CHAPTER

12

Complexity science-based spatial performance analyses of UNStudio/DP Architects' SUTD Campus and WOHA's Kampung Admiralty

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Introduction

Singapore is a city-state in maritime Southeast Asia. It is located one degree of latitude north of the Equator off the southern tip of the Malay Peninsula and covers an area of about 728 km^2. It currently has a population of about 5.7 million with a population density of about 7810 per km^2. Singapore's high population density leads to its urban development to become more spatially efficient and convenient to improve the quality of life of the residents. This creates a demand for using advanced technology to improve urban planning and design.

In Singapore, the approach to the use of AI in urban planning and design is fivefold: transport, home and environment, business productivity, health and enabled aging, and public-sector services (Kong and Woods, 2018). In the city-state's urban planning, particularly in the transportation domain, the use of AI is currently explored in areas such as the study of mobility patterns, traffic flows, devising active learning and sensing algorithms, developing decision models for real-time data, and enhanced automated systems for safety (Varakantham et al., 2017). The development of Virtual Singapore, a semantic 3D-model that virtually replicates Singapore and inputs real-time data including on demographics, climate, and traffic, signals the country's vision for an AI-enabled future (Liceras, 2019).

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Singapore's land scarcity and increasing urban density require innovative approaches to the further intensification of land use, which has resulted in urban planners and designers experimenting with increasingly complex and often vertically integrated building types. These often combine residential, civic, and commercial programs with public and common spaces on elevated levels such as sky bridges, parks, terraces, and roof gardens, producing "vertical cities" (Schröpfer, 2020).

Analyses of two vertically integrated spatial networks

The following examples are part of a larger ongoing Complex Systems Studies project funded by the Singapore Government under its Urban and Complexity Science for Urban Solutions Research Program. Of the two case studies, we present, in this chapter, Kampung Admiralty (KA) and the Singapore University of Technology and Design (SUTD) Campus, the former is conducted in collaboration with the Urban Redevelopment Authority Digital Planning Laboratory, the Ministry of National Development, the Ministry of National Development Center for Liveable Cities, and the Housing & Development Board Singapore. The latter is part of the cities: Urban Science and Design for Density research thrust at SUTD. The basic statistics of the two case studies are shown in Table 12.1.

Located in the northern part of Singapore and adjacent to the Mass Rapid Transit (MRT) hub Admiralty Station, KA, designed by Singapore-based architecture firm WOHA, is Singapore's first integrated public development that brings together a mix of public facilities, shops, open and green spaces, and residences in a vertical arrangement . Conceptualized as a "vertical kampung" ("kampung" means "village" in Malay) and completed in 2017, it is a building prototype that addresses two key issues in Singapore, the city-state's land scarcity and rapidly aging population. The project was awarded the World Architecture Festival "Building of the Year" Prize in 2018.

TABLE 12.1 Information on the two studies, including Plot Area, Gross Floor Area (GFA), number of floors, number of types of space, number of spaces (nodes, N), number of vertical street (and the percentage to N, VP), number of adjacent links, number of 50 m reachable links and the corresponding network density (ND) in brackets.

Index	KA	SUTD
Plot area (m^2)	8981	Approx. 83,000
Gross floor area (GFA) (m^2)	32,332	106,000
Floors	13	8
Different types of space	7	8
Number of spaces (nodes)	124	271
Number of "vertical streets" (VP)	69 (55.7%)	133 (49.1%)
Number of adjacent links (ND)	396 (5.2%)	560 (1.5%)
Number of reachable links (ND)	1566 (20.5%)	2319 (6.3%)

Network density is calculated as the number of links divided by the maximum possible links (pair of nodes). Vertical streets include stairs and lift lobbies.

SUTD, established in collaboration with the Massachusetts Institute of Technology (MIT) in 2009, is the fourth autonomous university in Singapore. The SUTD Campus, completed in 2015, was designed by the dutch architecture firm UNStudio together with Singapore-based DP Architects., The campus encourages cross-disciplinary interaction between faculty, students, and professionals by incorporating informal meeting and working spaces in an adaptable, flexible layout. SUTD's Campus Center serves as a flexible space for exhibitions and events, while the faculties and various campus programs are spatially distributed with a focus on connectivity. Lecture halls, classrooms, laboratories, and meeting rooms are located in currently three of the originally planned four main blocks that are connected vertically and horizontally through various circulation systems (UNStudio, 2019).

Responding to the tropical climate and the natural landscape of Singapore, natural ventilation and cooling principles with covered walkways and louvred facades were provided together with facade planters, green roof terraces, and sky gardens that use native trees and flowering plants. The campus design achieved the Singapore Platinum Green Mark rating with buildings that are 30% more energy efficient than typical institutional buildings (Mark, 2016).

Methodology and research phases

In both case studies, our research had two main phases. Phase 1 included an urban and architectural network mapping that was informed by a review of the planning and design concepts and intentions, a mapping of the resulting spatial networks, and a superimposition of node attributes such as Euclidean distance on the spatial network. Phase 2 comprised an empirical on-site sensing of human mobility with people counters and Bluetooth beacons. ML algorithms were used to classify activity ML to inform the analysis of the collected actual space use data. The two phases allowed for a systematic review of the effectiveness of KA and SUTD (Figs. 12.1–12.5) in terms of their intended space use.

Phase 1: Architectural network mapping

Phase 1 included a mapping of the nodes and linkages of the buildings' circulation and function of spaces, based on information provided by the respective architects. These included architectural diagrams and drawings that illustrate spatial distributions, e.g., intended circulation and flow, collaborative zones, connections in, between, and across the buildings, as well as lateral and vertical program distributions.

KA: The architects designed and integrated programs vertically to comprise KA's public spaces that include a community plaza and a hawker center located on the lower levels, a medical and childcare center as well as an active aging hub (that includes senior care) on the intermediate, and a community park for the residents on the upper levels (Figs. 12.6 and 12.7). KA includes two 11-story residential towers with 104 apartments to house elderly singles and couples (Gopalakrishnan et al., 2021).

SUTD: In the case of the campus, the concepts of "circulation" and "interaction" (Schroepfer, 2017) served the architects as their two main conceptual guides—with

FIG. 12.1 Point cloud image of the Kampung Admiralty Level 1 Atrium. (Point cloud data was collected with FARO Focus 330D and visualized with FARO SCENE). *SUTD Cities: Urban Science and Design for Density.*

FIG. 12.2 Point cloud image of the Kampung Admiralty Level 4 Sky Garden. (Point cloud data was collected with FARO Focus 330D and visualized with FARO SCENE). *No permission required.*

horizontal, vertical, and diagonal flows connecting the various spaces of the four buildings (Figs. 12.8 and 12.9). UNStudio, the design architect of SUTD, designated two axes of circulation, the "Learning Spine" and the "Living Spine" with a large plaza at the center.

For our analysis, we extracted the nodes from the main program areas in both cases. Edges were defined by connecting each one of the nodes to other nodes which are spatially adjacent and connected, e.g., via doorways and corridors. We calculated the Euclidean distance between the nodes from their corresponding links. We then joined elevator cores and stair lobbies as

FIG. 12.3 Point cloud image of the SUTD Campus Center. (Point cloud data is collected with FARO Focus 330D and visualized with FARO SCENE). *SUTD Cities: Urban Science and Design for Density.*

FIG. 12.4 Point cloud image of the SUTD Level 3 Sky Garden. (Point cloud data is collected with FARO Focus 330D and visualized with FARO SCENE). *SUTD Cities: Urban Science and Design for Density.*

"vertical street lobby" nodes and connected them directly and to all other vertically adjacent elevator core and stair lobby nodes, considering elevator and stair cores as "vertical streets." Various network centrality measures, including Degree, Closeness, and Betweenness Centrality were calculated from the spatial networks. Fig. 12.10 shows the adjacent and 50-m reachable networks of the two case studies. The node colors correspond to different floor levels.

We mapped the spatial network analysis measures in a digital model to visualize the relative significance of each space in terms of its connectivity and accessibility within the overall

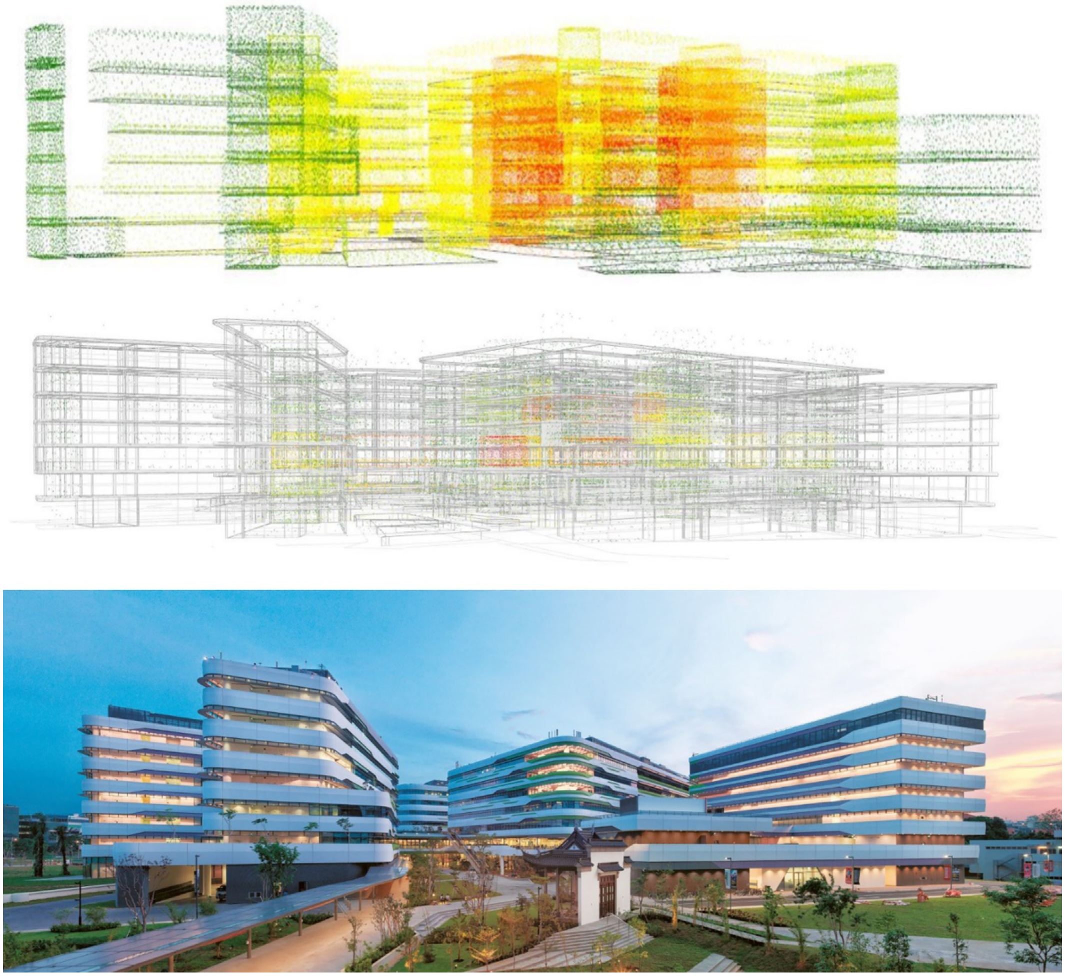


FIG. 12.5 From building to spatial metrics. Network centrality measures: Closeness and Betweenness diagrams, visualized in Rhinoceros Grasshopper, and actual SUTD Campus seen from the northeast. *Photograph by Daniel Swee.*

spatial network. Figs. 12.11 and 12.12 show the most central space of KA. From there, all other spaces can be reached within a travel distance of 50 m. Figs. 12.13 and 12.14 show the relative connectivity strength of all the spaces, illustrated through the varying sizes of the node measure.

