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Mapping Emergent Patterns of Movement and Space Use in Vertically Integrated Urban Developments

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ABSTRACT

In high-density urban environments, buildings with mixed-use programs increasingly include public and common spaces on elevated levels. The complex interactions of such spaces with those on the ground level, their impact on patterns of human movement in the city, and their scalability and potential contribution to providing a more livable high-density urban environment are currently not well understood. This paper presents an ongoing research project at the Singapore University of Technology and Design (SUTD) that uses a Complexity Science-based approach to quantitatively analyze the network effects of vertically integrated mixed-use urban developments on human movement and space use. The research uses Kampung Admiralty, a first-of-its-kind development in Singapore that integrates housing for the elderly with a wide range of social, healthcare, communal, commercial, and retail facilities, as a case study. The paper finally discusses the potential of the research approach to inform future urban planning and design of vertically integrated mixed-use developments.

Author Keywords

Vertically integrated developments; Complexity Science, spatial network analysis; Bluetooth localization; mobility patterns; co-presence networks; socio-spatial networks

ACM Classification Keywords

I.6.1 SIMULATION AND MODELING (e.g., Model Development).

1 INTRODUCTION

In land-scarce cities such as Singapore, public and common spaces and networks, traditionally located on the ground level, are increasingly complemented by such spaces and networks on elevated levels in the form of sky bridges, sky parks, sky terraces, and roof gardens. Combinations of these, often applied to mixes of residential, civic, and commercial programs, produce at times 'vertical cities' in which these spaces become components of larger urban systems and networks [8]. The interactions between these urban components are numerous, varied, and interrelated in complex ways.

In recent years, researchers from many fields including the Natural and Social Sciences have come together to study cities as 'Urban Complexity' [2,3,4]. Urban Complexity investigates three fundamental dimensions that can help to understand better the interactions between space users and the built environment. These include (1) spatial configurations, (2) human mobility, and (3) the co-presence of people in spaces. With the rapid advancement of new technologies and digital tools like Wi-Fi sniffers, Bluetooth sensors, etc., that allow for the tracking and recording of the movement of people in physical space, the last decade saw significant progress in Urban Complexity research [1,6,7]. More specifically, the studies related to understanding pedestrian movement patterns and behaviors in built environments were encouraging [1,9]. While extensive studies exist on horizontal mobility and lateral networks, very limited data and understanding of human vertical mobility is available [5] and the same goes for its impacts on the design and planning of vertical extensions of urban space networks.

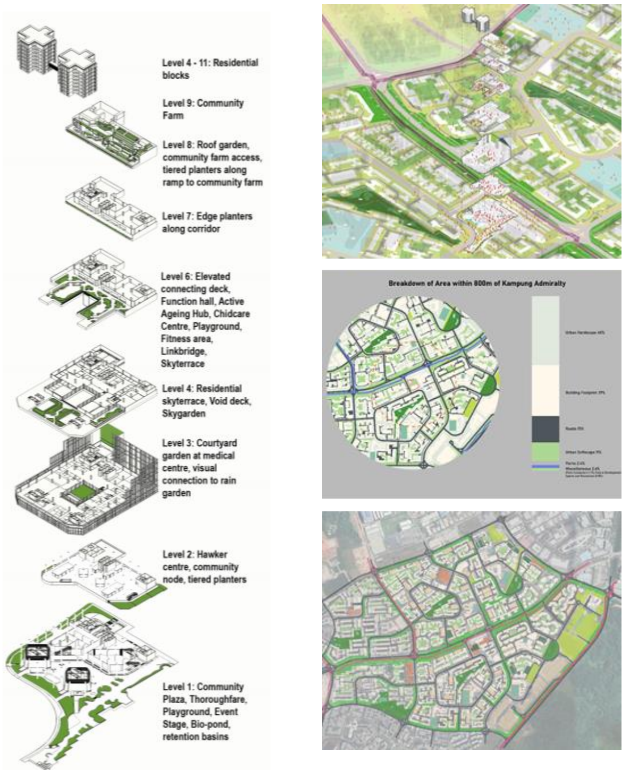
This paper addresses the knowledge gap in understanding the use of public and common spaces on elevated levels, their potential network effects, and their interactions with larger urban systems and networks on the ground level in high-density contexts. It discusses a new Complexity Science-based research approach to a systematic analysis of the effects of vertically integrated built environments on human movement using Kampung Admiralty (KA), a first-of-its-kind such public development in Singapore, as a case study.

