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Subjects:	Architectural/Design Urban Design
Keywords:	Human-Centric Public Space Urban Design Urban Planning Virtual Reality
Publication Date:	2020
Original Publication:	CTBUH Journal 2020 Issue I
Paper Type:	1. Book chapter/Part chapter 2. Journal paper 3. Conference proceeding 4. Unpublished conference paper 5. Magazine article 6. Unpublished

Tall Buildings' Lower Public Spaces: Impact on Health and Behavior

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Abstract

Tall buildings unquestionably need to improve their impact on the urban habitat. A human-focused approach to measuring the social impact of tall buildings' ground conditions, i.e., public space and interface, has been applied in three CBDs of Asian megacities facing similar problems: Shanghai, Hong Kong and Singapore. Specifically, typical patterns and categories of lower-level public spaces among the three CBDs were abstracted via typological analyses and field studies. Evaluations of social impacts were achieved through statistical surveys, wearable devices and virtual reality environments. The study revealed the quantitative relevance between tall buildings' lower public spaces and their social effects. The findings of this study could support more efficient place-making and promote better social benefits around tall buildings' ground planes. The research also suggests a design code for tall buildings aimed at a more human-oriented urban habitat.

Keywords: Urban Habitat, Ground Plane, Tall Buildings, Urban Design, Urban Planning, Spatial Analysis

Introduction

Designing tall buildings as participating components of the urban habitat, rather than as objects that stand aloof from their environments, has become an important concern. Evidence shows that positive behaviors encouraged by high-quality public spaces, e.g. social interactions and physical activities, may contribute to physical, mental and social well-being (Evans 2003). As public space is crucial to people's quality of life, there is strong justification for further studies on the most essential and urban parts of tall buildings, i.e., public spaces, podiums, and the interfaces of tall buildings with their environments, from the ground plane up to the fifth floor, referred to here as "lower public spaces."

Nevertheless, the lack of quantitative understanding cannot support efficient architectural design or urban renewal targeted at better place-making. Aiming to fill this gap, a human-focused approach for measuring the social impact of tall buildings'

lower public spaces has been applied. The stated preference (SP) survey is suitable for complicated scenes, in which observed behavior is inadequate and is thus widely applicable to high-density built environments (Ulrich et al. 1991). Three more approaches are used to compensate for the shortcomings of the SP survey. First, virtual reality (VR) techniques are introduced to compensate for the inability of SP to illustrate the complex features of the high-density built environment in social interaction (Schofield and Cox, 2005). Second, the analytic hierarchy process (AHP) is introduced to simplify the process of an SP survey faced with numerous features (Lo et al. 2003). Besides, exploratory data analysis (EDA) was used to evaluate lower public spaces' impacts on participants' health. The results were used to verify the discrete choice model. The combined application of SP, AHP, VR methods, and biometric data will help to achieve a systematic and objective evaluation of perception-based and behavior-oriented studies of the built environment.

2018 CTBUH Research
Seed Funding recipient,
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Methodology

Analytical Framework

First, three central business districts (CBDs) of Asian megacities were selected as cases: Shanghai, Hong Kong and Singapore. All three CBDs are facing similar problems because of the lack of urbanity around tall buildings at street level. Typical patterns and categories of lower-level public spaces among the cases were abstracted via typological analyses and field studies. The following evaluations on social impacts were achieved through the AHP via expert rating and SP survey. Virtual reality techniques were applied in the SP survey to create an immersive, three-dimensional environment for illustrating different combinations of spatial patterns. People's perceptions and personal preferences were collected as representations of social performance. Data collected from interview and biometric sensors were used to verify the results of the SP surveys. After that, the discrete choice model was used to run statistical analyses.

Finally, the assessment of tall buildings' lower public spaces was established and applied to three study areas. Finally, a total of 171 participants were invited via the Internet. Sixty-four participants were male and 107 were female. Most participants had no prior VR experience.

VR Scene Design

The simulation of real experience was crucial for spatial evaluations in the VR environment. The more a representative model resembles the real environment, the more reliable participants' responses are (Kuliga et al. 2015). The basic scenario of this research was selected from the typical features of the three CBDs.

Tables 1 and 2 present some built environment features collected from the three CBDs. Based on those data, the basic scene included six blocks with a width of 212.8 meters. Each block had four tall buildings. The buildings' basic volume was 40 × 40 meters, and the building spacing was 10 meters. Road facilities and signs, including street lamps, traffic signals and traffic signs, etc., were placed to increase the realism of the scene. To simulate a real pedestrian experience, public spaces' models in each scene were placed in pairs on participants' left and right sides. By observing a panoramic video in the VR environment, participants were asked to state their preferences between the two models (see Figure 1).

CBD	Block Length (m)	Sidewalk Width (m)	Street Width (m)	Building Length (m)	Building Spacing (m)
Lujiazui	160~220	6~13	4~8 Lanes	45~75	
Central	80~100		2~6 Lanes	15~60	
Marina Bay	150~200	3~18	4~5 Lanes	30~60	8~12

Table 1. Typical features of built environment in three CBDs.