Phase 2: Empirical on-site sensing

Tracking via smartphone app with BLE beacons

As part of our research, we developed a low-energy Bluetooth (BLE) tracking and localization method that we used in KA and SUTD to track and localize study participants (Figs. 12.15 and 12.16). These included residents, employees, and frequent visitors in KA and

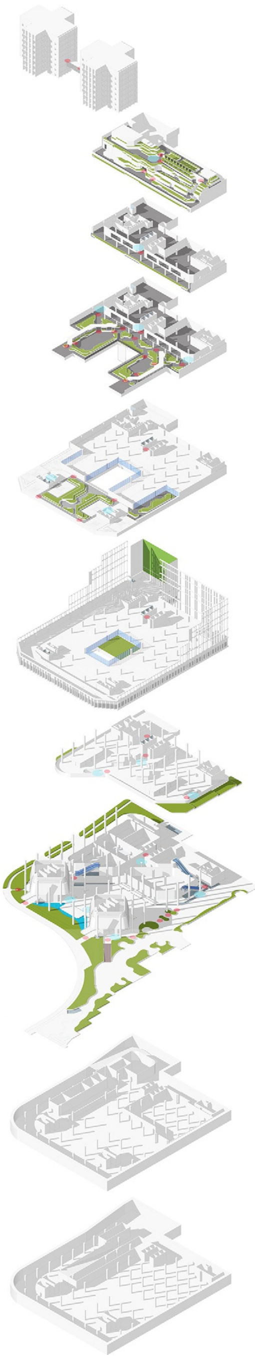
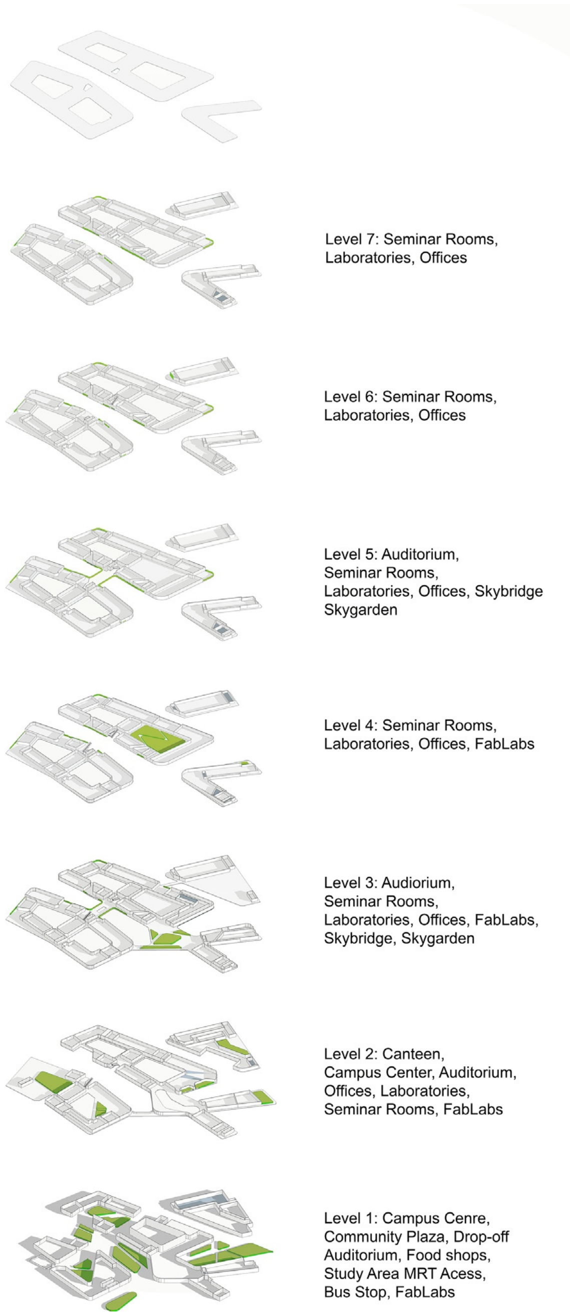


FIG. 12.6 Exploded isometric of KA showing the development's various programs. *Gopalakrishnan, S. et al., 2021. Mapping Emergent Patterns of Movement and Space Use in Vertically Integrated Urban Developments.*

FIG. 12.7 Exploded isometric of SUTD showing the development's various programs. *SUTD Cities: Urban Science and Design for Density*.



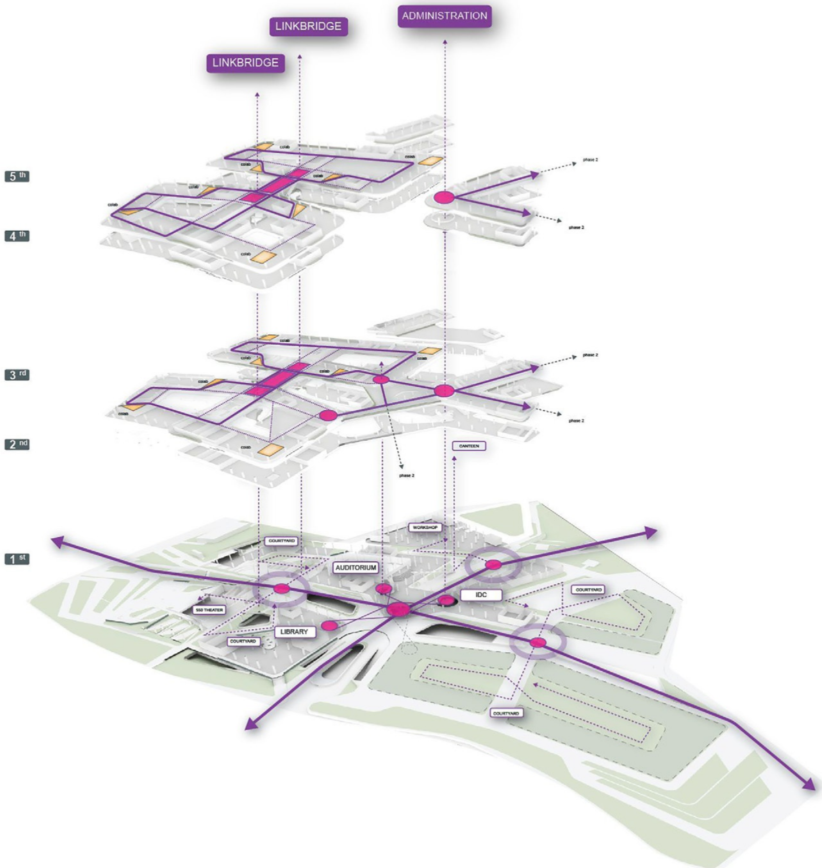


FIG. 12.8 UNStudio, SUTD, Singapore, 2014. Horizontal and vertical circulation, collaborative zones. *Source: UNStudio.*

faculty, students, staff, and vendors in SUTD. The Bluetooth localization consisted of four components, (1) stationary low-energy Bluetooth beacons placed around the study sites, (2) a mobile app that scanned for beacons when participants moved around the area, (3) a cloud server that recorded the data collected using the mobile app, and (4) processed the data for analysis. This approach is referred to as a "peer-to-environment" sensing system. The smartphone devices allowed for the mobile users to receive the data sent by beacons. The received data contained information about the transmitting beacon such as unique ID, time, telemetry (temperature, light, etc.) and the transmitting distance (indicating the stationary beacon's reach from the mobile app). Smartphones constituted the peer component of the system. A custom app installed on smartphones running iOS or Android worked in the background and scanned for Bluetooth data from the BLE beacons. It stored relevant data temporarily and then transmitted the information to our cloud server. The data

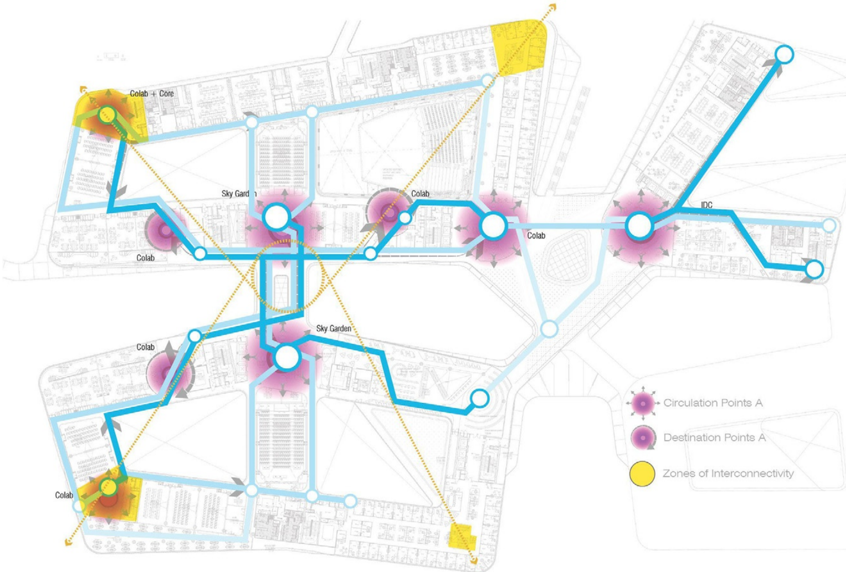


FIG. 12.9 UNStudio, SUTD, Singapore, 2014. Conceptual diagram of nodes of interactivity connected by circulation paths. *Source: UNStudio.*

