The mathematics of urban morphology. A cross-scale topological approach to analyzing morphological transitions in urban spatial structure

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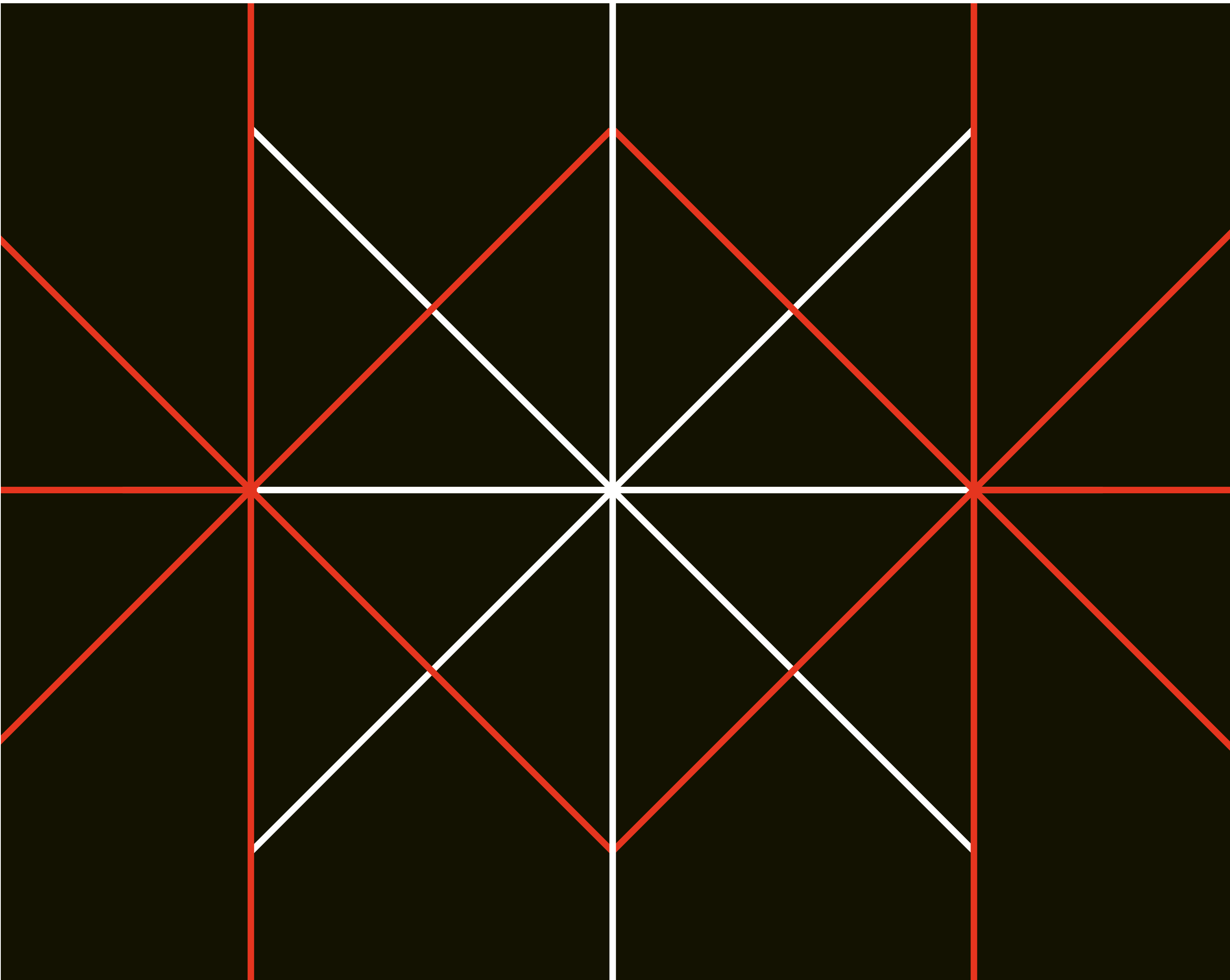

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PhD in Architecture.
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Politecnico di Torino
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GENERAL INDEX

THE MATHEMATICS OF URBAN MORPHOLOGY. A CROSS-SCALE TOPOLOGICAL APPROACH TO ANALYZING MORPHOLOGICAL TRANSITIONS IN URBAN SPATIAL STRUCTURE

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The research aims to explore a new way of describing urban spatial structure from the perspective of the cross-scale topological network combined with the graph machine learning. The research establishes a bridge between the field of urban morphology and advanced computational models, particularly Graph Isomorphism Networks (GINs) and Dynamic Graph Convolutional Neural Networks (DGCNN). While the bridge is the construction and application of cross-scale topological networks, an advancement that overcomes the limitations of traditional methods such as space syntax which were restricted to single-scale, either indoor or outdoor, models. Through the integrated use of historical morphological maps, mathematical models, neural networks, and data, the study will reveal the bottom-up evolution patterns of urban spatial networks at various scales, which will support urban design decisions in the future. The Introduction part lays the foundation by providing the necessary background and outlining the research objectives and questions. This chapter also introduces the methodological framework and the overall structure of the research. The first part and the second part review the existing studies on urban morphology, cross-scale topological networks, and the use of Graph Neural Networks in urban morphology. This review sets the stage for the novel methodological approach presented in this research. The third part, Methodology and Selected Cases, expounds on the construction of cross-scale topological networks, the generation of historical topological networks, and the application of Graph Isomorphism Networks (GINs) and Dynamic Graph Convolutional Neural Networks (DGCNN). This part also introduces the innovative concept of the Structure Evolution Degree, a metric designed to quantify the transitions of the urban spatial network: The first process of the core of this research is the transformation of urban morphology maps into cross-scale topological network graphs. This intricate process involves representing both outdoor urban spaces (like streets and plazas) and indoor function rooms as nodes, with their interconnections forming edges. By further categorizing these nodes into four distinct levels—Public spaces (streets), Front spaces, Courtyard spaces, and Functional room spaces—a layered topological network is established. The front space level as the transitional space connects the public space and private space to form the whole cross-scale topological network. This cross-scale representation successfully captures the inherent complexity and diversity of urban