Case	IAPM Shanghai (Lujiazui)	Shanghai Center (Lujiazui)	K11 Shanghai (Lujiazui)	Pacific Place (Central)	C-03 (Central)	C-111 (Central)	C-67 (Central)	M-04 (Marina Bay)	M-36 (Marina Bay)	M-39 (Marina Bay)
Building Footprint (m)	155x65	90x60	86x53	220x50	90x75	60x25	70x30	132x50	80x80	72x63
Spatial Diagram										

Table 2. Typical features of tall buildings with podium public spaces.

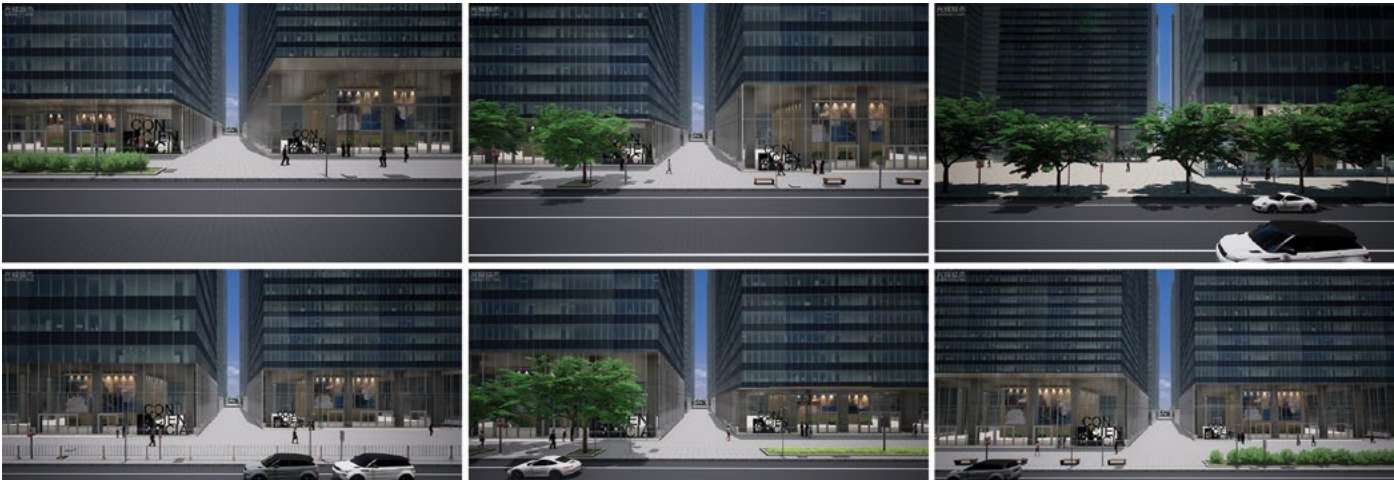


Figure 1. Part of the experimental scene in the VR simulation. Spatial attributes were added and removed, and participants' reactions scored and recorded.

Considering the number of variables, it was impossible to make pairwise comparisons between every set of two variables. Orthogonal design was used to test the effects of the variables simultaneously in a minimal number of experiments. Variables from four categories were tested separately during the experiment. The list of VR scenes was exported into SPSS software. Every scene includes different values of variables from one category. Each group had at least

20 scenes for pairwise comparison. To ensure statistical validity, each value of variable appears more than four times in the group.

Variable Design

This study concentrates on morphological variables that provide visual perceptions in tall buildings' lower public spaces. Beyond their spatial typologies, objects and artifacts therein, and the interfaces that help to define the physical boundaries of the spaces,

are also connoted (Mehta 2014). Considering that public spaces may be situated at height, the experimenters suggested that categories of lower public spaces should be classified from two viewpoints: from the street as well as from a podium's rooftop, at a height not to exceed 22 meters. For each category, detailed measurements of inner values were introduced. The potential effects among those variables were evaluated.