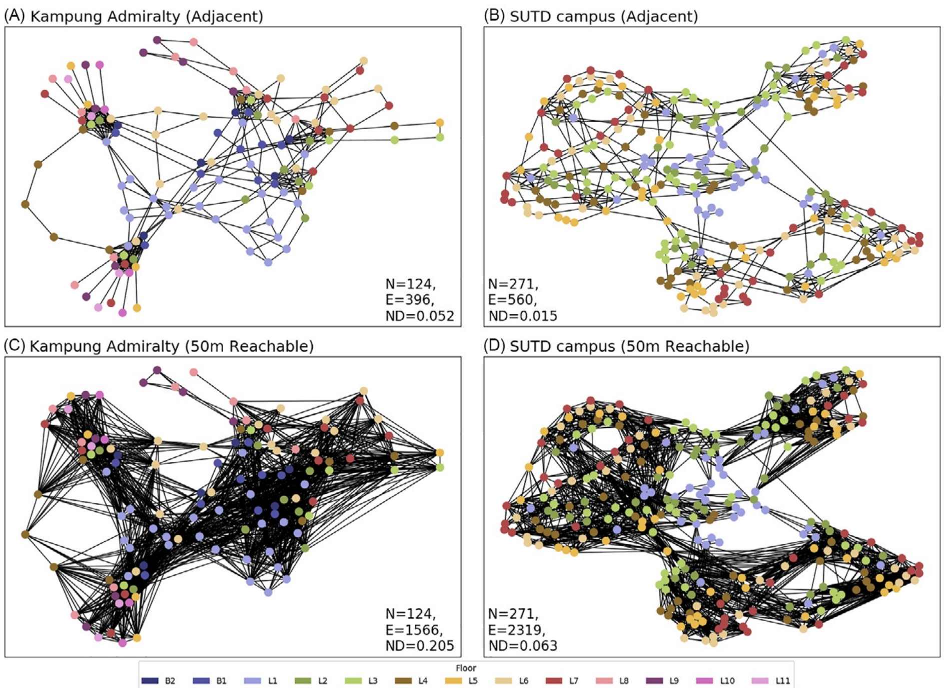


FIG. 12.10 The adjacency networks for (A) KA and (B) SUTD, and the corresponding walking distance (50 m reachable) networks [respectively (C) and (D)]. The numbers at the corner indicate the (N) number of nodes, (E) number of links, and (ND) network density. *SUTD Cities: Urban Science and Design for Density.*

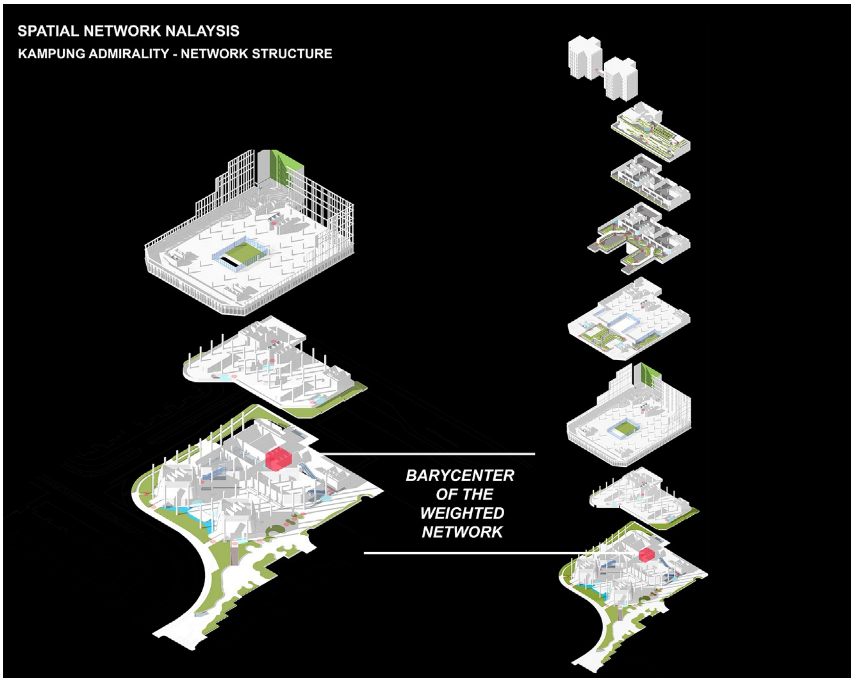


FIG. 12.11 Optimal location in KA. All other locations fall within the shortest travel distance of 50 m. *SUTD Cities: Urban Science and Design for Density.*

collected from the participants' Bluetooth devices was plotted on the spatial network to map their movement routines over the research period. We then deduced the experimental data measurements from the spatial network analyses and subsequently validated them with the real-world data, with the correlations between the designed and actual space use providing the basis for the performance assessment of KA and SUTD.

For the on-site experiment, we recruited a total of 73 participants in KA to track and record movement patterns. The BLE beacon scanning recorded a total of 42.6 million sensor data points which included beacon, accelerometer, barometer, and Bluetooth data (the SUTD study is still ongoing at the time of writing this chapter).

We used the collected BLE-localized movement data to construct socio-spatial networks and analyzed the dynamic network processes of mobility and occupancy as well as the correlations between network topologies, spatial configurations, and the network processes.

In addition, we constructed copresence networks constructed from the BLE-localized mobility patterns. In complexity science, when two or more people are in close proximity, they are said to be in copresence. Copresence is a necessary but not sufficient condition for interactions. A copresence network is a social network of friends and strangers that can help to analyze social relationships as a dynamic process. In our case studies of KA and SUTD, the participating users formed the nodes and the time spent in each other's proximity constituted the edges. Copresence networks are temporal networks, since their edges appear and disappear. Over time, a copresence network emerges that displays strong and weak ties. Persistent encounters between users indicate homophily (strong ties), while brief and chance encounters indicate

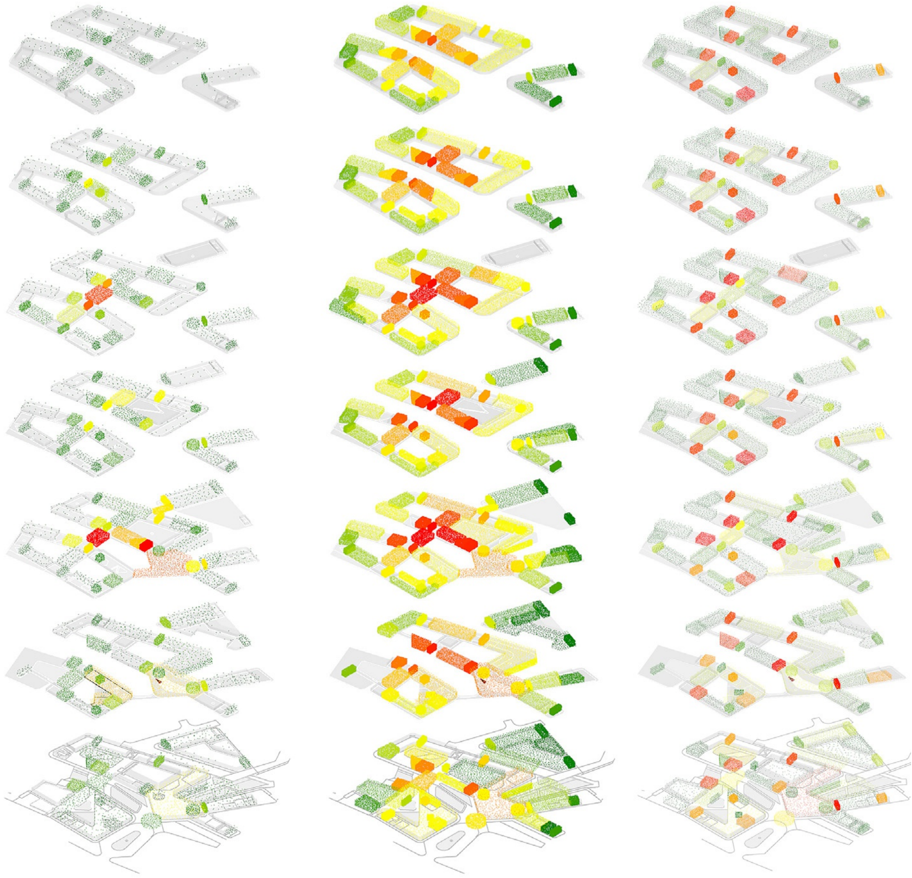


FIG. 12.12 Optimal location in SUTD. All other locations fall within the shortest travel distance of 50 m. *SUTD Cities: Urban Science and Design for Density.*

heterophily (weak ties). Stronger ties influence social behavior while weaker ties complete the connectivity within the network. When mapped onto the spatial layout of a building, the socio-spatial network reveals the patterns of user interaction and their relative strength over time. The aggregated network also shows the connectivity of different social spaces that enable homophily (active social interactions) and the areas that allow for more opportunities for chance encounters based on high movement flows. These results can provide important insights for the future planning and design of buildings and urban environments.

Measured mobility and occupation data of spatial nodes

Figs. 12.17 and 12.18 show the socio-spatial mobility analysis of KA by floor level and location type. Different types of users exhibited different mobility patterns. Residents and employees of KA showed a higher mobility "footprint" on the median than frequent visitors. Spaces with high connectivity like the Level 1 Community Plaza, elevated sky gardens, and vertical streets saw high pedestrian flow volumes.

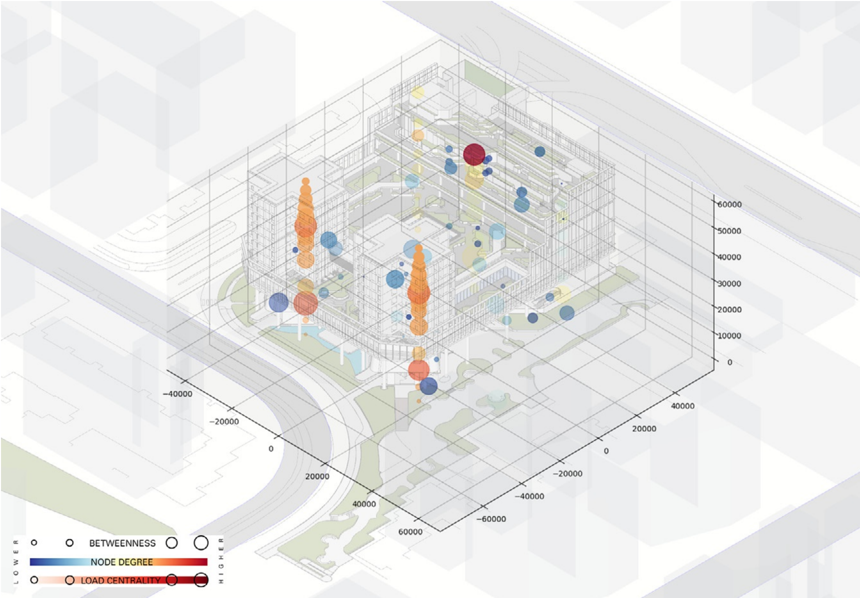


FIG. 12.13 Centrality measures visualized within the KA spatial model; the size of the circles indicates the significance of the space as a key connector within the network (Betweenness Centrality) and the color indicates the number of spaces each node is immediately connected to (Degree Centrality). *SUTD Cities: Urban Science and Design for Density*.

