urban vitality. Their framework can be applied to systematic research on the liveability and vitality of different areas and contexts.

Pan et al. [12] investigate the correlation between public participation and spatial form in urban space in Nanjing Xinjiekou, using observations and syntactic measures such as *choice* and *integration*. This empirical study assists in the development of a morphological understanding of location-specific spaces and their future spatial planning.

Guo, Hu, and Tang [13] propose a new method, a 3D Node-Landmark Grid Analysis Model (3D NL GAM), to quantify the structural salience of urban landmarks and evaluate the intelligibility of urban environments in Changsha, China. The 3D NL GAM integrates 3D visibility measurement and Space Syntax principles to calculate the structural salience of landmarks based on their visibility, spatial properties, and links between wayfinding decision nodes and landmarks. This can be applied to improve the intelligibility and attractiveness of new or existing urban districts.

Lee, Ostwald, and Zhou [15] provide a comprehensive and systematic review of 38 articles on socio-spatial experience, using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework. This is the first PRISMA-compliant scoping review of Space Syntax studies that contributes to identifying key socio-spatial phenomena in architectural, medical, and urban spaces, including significant research problems and directions for future research.

In contrast, two grammatical studies focus on the generation of architectural and spatial layouts. Paulino, Ligler and Napolitano [16] develop a shape grammar for *Sobrado* buildings in São Luís, Brazil, transforming the spatial configuration of the historic architecture into contemporary social housing (e.g., for a multi-family apartment). Their research contributes to the adaptive reuse of traditional architecture by offering a comprehensive explanation of the *reviver* grammar and its application.

Lastly, Muslimin [17] addresses a combination of Space Syntax and Shape Grammar approaches by incorporating graph and shape computation to generate schematic plan layouts. Two case studies on hospitality and retail sectors demonstrate the shape-to-graph and graph-to-shape transformations, leading to sequential rules for functions and spatial arrangements. This integrated method is useful for analysing the functional evolution of architecture and generating alternative building plans.

3. Discussion and Conclusions

This Special Issue offers valuable references for architectural and urban research, presenting new insights into analysing, evaluating, and generating spatial configurations in buildings and urban patterns in cities. While new or combined measures, such as urban vitality and 3D visibility, are introduced in this collection, three basic Space Syntax techniques—ALA, JPG, and VGA—are consistently employed to examine a variety of architectural and urban spaces. An important message from this collection is that syntactic properties can be regarded as either independent or dependent variables in such design information models, enabling the systematic measurement and development of the built environment.

In this Special Issue, two research articles discuss the use of Shape Grammar methods for generating spatial layouts, highlighting the incorporation of syntactic information in spatial configurations as part of the generative process. This research confirms that architectural design languages can be developed from a combined understanding of Space Syntax and Shape Grammar approaches.

The collective efforts of the 41 researchers whose articles are featured in this Special Issue contribute to future architectural and urban, promoting creative and systematic development of the built environment.

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