Title:	**Designing Tall Buildings to Promote Physical Activity in China**
Authors:	Mariela Alfonzo, Research Assistant Professor, Polytechnic Institute of New York University Zhan Guo, Assistant Professor, New York University Lin Lin, Assistant Professor, East China Normal University
Subject:	Social Issues
Keywords:	Density Social Interaction Vertical Transportation
Publication Date:	2013
Original Publication:	CTBUH Journal, 2013 Issue IV
Paper Type:	1. Book chapter/Part chapter 2. **Journal paper** 3. Conference proceeding 4. Unpublished conference paper 5. Magazine article 6. Unpublished

Designing Tall Buildings to Promote Physical Activity in China


Kristen Day


Mariela Alfonzo


Zhan Guo


Lin Lin

This study asks the question: how do the design of tall buildings and tall building districts impact walking and bicycling in Chinese cities? Little is known about the relationship between the design of tall buildings and physical activity. Research in Western countries links residential density to increased physical activity. Western research typically examines cities where relatively few residents live in tall buildings, and where density levels are low. China, in contrast, has the largest number of tall buildings in the world, along with high urban density (800–900 people per square kilometer, excluding the few largest cities).

Editor's Note:
This study is the result of a generous CTBUH Research Seed Funding grant made possible by AECOM.

Authors

Kristen Day, Department Head
Mariela Alfonzo, Research Assistant Professor
Polytechnic Institute of New York University
Six MetroTech Center, Brooklyn, NY 11201, USA
t: +1 718 260 3999, f: +1 718 260 3136
e: kday@poly.edu

Zhan Guo, Assistant Professor
New York University
295 Lafayette Street, New York, NY 10012, USA

Lin Lin, Assistant Professor
East China Normal University
500 Dongchuan Road, Shanghai 200241, China

Kristen Day is Professor and Department Head in the Department of Technology, Culture, and Society at the Polytechnic Institute of New York University. Her research examines the design of urban environments to promote well-being and safety. She has a specific interest in the design of environments to support physical activity among diverse populations.

Mariela Alfonzo is the founder of State of Place,™ a place rating and walkability diagnostic tool tied to economic value. She is also an assistant research professor at the Polytechnic Institute of NYU, where she is examining the links between the built environment and obesity in rapidly urbanizing Chinese cities.

Zhan Guo's research has focused on how the governmental regulation over the built environment limits travel options and encourages one particular travel means; and how travelers perceive different travel options. Within this framework, Zhan has conducted empirical studies in Boston, Chicago, London, Portland, and New York.

Lin Lin's research interests lie in conceptualizing and understanding the reciprocal relationship between the built environment, human behaviors, and public health, as she believes this relationship underpins the development of genuinely healthy sustainable communities. She has accumulated research experience in this field both in the United States and China.

Background

Preliminary research in China finds that density is inversely correlated with physical activity. These findings suggest that not all dense urban development patterns promote physical activity. Designing tall buildings to promote physical activity is an objective of increasing global significance.

China faces growing problems with obesity and chronic disease. A recent survey of adults in ten provinces of China found that 34% of adults between age 20 and 69 are overweight (Xiaochen and Lei 2013). One-fifth of all overweight or obese people in the world are Chinese. Chronic diseases cause 80% of deaths in China, costing billions of dollars in lost productivity (Bekedam 2006). Obesity is concentrated in Chinese cities and in its more affluent populations. This fact is of great

Primary Elements	Definition	Hypothesis
Orientation	Overall form or orientation for tall buildings	Buildings with higher connectedness (visual and actual) to neighboring buildings, will be associated with higher rates of walking and bicycling
Density	Number of stories for most buildings (low, medium, tall, supertall)	None
Envelope	Whether block is ringed by buildings and land use of perimeter buildings	Commercial perimeter of block will be associated with higher rates of walking and bicycling
Diversity of land uses	Single or mixed-use	Mixed-use will be associated with higher rates of walking and bicycling
Location	Urban or suburban	Urban location will be associated with higher rates of walking and bicycling
Secondary Elements		
Compactness	Degree to which development is concentrated	Compact development will be associated with higher rates of walking and bicycling
Age	Age of the tall buildings, by decade	None
Block size	Small, medium, or large	Smaller block size will be associated with higher rates of walking and bicycling
Street width	Narrow, medium, or wide	Narrower streets will be associated with higher rates of walking and bicycling
Streetscape	Continuous versus discontinuous	Continuous streetscape will be associated with higher rates of walking and bicycling
Shopping options	On street retail and/or shopping mall	On street retail will be associated with higher rates of walking and bicycling

Table 1. Characteristics of Chinese tall building developments hypothesized to be associated with walking and bicycling.

concern, given China's rapid urbanization. According to UN Habitat, by 2025 China will have 221 cities with one million or more people.

Obesity and chronic disease in China are caused by decreasing physical activity and other factors (especially changing diets and environmental pollution). In the last two decades, physical activity has declined over 30% among Chinese adults, including reduced walking and bicycling (Ng et al. 2009). In Shenzhen, for example, travel by bicycle dropped from 30% of trips taken in 1995 to 4% of trips in 2007.[1] Declining physical activity is exacerbated by Chinese development patterns that encourage sprawl and impede active modes of travel. China's urbanization will require massive additional development, including an estimated 170 mass-transit systems, 5 billion square meters of road, and 40 billion square meters of floor space. It is important to consider future development in China that can support increased physical activity, especially bicycling and walking for transportation and for recreation. This study directly examines the design of tall buildings tied to physical activity.