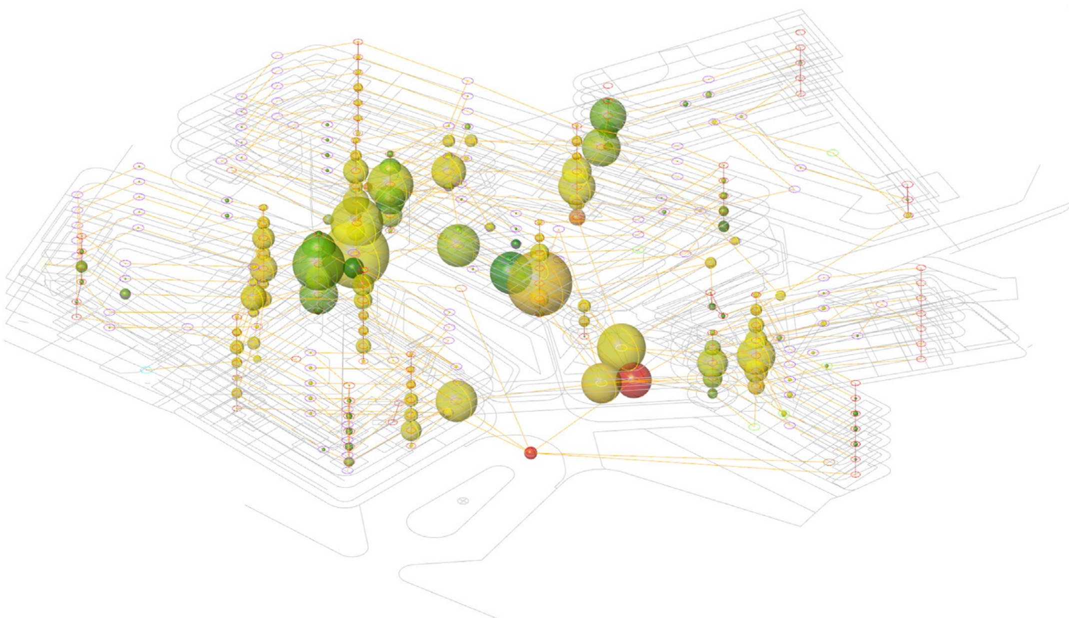


FIG. 12.14 Centrality measures visualized within the SUTD spatial model; the size of the circles indicates the significance of the space as a key connector within the network (Betweenness Centrality) and the color indicates the number of spaces each node is immediately connected to (Degree Centrality). *SUTD Cities: Urban Science and Design for Density.*

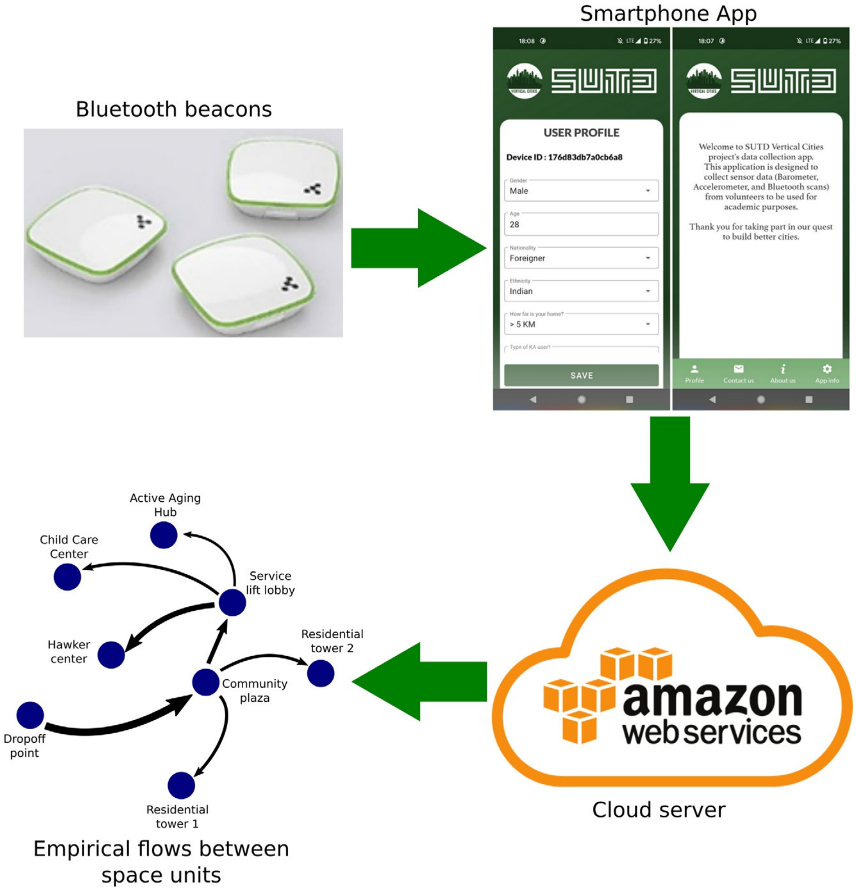


FIG. 12.15 Bluetooth (BLE) localization and tracking consisting of low-energy Bluetooth beacons, mobile app, and cloud server. *SUTD Cities: Urban Science and Design for Density.*

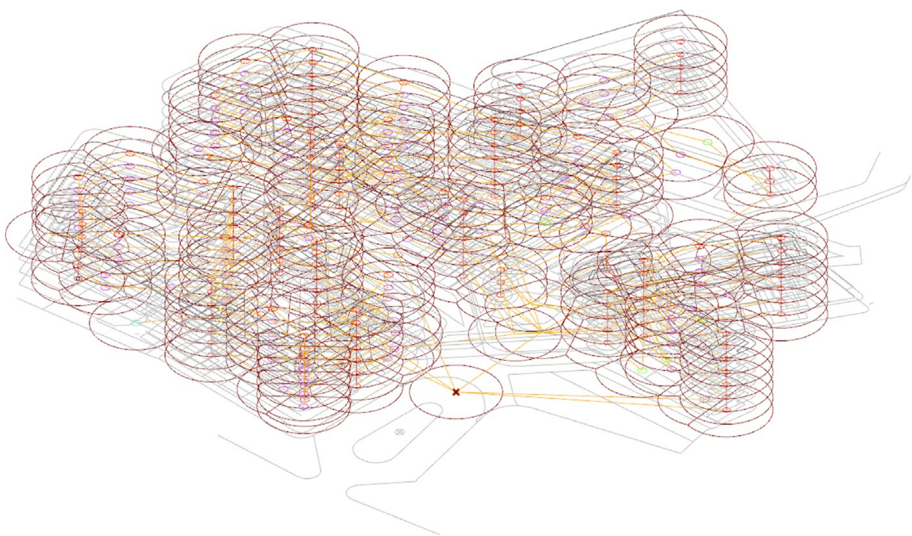


FIG. 12.16 20 m BLE detection radii in SUTD. *SUTD Cities: Urban Science and Design for Density.*

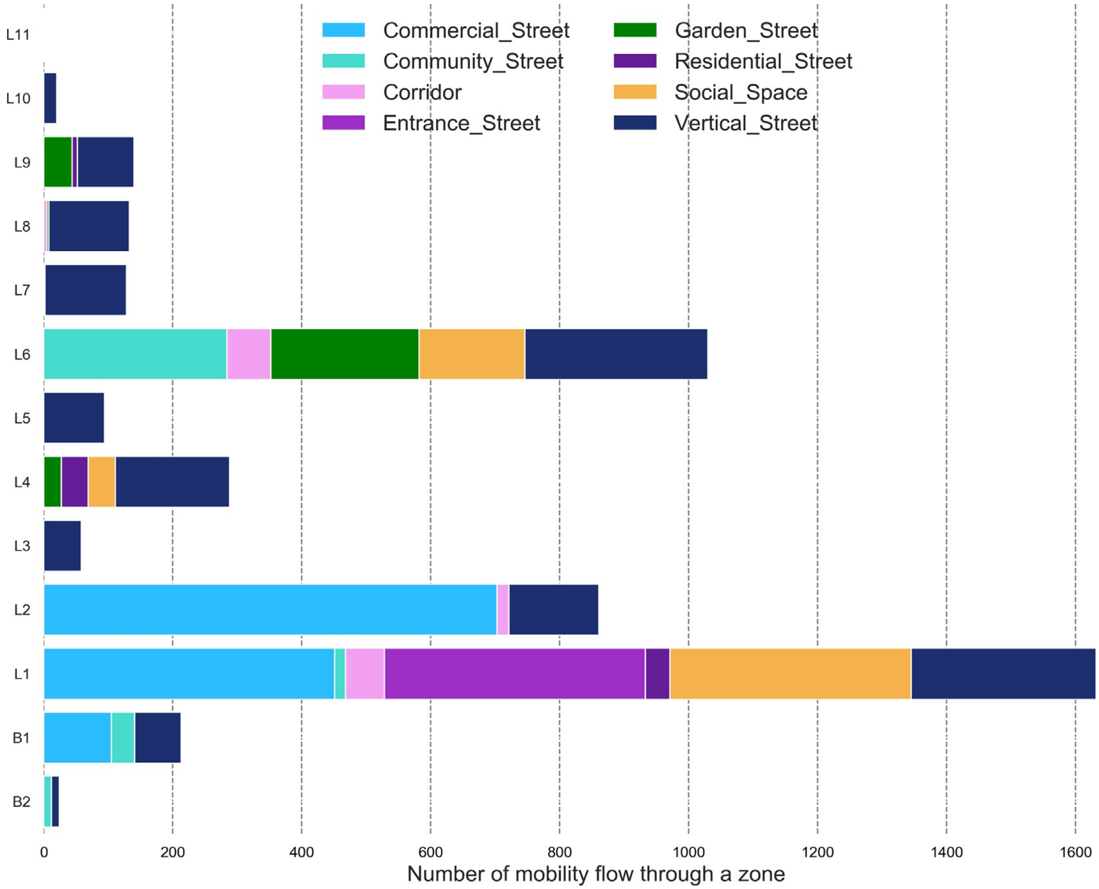


FIG. 12.17 Total distance traveled in KA public spaces per day per study participant. (A) Overall, (B) by gender, (C) by age group, (D) by KA user type. *SUTD Cities: Urban Science and Design for Density*.