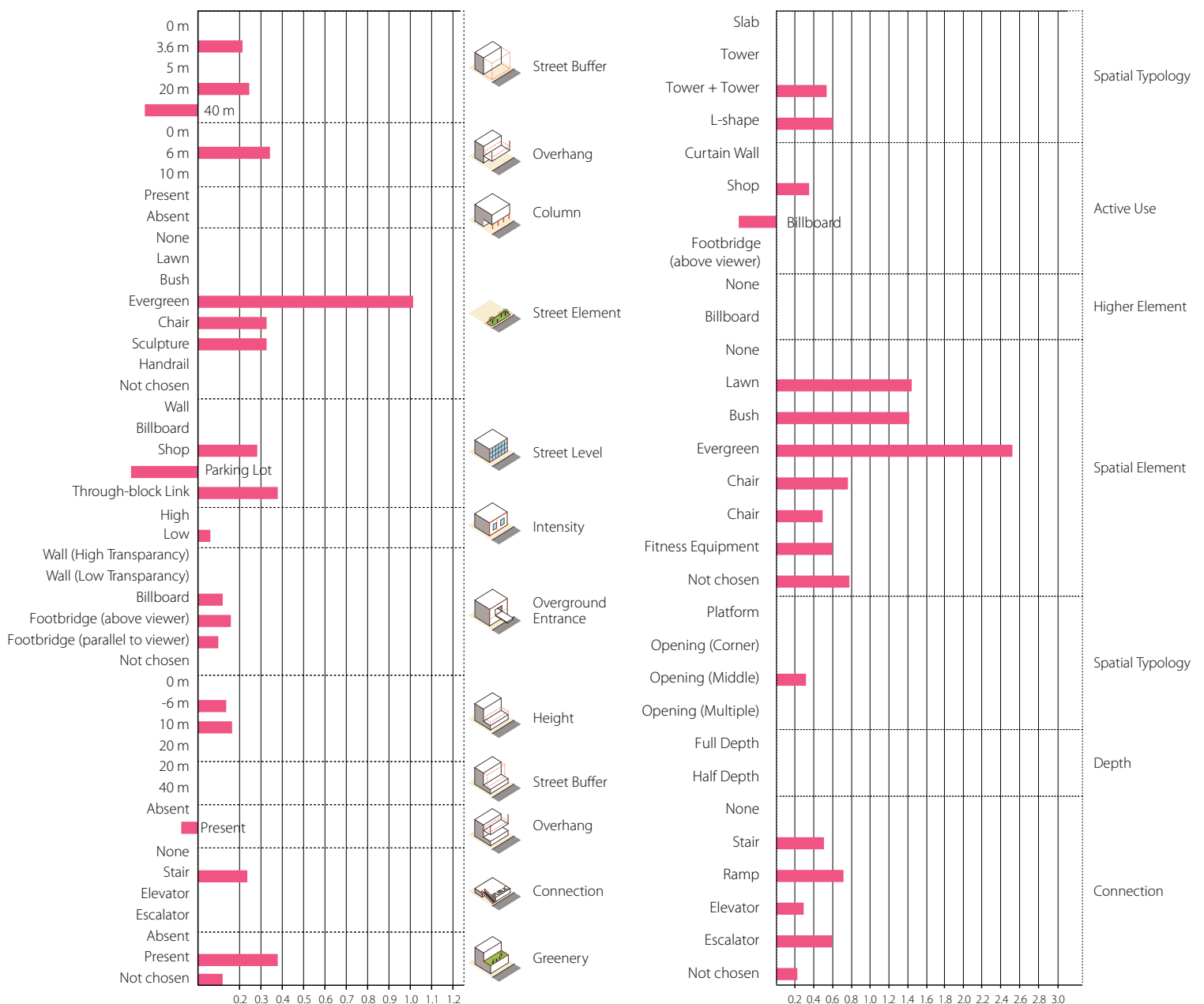


Figure 2. Utilities of categories, as rated by experiment subjects.

Summary of Results

Utilities of Variables

Figure 2 shows the results of the evaluation. According to the results, when viewpoints were on the street, “trees” along the streets had the highest scores. Next came “through-block links” and arcades at 6 meters’ height. “Sculptures” and “chairs” along the streets had similar utilities, slightly higher in weight than plazas of 20 meters square. The results showed that variables in the “spatial typology” could benefit lower public space environments by providing shaded spaces and shortcuts. Plazas at a small scale might have similar utilities as the street buffers placed every 3.6 meters. Both variables created a suitable sense of enclosure for pedestrians.

Meanwhile, variables of “spatial elements” might benefit lower public spaces by providing shaded and sitting places, satisfying enclosure, and visual stimulation for spatial imageability, as documented in Sullivan et al. (2004). The active use of tall building ground floors also showed significant scores. “Shops” had similar utilities to plazas of 20 meters square. Similar to results of Ye et al. (2018), stores and small catering businesses such as bars and restaurants are considered basic components of vitality and safety. “Parking lots” and plazas of 40 meters square had negative utilities in the model. The interruption of the sidewalk in the front, and the potential of vehicles hitting pedestrians while entering and exiting parking lots, may make pedestrians feel unsafe.

When viewpoints were on the podium rooftops, all greenery scored highly for the spatial environment. In line with results from Cook and Gilbert (2015), natural processes and built environments are integrated with the help of these features, allocating varied spaces for social activities. Next came “chairs” on the rooftops and “ramps” connecting to higher public spaces. The typologies of tall buildings also had strong influences by composing identical interfaces of lower public spaces. Typologies with strong enclosures (L-shapes and double towers) were preferred by participants for identity

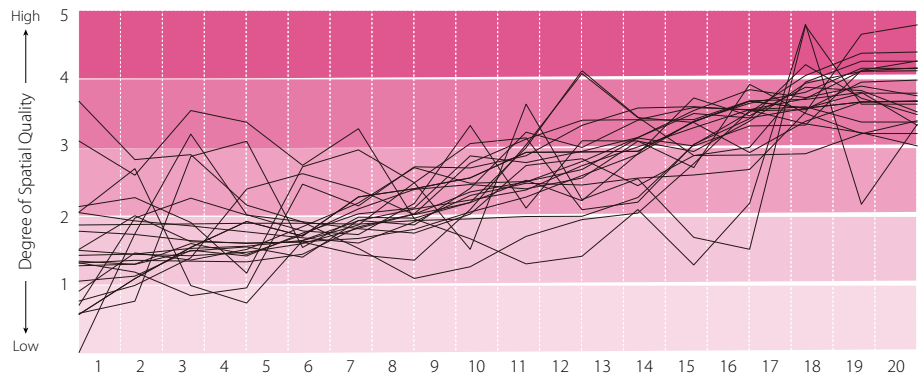


Figure 3. Smoothed EDA signals of 20 participants.

and safety concerns. Other public spaces that have a horizontal connection lower than a podium rooftop were rated higher. This finding suggested that public spaces that are higher than street level have lower visibility, whatever their functions might be. It is worth noticing that connections that provide places to stay (stairs, ramps) were preferred to direct transportation (elevators). Several participants believed that these connections implied that spaces behind them had higher openness and publicity. Advertisements on the first floors of rooftops were negatively scored. Many participants reported that advertisements might block communication between indoor and outdoor spaces.