2 RESEARCH METHODOLOGY

The following section outlines the research approach to our post-occupancy study of movement and space use in KA. We present a brief description of the case study, describing its architectural organization and its vertical distribution of public and common spaces. We further outline our network analysis framework for mapping and analysis.

2.1 Description of Kampung Admiralty

Awarded ‘World Building of the Year’ in 2018, KA is Singapore’s first integrated public development that brings together a mix of public facilities and services under one roof. Designed as a ‘vertical village,’ it optimizes land use and has since its completion in 2017 become an urban design and architectural prototype for addressing Singapore’s ageing population needs.



(a) (b)

Figure 1. (a) Vertically distributed public spaces in KA (b) The urban context and ground coverage distribution around Kampung Admiralty (Source: SUTD)

As described by WOHA, the KA’s architect, the design uses a ‘*sandwich layered approach.’* It comprises a community plaza located in the lower layer, a medical center in the middle layer, and a community park with senior apartments in the upper layer of the building. The community plaza provides a fully public and zpedestrianized ground plane to serve as a community ‘living room.’ The community park on the roof is a more intimately scaled, elevated village green space where residents and visitors can gather and interact. The co-location of complementary programs such as childcare and an active ageing hub (that includes senior care) brings together multiple age groups.Two 11-story residential towers, consisting of 104 apartments, house elderly singles and couples. KA is located next to Admiralty Station, a Singapore public transport hub. It provides a significant catchment of visitors and users from the adjacent neighborhoods. KA’s community park on the roof creates a strong visual identity for the area and attracts visitors from the larger city.

2.2 Network Analysis Framework

In our ongoing study, we are applying network analysis to the development’s spatial layout. This will allow us to compare the analysis findings to actual space use in KA. Our research process has three stages that will lead to the formulation of design strategies:

- Spatial network framework
- Human mobility mapping
- Co-presence networks

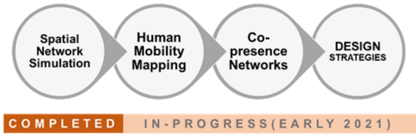


Figure 2. Methodology framework and timeline of work in progress for the different stages of network analysis

At the time of writing, we have completed Stage 1 and Stages 2 and 3 are in progress. In Stages 2 and 3, we are comparing our real-world data with the spatial network measures that resulted from Stage 1. This will facilitate a better understanding of the user-space relationships and provide empirical evidence of (1) how the vertically integrated public and common spaces in the development are used, (2) how they influence user behavior and movement, and (3) how they impact social interactions and user activities over time.

2.2.1 Spatial network framework

In Complexity Science, a spatial network is a network structure embedded in space with nodes and edges obtained from the built space, with definitive properties and structural attributes [2]. The analysis of this spatial network allows us to quantify specific network measures. These are understood as metrics of the effectiveness of various functions of a node, clusters, or the overall network structure. In KA, we consider two-node attributes, (1) space type, and (2) floor level. Space type includes residential, commercial, social programs, community facilities, F&B programs, health facilities, and vertical streets (lifts and stairs lobbies). Floor level includes corridors, staircases, escalators, and ramps connecting the nodes that form the edges for the analysis. The edges are the shortest routing distances connecting immediately adjacent nodes. In the vertical dimension, the lift and staircase lobbies have all-to-all connectivity, i.e., each lift lobby is connected to all other lift lobbies if they share the same lift core. Based on the above classifications, the spatial layout of KA translates into a spatial network with 119 nodes and 389 edges (Figure 3).