The occupancy analysis shows the time spent in different KA spaces. The total time spent in the development by floor level and location type over time is shown in Figs. 12.19 and 12.20. We studied the occupancy patterns of different users to understand the effective use of spaces, e.g., users spent significant amounts of time in the social areas at ground and the elevated levels. Activity destinations like community gardens showed the longest occupancy compared to the other areas.

The beacon data points were visualized in a spatial model allowing for comparisons across different nodes within the architectural space and the timing of activities. Fig. 12.21 shows the spatial distribution of the daily aggregated beacons reading heat maps by the day of the week (from Monday to Sunday). Clear activity patterns at different locations and during different times were visible with consistent peaks and lows throughout the week, thus revealing the effective patterns of movement and space use.

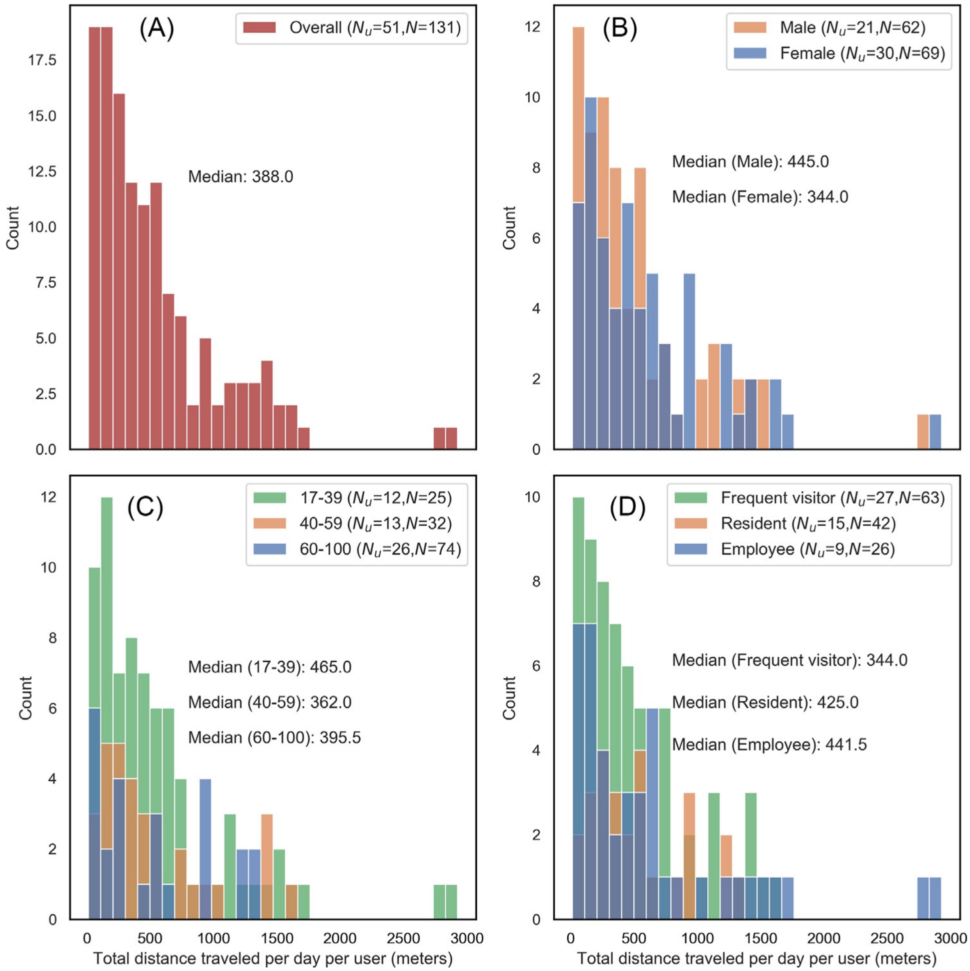


FIG. 12.18 Number of mobility inflows through KA public spaces per floor and location type. *SUTD Cities: Urban Science and Design for Density.*

Tracking with radar and infrared-based bidirectional people counters

Our mobility mappings included tracking and recording of pedestrian movement in significant public and common spaces and key collaborative zones at the ground and elevated levels in both of our case studies. We recorded the frequency and intensity of actual space use using radar- and infrared-based bidirectional people counter sensors. People counters measure the volume and the time of human traffic flows across predefined points and zones. The devices were installed at key access points to the nodes that we identified in Phase 1 of our research to collect data of inflow and outflow volumes at different times of the day. The collected data provided us with the total volume of users circulating through the selected spaces. The variations in usage volumes allowed us to identify micro- and macro-patterns over hours, days, and weeks, providing a measure of actual space use and performance. Photographs of the people-counter devices and an illustration of the results are shown in Figs. 12.22 and 12.23.

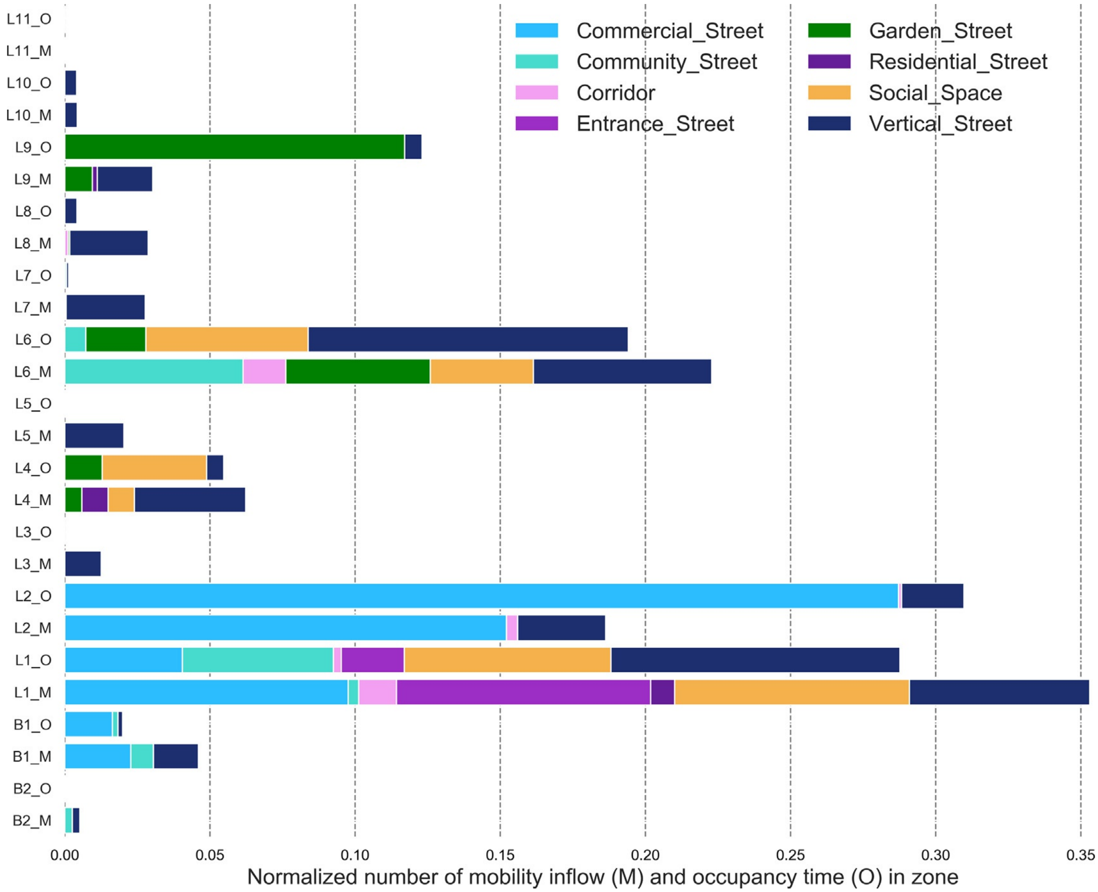


FIG. 12.19 The graph shows the interplay between mobility and occupancy in KA's public spaces per floor and location type. X-axis values also represent relative scaling for location types. *SUTD Cities: Urban Science and Design for Density*.

We analyzed the people counter data in terms of temporal patterns of movement and space use at key social spaces. Fig. 12.24 shows the hourly aggregated use of garden spaces and community facilities at KA. Garden spaces were regularly used during daytimes with fewer visits in the evenings, while the community facilities were used more frequently on weekdays compared to weekends.

In the following paragraphs, we present a comparison between the movement flows in two important SUTD spaces. Area 1 includes the Level 1 Campus Center and the Level 3 Sky Gardens directly above it. Area 2 refers to the L1 Community Plaza, and the Levels 3 and 5 Sky Bridges directly above.

Fig. 12.25 illustrates the flow on weekdays and weekends across four different time periods (0000–0559, 0600–1159, 1200–1759, 1800–2359), showing peaks in the afternoon both on weekdays and weekends, albeit significantly lower weekend traffic across all time periods. The peaks occur at lunch and dinner times, with a significant rise and drop in overall use before 0800 and after 1900 h. Also, the afternoons generally show greater volume of movement than the mornings (Fig. 12.26).

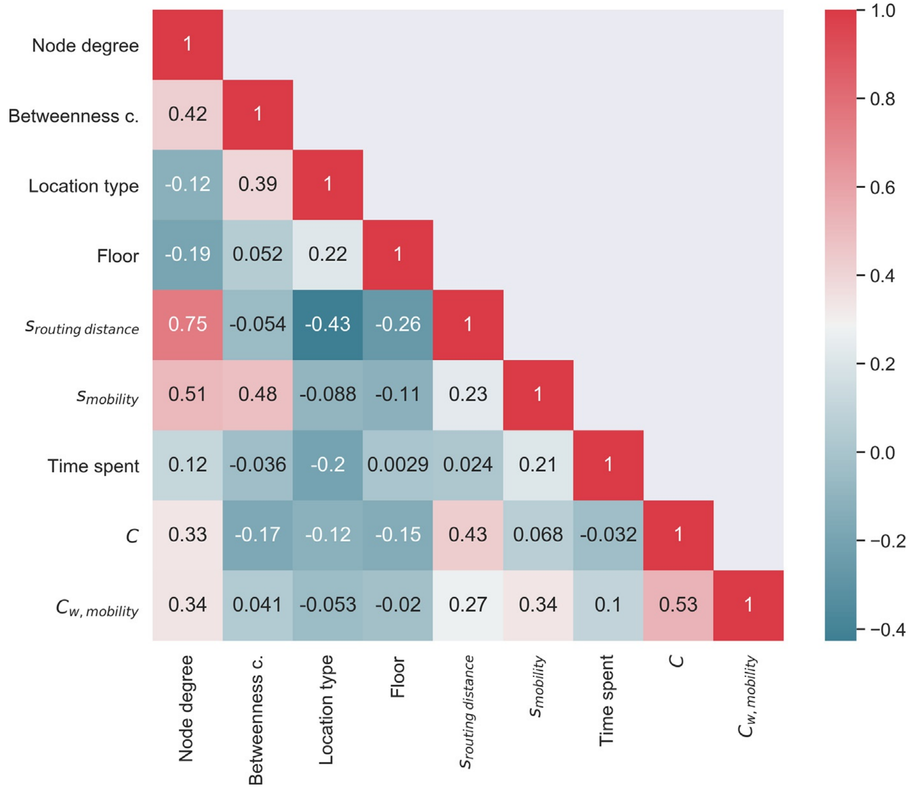


FIG. 12.20 Correlation matrix between network topology, space, and network processes of KA. *SUTD Cities: Urban Science and Design for Density.*

Figs. 12.27 and 12.28 show the comparative proportion of flows per node; we can see that nodes generally have a mid-week peak followed by a drastic drop in use on weekends, except in the Level 1 Community Plaza/Study Area (Area 2) which had a larger proportion of flow despite the overall dipping trend.