Verification with Biometric Sensors

In this study, EDA was used to verify results from the SP survey. The EDA measured by the biosensors is an index of sweat excreted by the eccrine glands, which is connected to the sympathetic nervous system. It gives real-time measurements of participants' emotional responses, especially in the progress of stress and recovery (Boucsein et al., 2012). Empirical studies show that the EDA increases when people are facing urban environment with heavy traffic, and it decrease when facing natural environment or green spaces (Ulrich et al., 1991; Zhang et al., 2018). Therefore, it could be used as a reflective index of the spatial qualities of VR scenes. Herein, the team applied the E4 wristband to achieve the measurement on participants.

Nevertheless, collecting the EDA by way of a wristband is quite time-consuming. Herein, the scenes in “Single Spatial Typology” were

selected as the test. A total of 26 participants were involved in this study, with all having their EDA values measured. Fourteen were male and 12 were female. None of them had participated in the previous experiments. The experiment began after a short break, when EDA became stable. Then participants were arranged to view VR scenes according their measured spatial quality, from high to low. They were not informed on the detailed sequence of the scene arrangement in the whole procedure. Figure 3 shows the smoothed EDA signals of valid data. Most of the participants' EDA signals rose when the spatial qualities of VR scenes became worse.

Multiple linear regression analysis validates the impact of lower public spaces' variables on the physiological indicators of the participants. As shown in Table 3, the R square of the model is 0.210, and the adjusted R square is 0.194. The F statistic is significant at the 1% level. Most variables of lower public spaces obtain weak but significant correlations with participants' stress, as reflected in EDA signals. The results verify that lower public spaces may affect users' physiological levels.

As shown in Table 3, most variables are significant at the 5% level per the t tests. Variables were ranked according to their utilities, from low to high. Specifically, the values of “street buffer,” “covering height,” and “street element” are significantly negatively correlated to EDA signals, which means that participants feel more nervous while giving low scores. Observations of “columns” are positively correlated to EDA signals. The existence of columns in arcades could bring a

Variables	Coefficient	StDev	t-statistic	p-value
Constant	5.476	1.967	2.784	0.006
Street Buffer (Left)	-0.372	0.412	-0.903	0.367
Overhang (Left)	-1.569***	0.382	-4.106	0.000
Column (Left)	1.809***	0.577	3.137	0.002
Street Element (Left)	-0.269**	0.134	-2.012	0.045
Street Buffer (Right)	-0.719***	0.252	-2.852	0.005
Overhang (Right)	-1.451***	0.367	-3.958	0.000
Column (Right)	1.099*	0.616	1.784	0.075
Street Element (Right)	-0.476**	0.214	-2.218	0.027

***, **, * = Significance at 1%, 5%, 10% level.

Table 3. Coefficient of variables in “Single Spatial Typology”