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The transition of Topological Networks of Xiaoxihu
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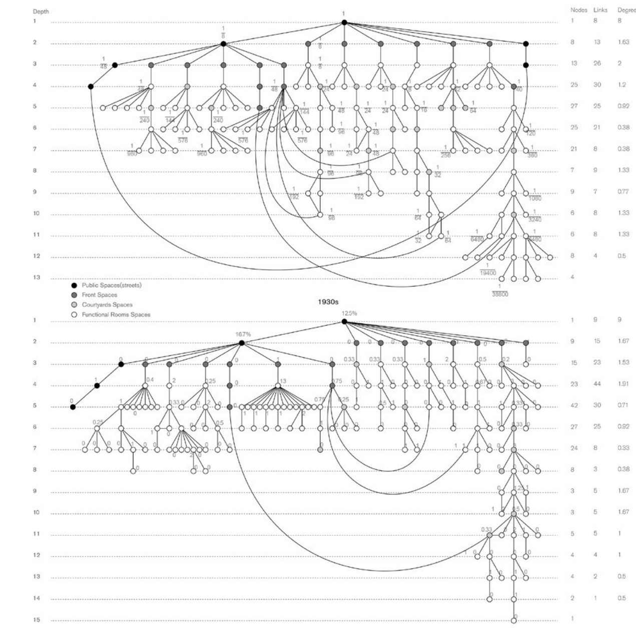

Calculation Graphs of Xiaoxihu Block in 1930s and 2010
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spatial structures across different scales, providing a comprehensive and realistic depiction of urban environments. Then the research furthers the utility of these cross-scale topological networks by generating historical representations for specified urban areas across different time periods. These networks are also enriched with the spatial data associated with each node, through the GIS software. This approach facilitates a detailed comparative analysis of urban morphological changes, allowing for a richer, temporal understanding of the dynamics of urban development. Upon the generation of these historical cross-scale topological networks, this research introduces the innovative 'Structure Evolution Degree.' This unique metric provides a quantitative representation of the transitions in the urban spatial network. The introduction of the Structure Evolution Degree enhances the analytical precision of the research and offers a robust tool for understanding, describing and comparing spatial changes across different urban areas and time periods. The research methodology is further distinguished by the application of GINs and DGCNN in the analysis of these networks. GINs, a type of graph neural network, are used to compare entire graphs. By identifying and encoding unique graph structures, GINs (Xu et al., 2019) enable the analysis of the global changes in the urban spatial structure over time. On the other hand, DGCNN, another innovative graph convolutional network (GCN), provides a more localized perspective. By aggregating and transforming local network features, DGCNN(Wang et al., 2019) allows for the identification of critical micro-level transitions. The combined application of GINs and DGCNN, along with the quantification provided by the Structure Evolution Degree, presents an unprecedented, nuanced view of morphological transitions across scales. The application of these computational models reveals intricate changes within the urban spatial structure, shedding light on the complex dynamics that shape urban environments. The results of this study are meticulously analyzed and presented through the use of subgraphs. These subgraphs effectively represent the evolution of cross-scale spatial relations across different periods. Each subgraph, derived from the GINs and DGCNN analysis, presents a detailed visualization of various transitional forms of urban spatial relationships, such as transitions from open street spaces to enclosed courtyard spaces or transformations of functional room spaces over time. This representation not only reveals transformative trends in urban spatial structures but also underscores the importance of considering multiple scales in urban morphological studies. The final part, the Conclusion, summarizes the key findings of the study. It discusses the theoretical and practical implications of these results for urban development and planning. It also acknowledges the potential limitations of the study and suggests areas for future research. By integrating cross-scale topological networks and the novel measure of Structure Evolution Degree, this study marks a significant stride in urban morphology research, heralding a new era of comprehensive, multi-scale urban spatial structure analysis.

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“The PhD Program in Architecture. History and Project (DASP) was born out of two long lasting traditions of doctoral level studies and research in the area of Architecture at Politecnico di Torino. The PhD Program programmatically investigates the complexity of architectural cultures starting from the multi-disciplinary and trans-disciplinary interweaving between the history and the design of buildings, cities, territories.

On the one hand, in fact, urban and architectural composition and technology of architecture favor an interpretation of the project as a tool for measuring the stratifications of theoretical elaborations, technical innovations and modifications of built environment.
On the other hand, the historical disciplines for architecture and the city, far from a local vision and thanks to the cooperation with other histories (the economic, social, anthropological and aesthetic ones), trace paths that can be traveled by architects and urban planners, but also by other humanities scholars, such as philosophers and linguists”

Marco Trisciuoglio

(from the document Proposal for the accreditation of doctorates - a.y. 2023/2024, presented to the Italian Ministry of University and Research on June 5th, 2023)

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