On weekends, the elevated links on Level 3 and Level 5 all show significantly lower use than the ground nodes. This suggests a bias or preference toward ground level space use. The Level 3 Skybridge (Area 2) shows a greater flow of use than the other elevated links. There are small daily fluctuations in flow volumes on weekdays for the elevated links and ground nodes, with the Level 1 Campus Center (Area 1) showing the most variation.

Importance of space levels in the KA and SUTD networks

We calculated the Degree Centrality, Closeness Centrality, Betweenness Centrality, PageRank, and Geographical PageRank for the 50 m reachable networks. Fig. 12.29 shows the distribution of these network metrics according to floor levels and location types. In the left column, almost all boxes (showing 25–75 percentile) of the same cases overlap, indicating that floor levels had weak effects on the nodes' importance levels. One exception exists

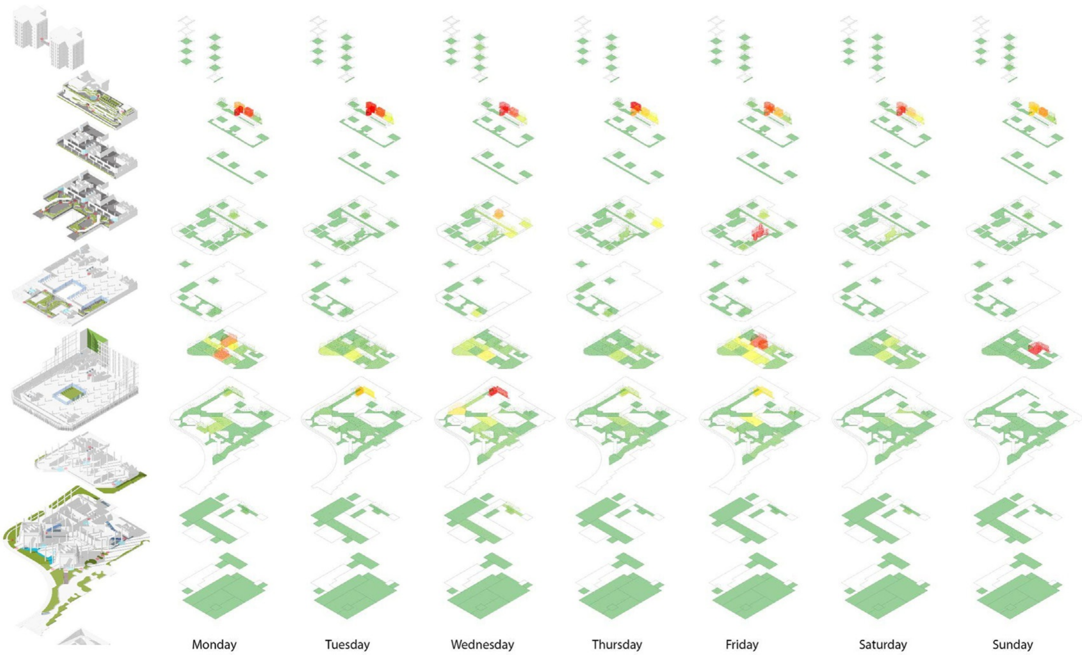


FIG. 12.21 Visualization of daily beacon activity heatmap, aggregated by the day of the week: (from left to right) from Monday to Sunday. *SUTD Cities: Urban Science and Design for Density.*

in the result for Betweenness. Boxes are low at lower floors and higher floors, i.e., Basements 1 and 2 and Level 11 for KA, and Levels 1 and 7 for SUTD. In the right column, we aggregated metrics according to five major location types and other groups, including main (residential for KA and education for SUTD), vertical street (Ver), community facilities (Fac), social spaces (Soc), and commercial spaces (Com). In the KA network, vertical streets, social spaces, and commercial spaces have slightly higher Degree Centrality, Betweenness Centrality, and PageRank. In the SUTD network, the patterns are slightly different. Commercial spaces have lower Degree, Betweenness, and PageRank. The vertical streets and social spaces have higher Betweenness Centrality in both networks, indicating that these locations might be used more than others. The Closeness Centrality result is similar to the left column. Most of the boxes are covering each other. The geographical PageRank result shows that the vertical street's scores are higher than the four other groups in both networks.

One interesting observation is about the vertical streets. In buildings, the spaces on each level are typically connected and form clusters of nodes (communities) and the vertical circulation or "streets," including stairs, escalators, and lifts, connect the different levels. Thus, we expected the vertical streets to act as "bridges" between floors. However, we found that these vertical streets (especially the lift lobbies) not only have higher Betweenness, but also higher Degree PageRank and Geographical PageRank. This indicated that the vertical streets also act as hubs in the two networks. Looking more closely at the KA network structure result, the connected lift lobbies form the cores of densely connected communities, while other spaces (e.g., residential units and community facilities) connect to the lift lobbies core nodes.

FIG. 12.22 Placement of Sensmax people counter in SUTD. *SUTD Cities: Urban Science and Design for Density.*

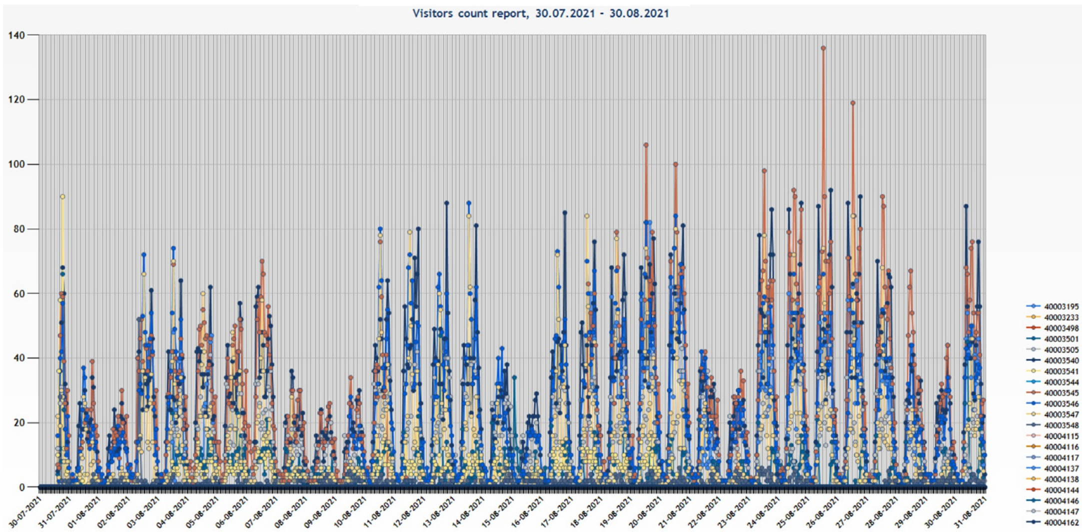


FIG. 12.23 Visitor count report over 7 weeks (July 30 to September 16, 2021). *SUTD Cities: Urban Science and Design for Density.*

This observation also highlighted the uniqueness of a vertical urban network in which hub-like bridge nodes exist.

When comparing the Network Centrality measure patterns with actual movement flow data in KA and SUTD, we see that the results indicate the use of vertical streets (lifts and staircases) as dominant connecting nodes between clusters of levels. However, it is also worth important to note that several vertically elevated nodes that serve as horizontal connectors or bridges between buildings also stand out, showing substantial movement flows. In KA, these include the Level 6 skygardens which serve as a bridge between the residential program clusters and commercial/social programs. In SUTD, they include the Level 3 and 5 skybridges between Buildings 1 and 2, as well as the Level 3 Skygarden that connects the Campus Center with the Library in Building 1.

The shared features of the buildings—vertical integration with social and landscaped spatial programs located at ground and elevated levels—result in shared characteristics in terms of vertical streets that connect clusters. This is despite of the fact that the two developments are different building types, one with a mixed-use and the other with an institutional program. This points to a possible correlation of space use in vertically integrated buildings in general.

In conclusion, the comparison of the predicted space use and movement patterns with the actual user-space interactions provided us with important insights into the performance of social spaces. We were able to identify critical factors that influence the performance of the public spaces in KA and SUTD by studying network metrics, node configurations, attributes, adjacencies, and topologies within the respective networks. The analysis of the various socio-spatial network measures provided us with important insights regarding the