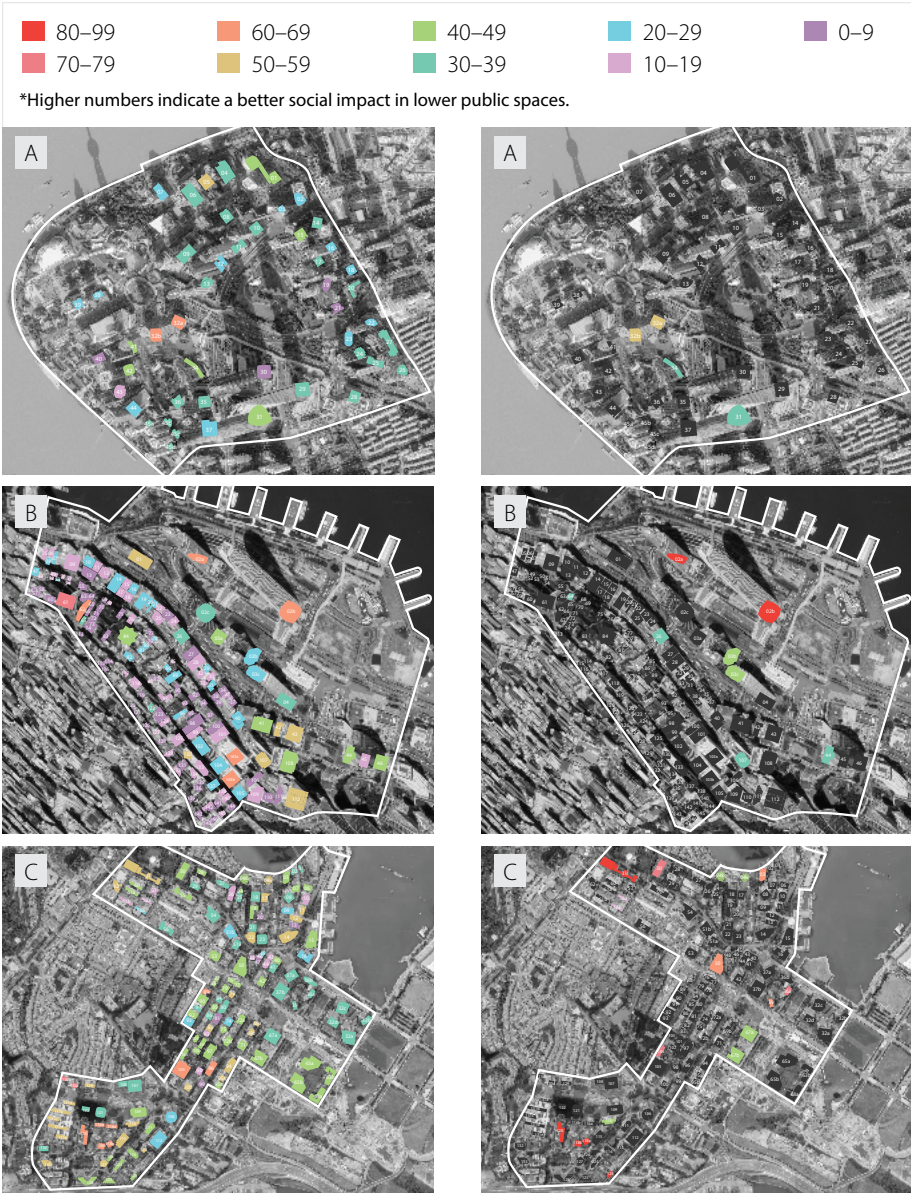


Figure 4. Evaluation results in study areas (viewpoint on street) (a. Shanghai, b. Hong Kong, c. Singapore).

Figure 5. Evaluation results in study areas (viewpoint on podium rooftop) (a. Shanghai, b. Hong Kong, c. Singapore).

sense of stability by defining the boundaries of the space more clearly. Overall, the model fits well with the results from the SP survey.

Visualized Evaluation and Design Paradigm

Evaluation at the Urban Scale

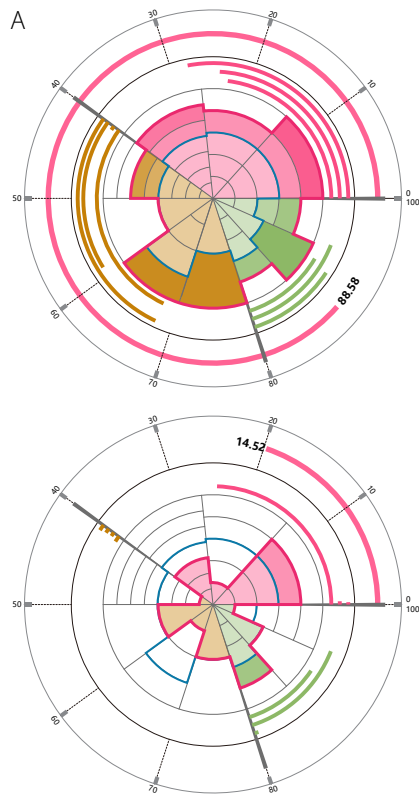
The results of the evaluation were applied to evaluate the performance of study areas. Ranging from 0 (colored purple) to 100 (colored red), a higher rate indicated a better social impact in lower public spaces or, in other words, a stronger capacity to encourage positive social behavior and use of the environment (see Figures 4 and 5).

The areas with average scores ranked from highest to lowest were Marina Bay, Lujiazui, and Central. However, both the maxima and minima scores in Central were higher than those of Lujiazui. The low proportion of shops and oversized streets make lower public spaces in Lujiazui unpleasant for pedestrians. Most of the tall buildings in Marina Bay provide arcades and greenery in their lower parts. The street buffers in Marina Bay are more pleasant at a human scale than those in the other locations. “Shops” represent 83.8% of “active uses” in Central. Nevertheless, pedestrian pleasure is decreased by narrow sidewalks without setbacks and the lack of urban furniture and greenery.

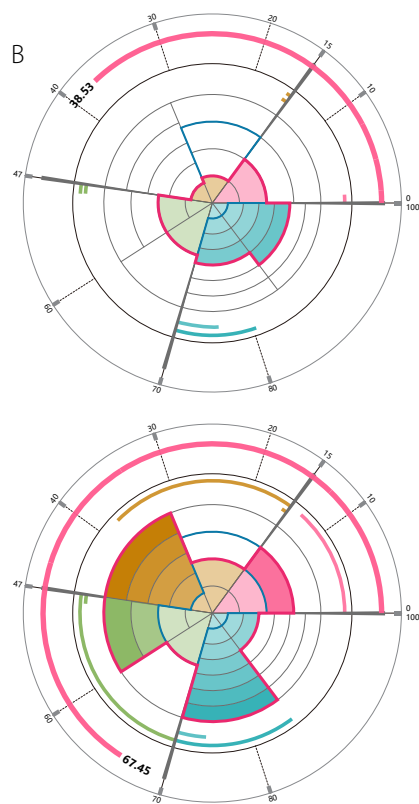
Only a few tall buildings provide public spaces on their podiums in the study areas (four in Lujiazui, eight in Central and 18 in Marina Bay, including tall buildings that share the same podiums). Scores of lower public spaces on podiums in three study areas are alike. These spaces are usually indicated by greenery (evergreens and bushes) inside, and most of the “fitness equipment” on podiums consist of swimming pools. However, without strong connections to ground level, the visibility of these spaces is doubtful.