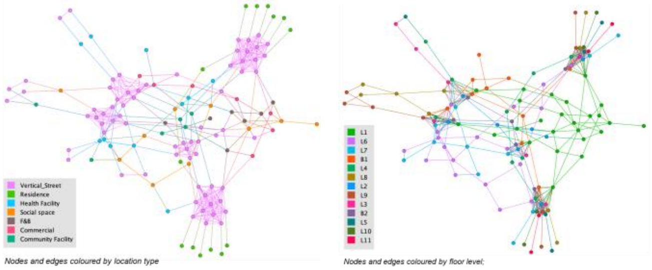


Figure 3. Spatial network of nodes and edges of KA using Yifan Hu force-directed algorithm (Source: SUTD)

A 3D-network link model connects the different nodes in the physical layout at each level and between other levels to analyze the routes' strength linking the other nodes within the development (Figure 4).

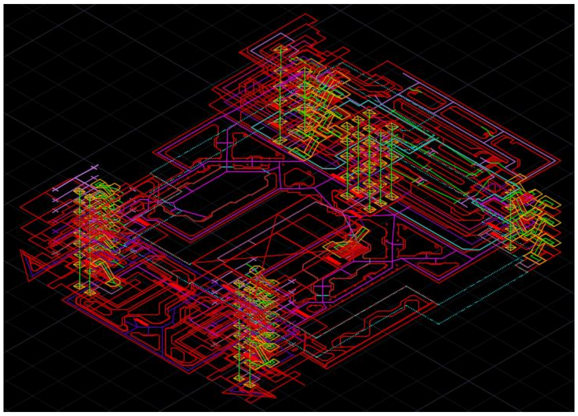


Figure 4. 3d-model of network links linking the public spaces within KA for network analysis (Source: SUTD)

2.2.2 Human Mobility Mapping

Human mobility mapping consists of tracking and recording pedestrian movements, activities, and space use in significant public and common spaces within and around KA. Bi-directional outdoor people-counters with infrared sensors are installed at key nodes identified during the spatial network analysis to collect data of inflow and outflow volume during different times of the day. The variations in space use volumes over time will help to identify space use patterns and programmed facility's effective performance. The mapping of pedestrian movements within KA uses a Bluetooth tracking and localization method. Low-energy Bluetooth (BLE) devices combined with smartphone sensors, are used to track and localize a participant sample consisting of resident and non-resident space users. The Bluetooth localization consists of three components, (1) stationary low-energy Bluetooth beacons, (2) a mobile app and (3) a cloud server (Figure 5). The data collected from the participants' Bluetooth devices is plotted on the spatial layout to map the participants' movement routines over a period of two to three weeks. This information provides the actual use of the public and common spaces within KA. The measures deduced from the spatial network analysis are then validated with the real-world data.

Figure 5. Bluetooth localization and tracking consisting of Bluetooth beacons, mobile app and cloud server (Source: SUTD)

2.2.3 Co-presence Networks

Co-presence networks are temporal, where the edges start and disappear over time in relation with actual human co-presence. (Figure 6).

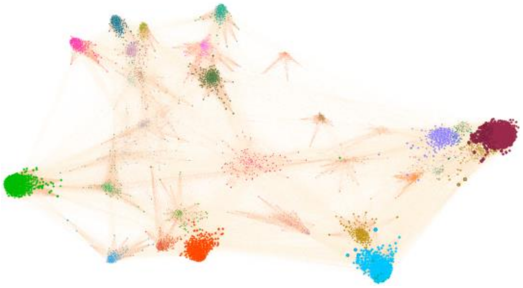
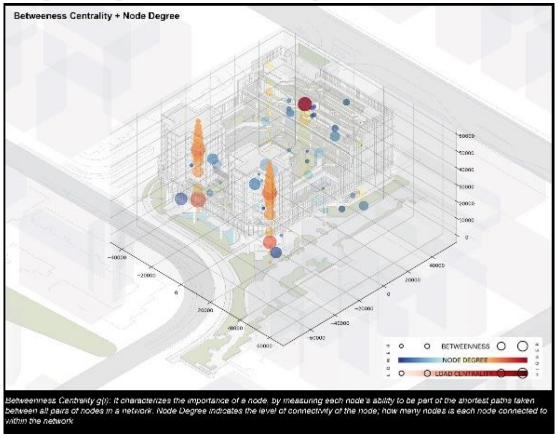