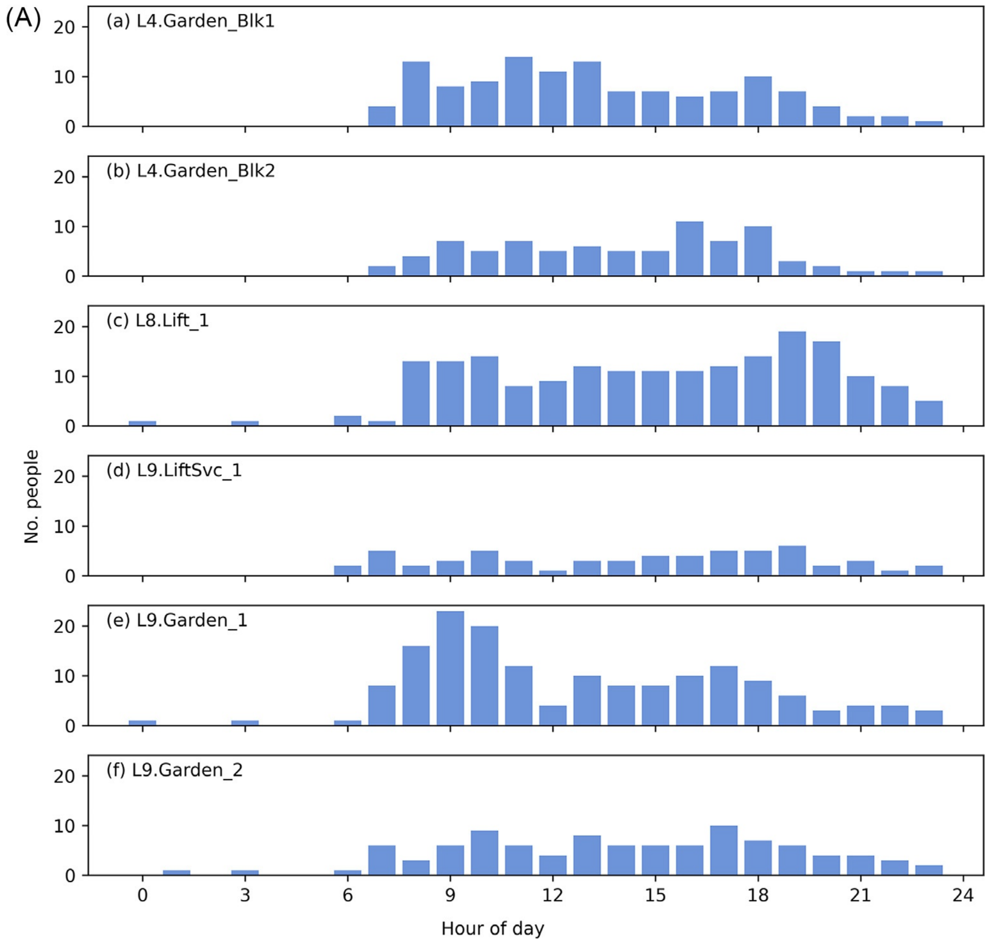


FIG. 12.24 The people counter data aggregated to show the hourly use of gardens (A) and the hourly aggregated use of all community facilities (B). *SUTD Cities: Urban Science and Design for Density*.

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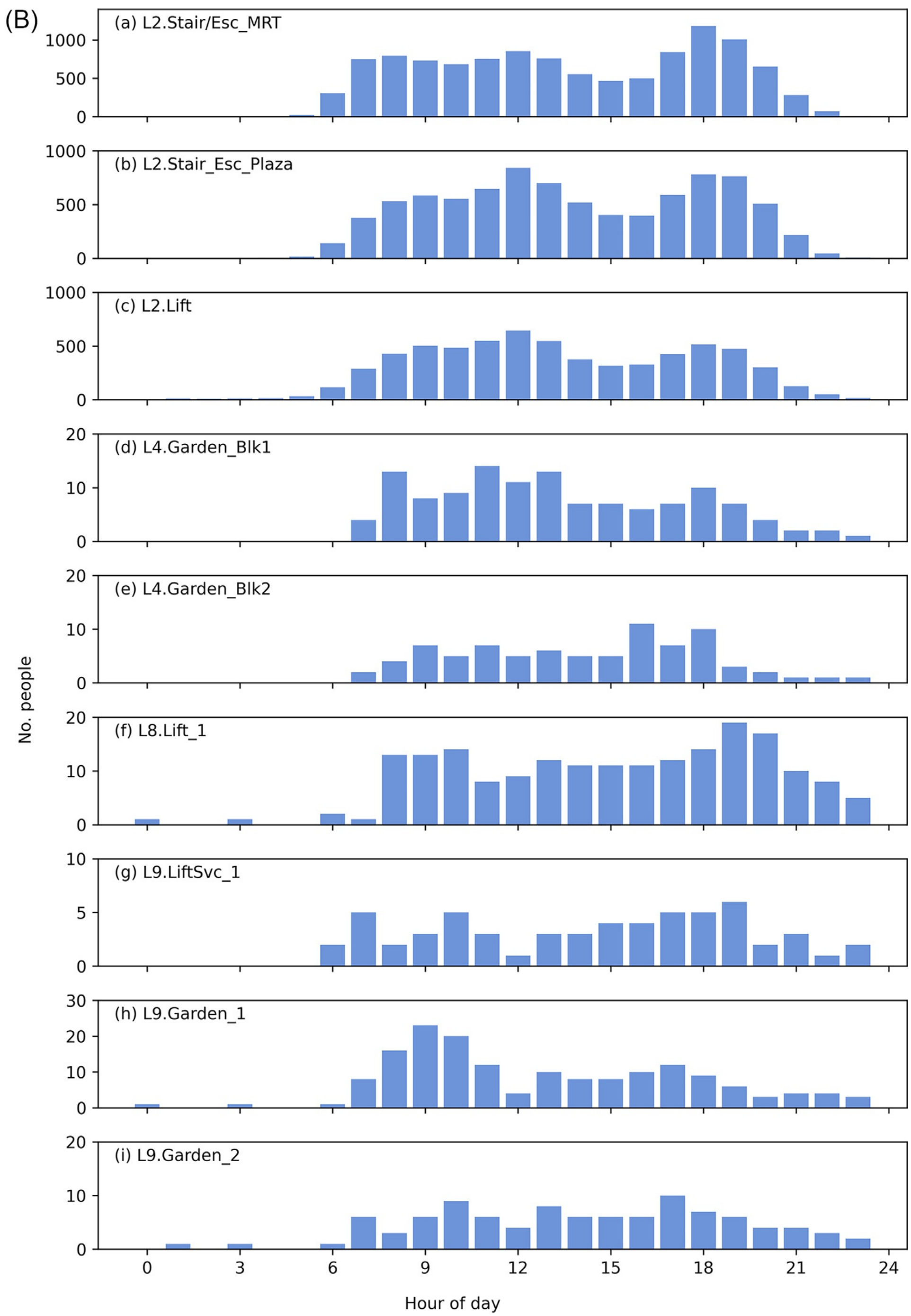

FIG. 12.24, CONT'D

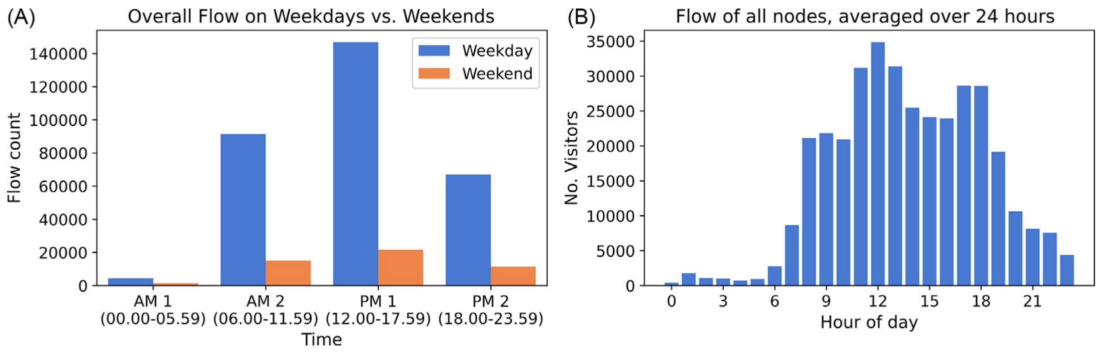

FIG. 12.25 Graph of overall flow on weekdays vs weekends (A) and flow of all nodes in Area 1 & 2, averaged over 24h (B). *No permission required.*

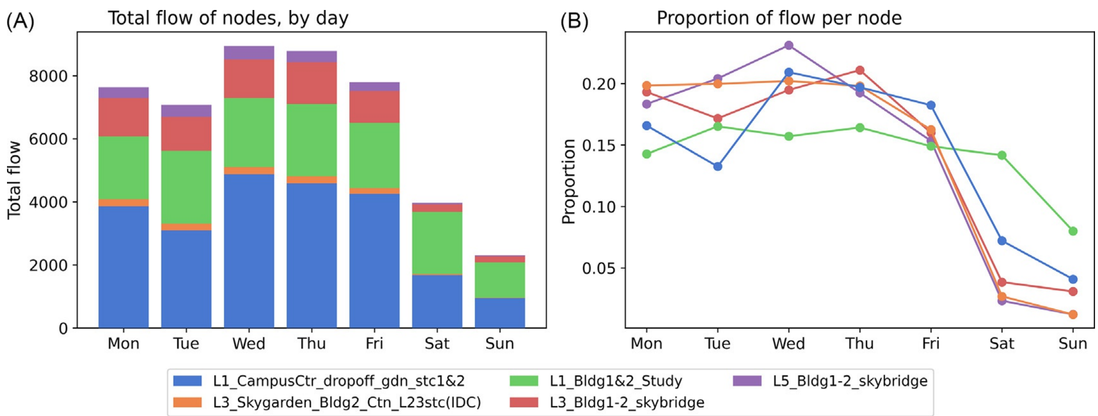

FIG. 12.26 Graphs of Total Flows of Nodes by Day (A), and Proportion of Flow per Node, divided by the total of the same location (B). *No permission required.*

FIG. 12.27 Comparison of weekday and weekend relative flow. *No permission required.*

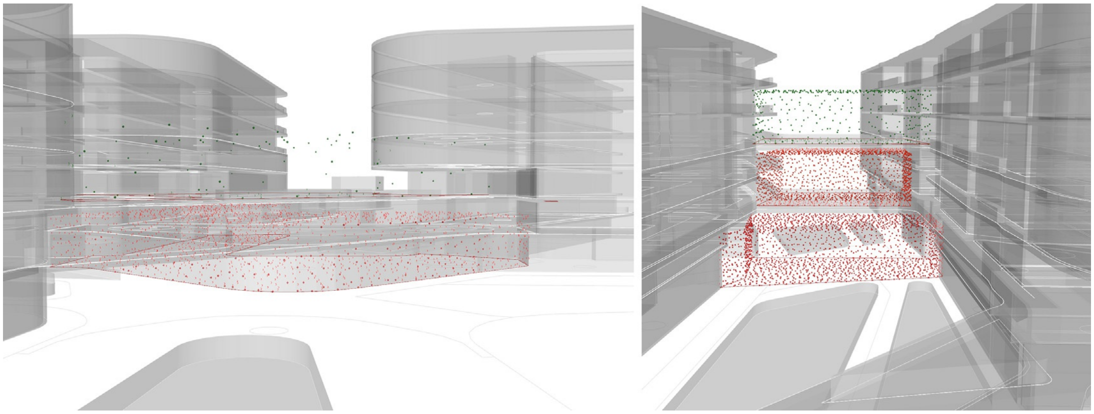

FIG. 12.28 Comparison of overall relative flow between ground and elevated areas in Areas 1(left) and 2(right). *SUTD Cities: Urban Science and Design for Density.*

parameters that should be considered in the further development of complexity science-based predictive planning and design methodologies.