Evaluation at the Architectural Scale

Figure 6 shows the visualized evaluation for measuring the positive effects of tall building’s lower public space on behavior and health. This diagram is composed of four parts: first, the circle is divided into different



A: Viewpoint on street
(top: high-quality case; bottom: low-quality case)



B: Viewpoint on podium's rooftop
(top: high-quality case; bottom: low-quality case)

Figure 6. Visualized evaluation for measuring the positive effects of a tall building's lower public space on behavior and health. The length of the arcs represent the final scores of each lower public space.

sectors according to their utilities computed in the AHP model (e.g. for street viewpoint, the categories are "spatial typology (single)," "spatial typology (multiple)," "active use," and "street element"). Second, variables in each sector are arranged according to their utility. The closer the utility is to 0, the closer the variable is to the center of the circle.

Therefore, as seen previously in Figure 2, the higher score occupies a larger space in the diagram. Meanwhile, the length of arcs represents the final scores of each lower public space. In this way, this diagram is applied in the evaluation of the lower public spaces' effects at the architectural scale. Figure 7 shows the results of representative examples.

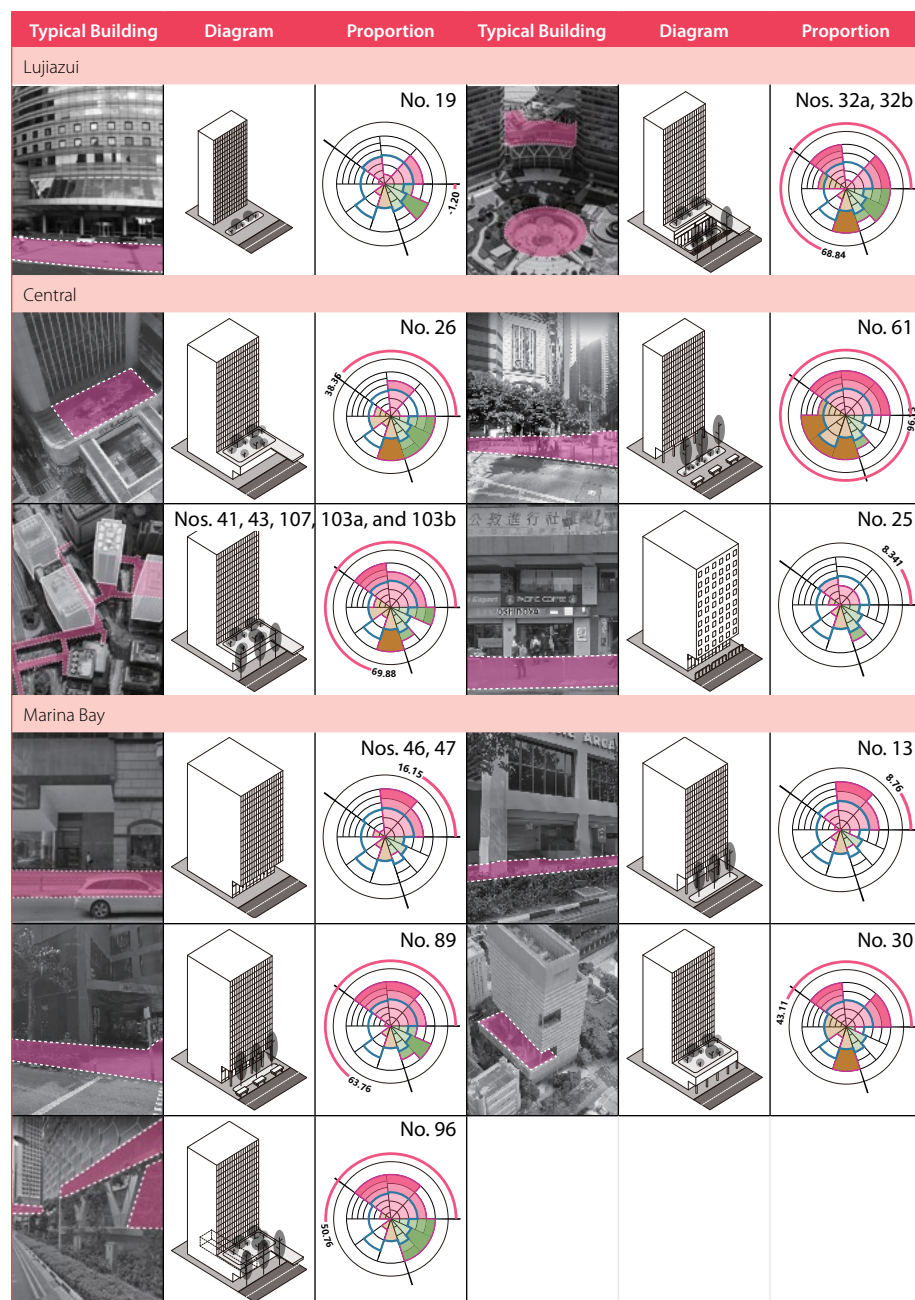


Figure 7. Lower public spaces in each of the study areas. The length of the arcs across all categories represents the final score of spatial quality for each location.