Figure 6. Example of an aggregated co-presence network (Source: SUTD)

The spatial layout enables co-presence, and over time, a temporal co-presence network emerges, exhibiting strong and weak ties. Strong ties are known to influence social behavior, while weak ties complete the connectivity within the network. When embedded into the spaces of KA, the temporal co-presence network enables the identification of the patterns of user interactions and their relative strengths over time. The aggregated network can also highlight the connectivity of different social spaces that enable interactions and the areas that generate more opportunities for brief chance encounters of space users. This provides valuable insights regarding the performance of spaces that can inform planning and design strategies for future vertically integrated developments such as KA.

3 NETWORK ANALYSIS MEASURES

In our research, we study the socio-spatial network for its measures of centrality and structure. Centrality measures indicate the significance of nodes and their connectivity strength within a network. The centrality measures considered are *degree centrality*, *closeness centrality*, and *betweenness centrality*. The network structure measures indicate the overall character of the network and how it behaves as a system. The network measures we study are *degree distribution*, *shortest paths*, and *clustering coefficient*. The analysis of the centrality and network structure helps us to break down the effectiveness of the designed spaces for their designated uses. It also helps us to identify key points of intervention within KA to improve space use. When extended to the surrounding urban context on the ground level, our analysis will enable us to better understand the connectivity of the elevated public spaces with those around the development and to identify nodes that provide a higher degree of influence to lead to the desired socio-spatial qualities of urban spaces.



Betweenness Centrality g(i): It characterizes the importance of a node, by measuring each node's ability to be part of the shortest paths taken between all pairs of nodes in a network. Node Degree indicates the level of connectivity of the node; how many nodes is each node connected to within the network

Figure 7. Visualization of the centrality measures embedded into the physical structure of KA. (Source: SUTD)

4 DISCUSSION AND SUMMARY

The presented research is ongoing, and the mobility mapping of participant users at KA is currently in progress. This stage of our study is scheduled to be completed in the first quarter of 2021. In the following, we discuss the potential of the presented approach and methodologies and their significance for the planning and design of future vertically integrated urban developments.

The computed spatial network analysis measures applied in our research provide a strong basis for understanding the vertical distribution of public and common spaces and their relationship with the surrounding horizontal urban public and common space network on ground level. The various network measures and properties deliver a rich set of data that enables us to study and analyze the complex dynamic interplay between the space users and the built environment of our case study. Exploring the urban socio-spatial networks as complex networks facilitates a better understanding of how individual components of the network perform within a larger system such as the centrality and connectivity of the community plaza and their potential to influence and adapt to future changes in the built environment.

By classifying built spaces as relationships with attributes, the application and combination of various network measures to quantitative analytical models will complement the spatial planning and design processes and result in more informed decisions. Extending the network connectivity into the larger horizontal urban context of KA will help us to better understand the complex correlations between humans and the built environment across multiple scales of urban planning and design.

5 CONCLUSION

The ongoing research project contributes to the development of a new integrated urban planning and design paradigm. Its Complexity Science-based approach provides us with a deeper understanding of user interactions within built environments. The analysis of movement and space use (vertical and horizontal) within vertically integrated developments such as KA allows for the identification of key connectors that impact (encourage, enable) socially and spatially effective vertical space networks. Once completed, our study of KA will help to identify emergent patterns of human mobility using Bluetooth tracking and localization methods. It will further allow for the establishment of structural and statistical properties of temporal co-presence networks through the sensed data in vertically integrated urban developments. The completed study will also provide us with a better understanding of the relationship between mobility patterns, co-presence, and space use in vertically integrated developments and their impacts on the larger urban areas they are part of. Most significantly, our study will establish a systematic method for analyzing and evaluating the socio-spatial network properties of vertically integrated urban developments. This will provide a basis for more extensive urban research.

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