Limitations of research and future plans

At the time of writing, our data collection in the SUTD study is still underway. Continuing our research, we plan to capture seasonal events such as term breaks as well. The analyses of the additional data will allow for a better understanding of longer-term space use patterns. Once available, we will process the additional Bluetooth-based tracking data with machine learning algorithms. This will allow for a finer granularity in terms of findings and therefore for a more detailed comparison of network measures with actual space use.

Our findings presented in this chapter are based on data collection that took place in 2020–2021 in a situation that was affected by the COVID-19 pandemic (Fig. 12.30). The population of Singapore was advised to stay at home as much as possible, to reduce outdoor activities and gatherings, to work and study from home, and to generally reduce physical interactions as much as possible. Although most human activities resumed to a certain degree after Singapore's "Circuit Breakers" (lockdown measures that started in April and ended in June 2020), the human movement patterns discussed here should be assumed as being irregular. For example, the circulation on the upper levels of SUTD was limited as access was only possible through the University's Campus Center. This situation led to an increase in the measurements of actual space use of the Campus Center and other main access points. Similarly, in the case of KA, social distancing was practiced and affected the activities (particularly, community gathering, various events that used to be held in the public space at Level 1, activities used to be held by the active aging hubs for elderly people, etc.) in the community facilities.

Further detailed analysis of the collected empirical flow data, flow network, and copresent network analysis should be conducted. In addition, through the analysis of the distribution of

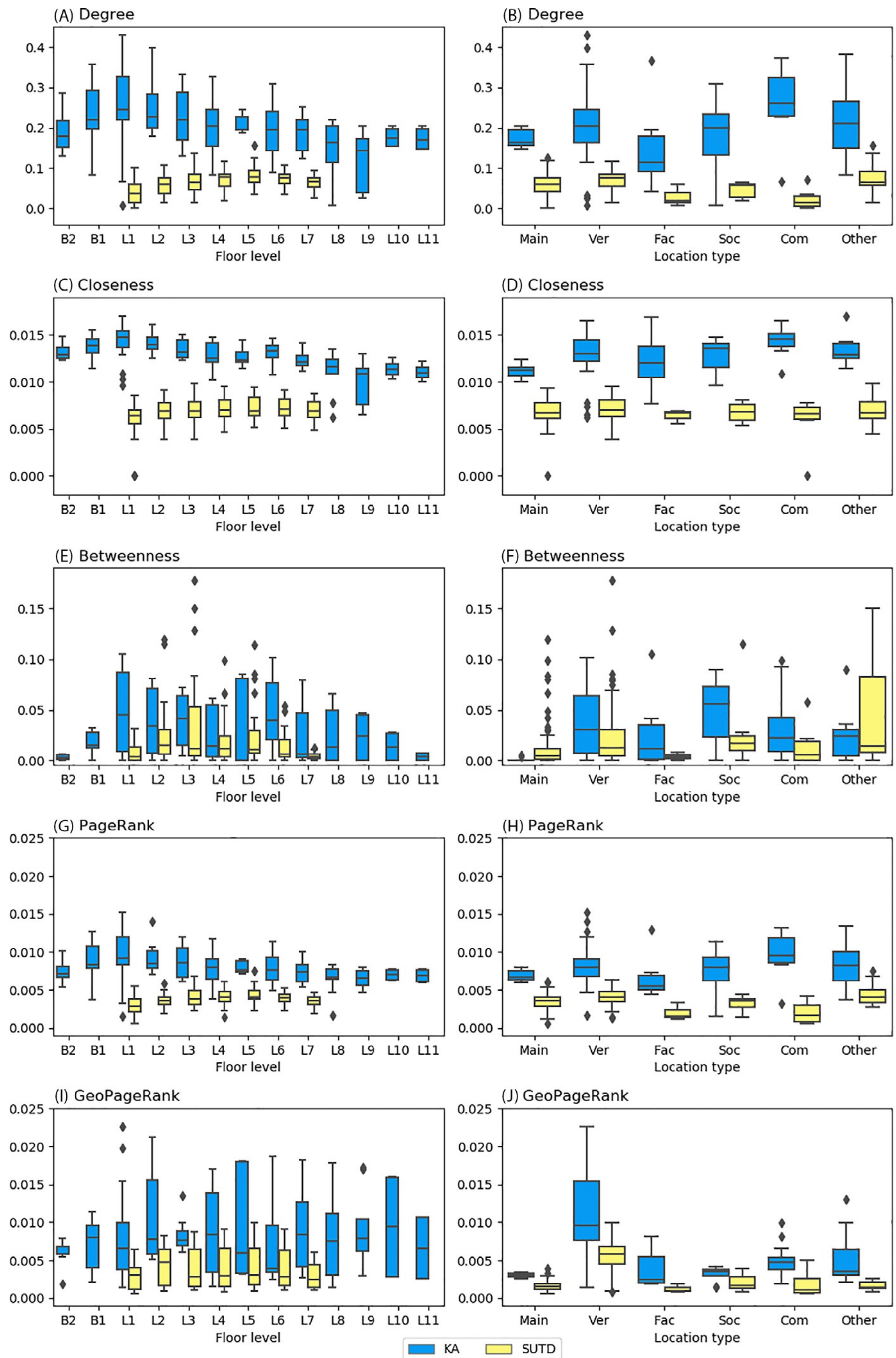

FIG. 12.29 Boxplots showing the distribution of the five network indexes for nodes on (left column) different levels and nodes in (right column) different location types for KA and SUTD. The box indicates the first and third quartile and the whiskers indicate the interquartile range (IQR). Note that the location type "Main" in the right column indicates the main program of the two networks, i.e., residential for KA and education for SUTD. *SUTD Cities: Urban Science and Design for Density.*

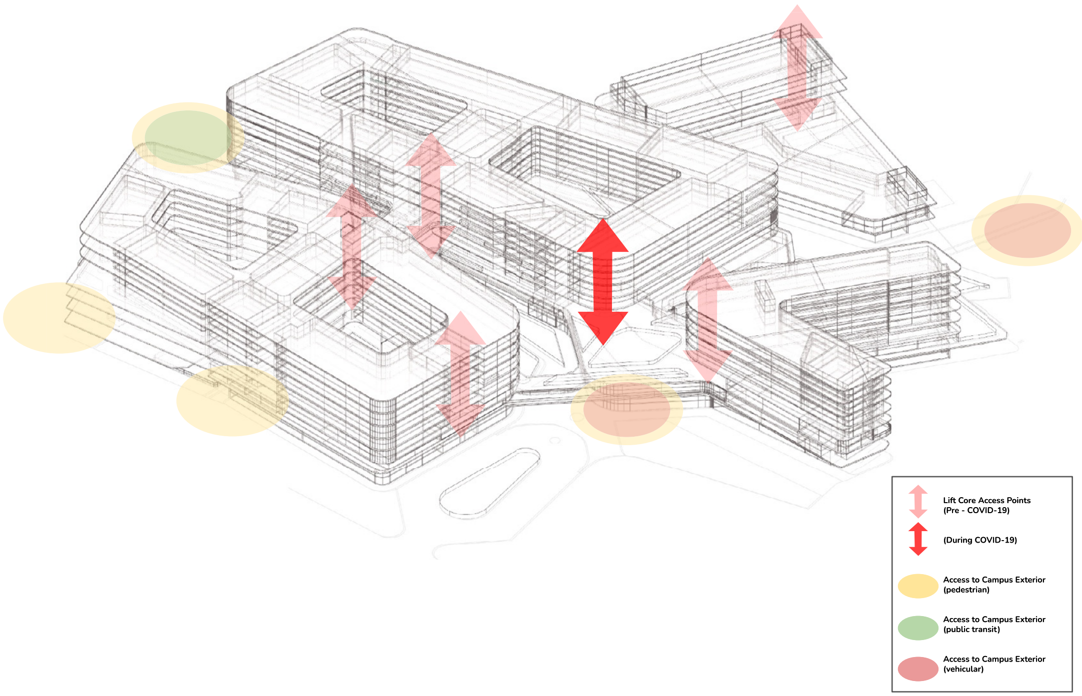

FIG. 12.30 COVID-19-related vertical circulation constraints in SUTD. *SUTD Cities: Urban Science and Design for Density.*

the flow data, appropriate distribution parameters should be obtained. This would allow for future agent-based simulations and large-scale scenario-testing analyses, such as: What would be the magnitude of the affected population if some movement policies (i.e., different stages of lockdown measures, such as movement control according to age groups or household sizes, or movement restriction according to distance) are applied.

Lastly, as mobile apps, social media, and governmental COVID-tracking health programs already capture proprietary movement ostensibly used in activity pattern analysis, compliance with ethical standards was paramount to our approach. Much debate and discussion around these issues in contact tracing apps such as Australia's COVIDSafe and Singapore's TraceTogether programs have taken place over the past months. Anonymization and opt-out options are therefore crucial and need to be implemented.

Conclusions

The research discussed in this chapter is based on both complexity science and AI. It enables us to study everyday space uses on a scientific basis. The scalability of the methodology allows for new ways of analyzing and evaluating multiple measures of space performanceand therefore future planning and design. In providing an empirical model of the socio-spatiality of an urban environment, it can help us to better understand its actual performance.

Our research methodology harnesses the ubiquity of smart devices and uses AI techniques to cluster emergent patterns of user activities that are subsequently embedded in the specific dimensions and spatial parameters of the built environment. The further use of AI tools and techniques that we are currently developing for activity classification will allow us to understand better how human flows and space uses form emergent clusters and patterns that correlate with spatial nodes and their properties. This will ultimately result in more complete spatial analyses that include temporal and copresence patterns and factors that can help us comprehend the correlation of planning and design intent and the actual performance of built environments.

Until now, complexity science-based approaches to urban planning and design have been mainly applied at large scales, using statistics to understand emergent patterns and flows of resources, e.g., urban metabolism (Kennedy et al., 2011) or scaling effects of wealth, innovation, and crime (Bettencourt et al., 2010). AI-aided approaches to the study of mobility have mainly been used to provide commercial services such as geolocation for advertising on the Web and social media-based platforms, traffic management and sensing systems such as autonomous vehicles, and transportation intelligence, e.g., in ride sharing systems and urban mobility mapping, but not to analyze buildings and their relationships to the urban contexts they are part of. Our approach aims to fill this gap to inform planning and design decision-making processes more holistically. The comparison of intent with results of spatial network analyses and actual on-site measurements can provide important insights regarding spatial performance. This includes, but is not limited to, the placement of important social urban and architectural spaces at locations that correlate with high Degree Centrality, elevated connections at node points with high Closeness and Between Centrality measures, and the provision of programs that support the function of nodes. Such insights into spatial performance suggest show the potential of applications of complexity science and AI for future urban planning and design processes.

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