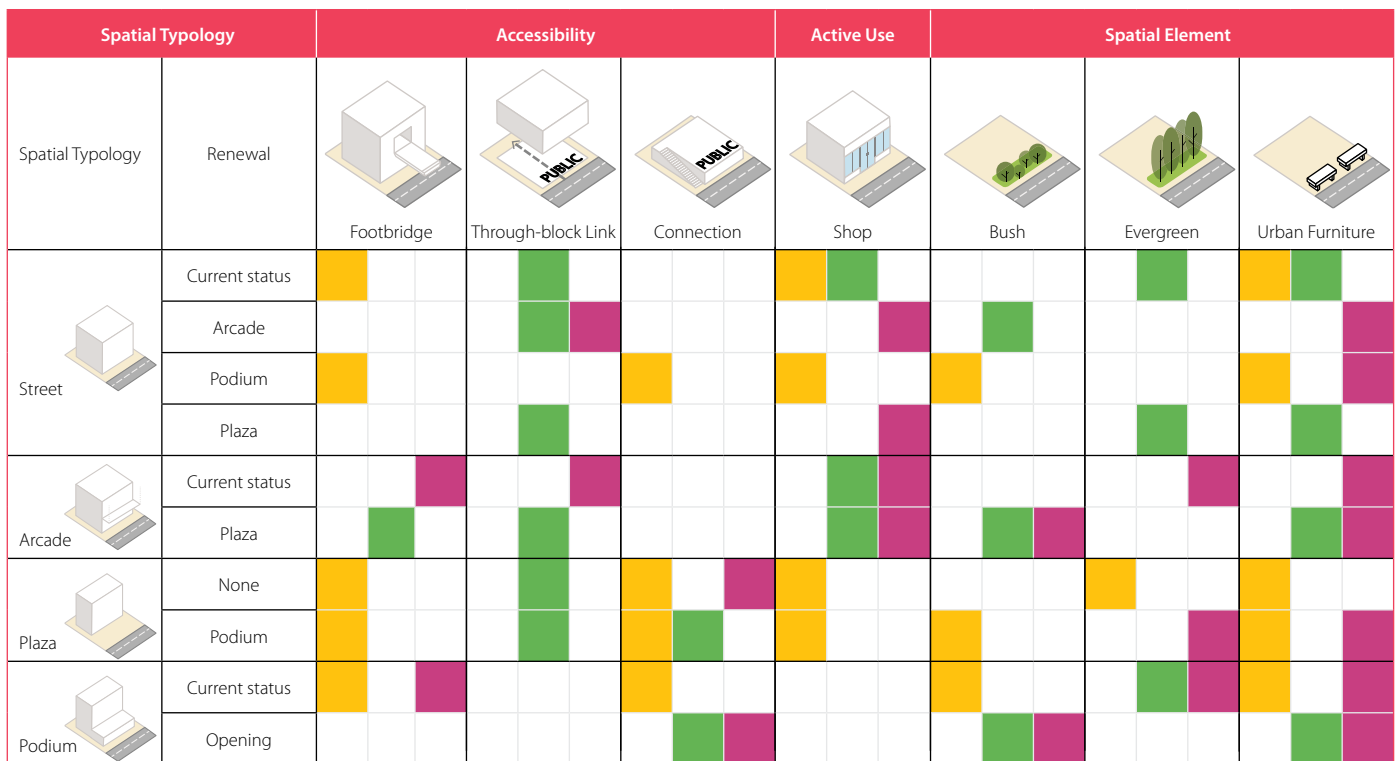


Figure 8. Lower public spaces in each of the study areas.

■ Lujiazui ■ Central ■ Marina Bay

Examples from Marina Bay and Central prove the importance of multilevel walking networks to lower public spaces. Nos. 94 and 96 in Marina Bay are linked with another building on the opposite side via a skybridge. In addition, the through-block link in the middle of No. 94 provides a shortcut to cross the block, which improves the quality of its public space as well. The gathering effect of a multilevel walking system appears strongly in Central. In two cases, where an elevated walkway links Nos. 41, 43, 103a, 103b, 107; and a second elevated walkway connects 2a, 2b, 2c, 3a and 26, scores are higher than their surroundings. The central elevated walkway connecting these buildings extends their public spaces among each other, thereby overcoming the disadvantages brought by narrow streets and heavy traffic.

The evaluation results also help to suggest paradigms for the design of lower public spaces (see Figure 8). Since the urban environment of the three CBDs has been basically formed, the design paradigms need to achieve maximum benefits with minimal

construction or retrofit costs. Targeted discussions on three CBDs are needed (see Figure 9). Lujiazui has been criticized for its large-scale and imperfect city functions. Given that reforming of public spaces should be considered as the primary goal, the model suggests expanding the building volume into additional podiums using existing setback spaces, providing room for retail enterprises and other urban facilities. A multi-level public space system component with a small-scale plaza and roof garden, instead of large setbacks, is recommended to bring the public spaces in this area back to a human scale.

The model suggests that tall buildings in Central should engage with their surroundings more positively through plazas or pocket gardens around the sites' corners or edges. These public spaces could create open spaces and even passages for pedestrians. Given the local climate, the plaza could be partly covered and filled with plants and urban furniture for validating social activities.

Marina Bay is faced with a new period of transformation, because of the uneven and highly selective nature of multinational corporations (Wong, 2004). Creating an urban public system that connects this district as a whole matches the increasing demands for flexibility. A paradigm focusing on accessibility between the urban environment and several lower public spaces would be helpful. We suggest creating more passable public spaces on the ground level, with higher levels of gardens and platforms linked via clear connections, such as escalators. Arcades should also be continuous between neighboring buildings, given climate considerations.

Conclusions and Limitations

Taking three CBDs in Shanghai, Hong Kong, and Singapore as cases, this study provides a quantitative approach to evaluating the social impacts of tall buildings' lower public spaces. The integration of SP, AHP and VR methods reveals how different patterns of

tall buildings and their surrounding environments encourage social interaction and physical activities, and hence influence users' behavior and health. In-depth, quantitative understandings achieved from this study can assist in efficient place-making for tall building ground conditions, promoting positive social benefits.

This study also helps to suggest a design code for tall buildings aimed at a more human-oriented urban habitat. The public spaces in CBD areas should not only be promoted on the ground level, but also should be developed in the vertical dimension. Vertical pedestrian networks with high accessibility could mitigate the limits of cramped public spaces around particular buildings. Meanwhile, creating public spaces in the vertical dimension could also relieve the contradiction between floor-area ratio (FAR) maximization and civic activity demands. Understandings suggested by this study might contribute to achieving a balance between social and economic benefits of tall buildings, and the improving the accessibility and security of public spaces.

There are several unresolved issues, for future research. First, the pool of participants needs to be expanded to provide in-depth descriptions of lower public spaces' social impact. Besides, the social impact of public spaces is a multidimensional, complex problem. Impacts of economic, management, and transportation aspects should be included and evaluated to build a more comprehensive model. ■

Unless otherwise noted, all image credits in this paper are to the authors.

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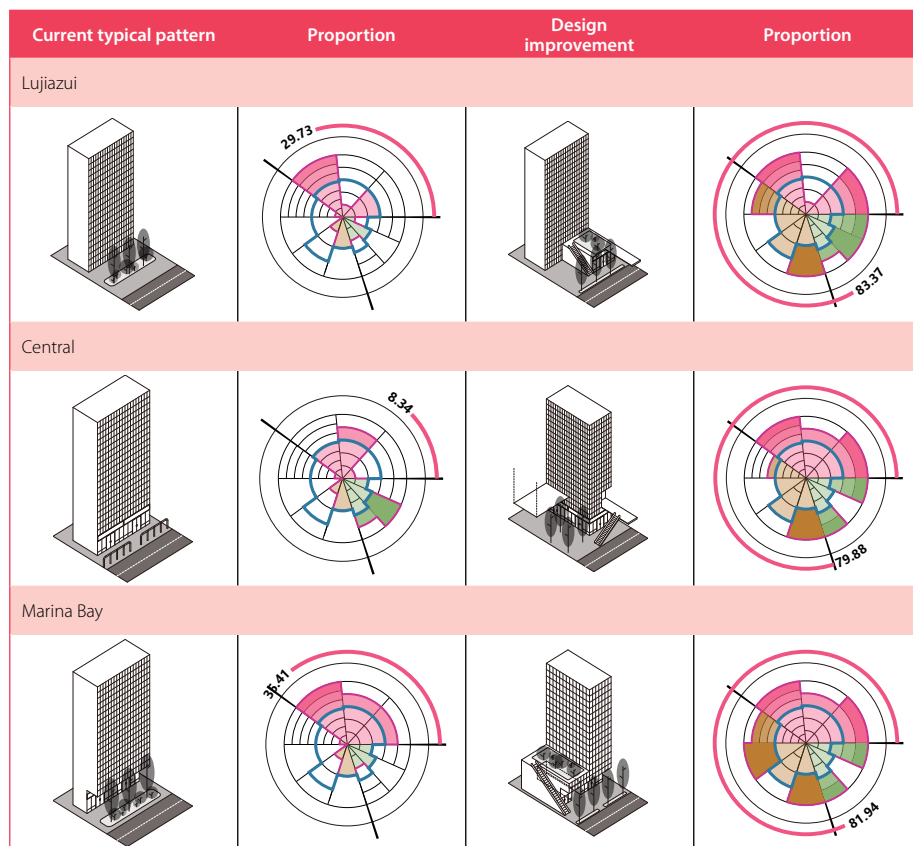


Figure 9. Recommended design paradigms in each of the study areas. The length of the arcs in the "proportion" columns reflect current (left) and potential (right) scores after design improvements.

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