The objectives for this study were to:

1. Develop a typology of tall building design and development tied to walking and bicycling for Chinese cities;
2. Identify associations between walking and bicycling and the design of tall buildings and tall building districts, for three types of districts in Shanghai.

Typology of Urban Development Tied to Walking and Bicycling in Chinese Cities

This typology of Chinese building design and development was intended to increase understanding of the features of tall building design and tall building districts that may impact walking and bicycling. The typology is also intended to help inform future urban development in China, by characterizing a range of current development types and identifying which of these types may be associated with the highest rates of walking and bicycling. Development of the typology was guided by a review of the literature to examine urban design, walking, and bicycling in Chinese cities. It was also informed by systematic observations in several Chinese cities, and by interviews with six Chinese urban development experts.

The typology characterized urban districts according to several elements. Primary elements were those that most strongly differentiated various development types. Table 1 also includes hypotheses on how various elements may be associated with walking and bicycling, based on existing research in mostly Western contexts.

The typology includes seven current urban development types in Chinese cities. These types vary in terms of the primary and secondary elements described above. The typology is not exhaustive. In reality, many urban developments display elements of more than one type. As demonstrated in Table 2, several types include more of the elements that are expected to impact walking and bicycling. The relative importance of each of these elements, and its actual impact on walking and bicycling, is unknown, and thus became the focus of this study.

Associations between Walking, Bicycling, and Tall Building Design

This study examined associations between walking and bicycling and the design of tall buildings and tall building districts, for three types of districts in Shanghai. This study focused on Shanghai as China's densest city (3,631 persons/km^2), with among the most completed tall buildings (116 buildings of 150 m+) (eChinacities.com 2011, The Skyscraper Center 2013).

Site selection

Based on the typology described above, three tall building districts were selected for inclusion in the study. Each district was one kilometer in area, centered on a subway station. Districts included:

- **Xintiandi area: old urban tower type**
  This mixed-use district in central Shanghai is famous for the upscale Xintiandi retail and nightlife center built around reused historic *shikumen* ("stone gate") buildings. The area includes several tall, luxury residential towers and high-end retail, as well as traditional, low-rise courtyard housing units that serve a low-income resident population (see Figure 1). The area includes many pleasant

Primary Elements	Tower in the Park	Old Urban Tower	New Urban Tower	Inward-Facing Block	Mixed-use Block	Historical District	Exurban
Orientation	Tower in the park	Discrete buildings	Tower in the park	Oriented towards block interior	Linear	Linear	Interior orientation
Density	Tall	Tall	Supertall	Mid-rise	Mid-rise and tall	Low-rise	Low- to mid-rise
Envelope	None	None	None	Commercial perimeter	None	None	None
Diversity of land uses	Single-use (residential)	Mixed-use	Predominantly single-use	Single-use (residential)	Mixed-use	Mixed-use	Single-use (residential)
Location	Suburban	Old urban center	New urban center	Right outside urban center	Edge of urban center	Urban center	Exurban/new town
Secondary Elements							
Compactness	Medium	High	Medium to high	Medium to high	High	High	Low
Age	1990s to present	2000 to present	1990s to present	1980s	1950s to 1980s	Before 1950	After 2000
Block size	Large	Small to medium	Medium to large	Medium to large	Small to medium	Small	Large
Street width	Wide	Narrow	Wide	Medium to wide	Medium	Narrow	Wide
Streetscape	Discontinuous	Continuous	Discontinuous	Mostly continuous	Mostly continuous	Continuous	Discontinuous
Shopping options	Shopping mall	Street retail	Shopping mall	Street retail and shopping center	Street retail	Street retail	Shopping mall

Table 2. Primary and secondary elements of current Chinese urban development types. Shaded cells are elements that are hypothesized to be associated with higher levels of walking and bicycling.

[1] At: http://www.china.com.cn/news/local/2009-09/02/content_18452604.htm.

Figure 1. Xintiandi area. ©①◎ Peter Verkhovensky / HirotakaNakajima / AnnaCarin

Figure 2. Zhongshan Park area. ©①◎ Jucember / Rüdiger Meier

Figure 3. Lianhua Road area.

sidewalks and public spaces for strolling; several parks are nearby.

- **Zhongshan Park area: variation on mixed-use block type with tall buildings**
  This bustling mixed-use district in northwestern Shanghai includes several stories of retail along the perimeter of several superblocks, with gated residential towers in the middle of the blocks. The area is intersected by wide, busy streets. A large public park is located nearby (see Figure 2).
- **Lianhua Road area: tower-in-the-park type**
  This suburban area in southwestern Shanghai includes gated communities of tall residential buildings. It also hosts a regional shopping center adjacent to the subway station. Some small retail areas are located outside the gates of the residential communities (see Figure 3). The gated communities feature several interior open spaces for residents.

Environmental Audit

Environmental audits were conducted in the three districts. The audits used and expanded the Irvine-Minnesota Inventory (IMI) (Day et al. 2006), which was developed by the research team to measure built environment features tied to walking and bicycling in the United States and other Western cities. Based on input from a literature review, observations of built environments in Shanghai, Guangzhou, and Beijing, and interviews with six experts on Chinese urban development, the IMI was expanded from 162 to a total of 286 items. The new audit tool is called the Irvine-Minnesota Inventory-China (IMI-C). Examples of new items added to the IMI-C include some common issues in high-density Chinese cities, such as measures of obstruction of sidewalks by vendors or parked cars, visible air pollution, and the presence of overhead pedestrian bridges (which require more effort for street crossing). Research assistants audited all segments (or street blocks) in each of the three districts, for a total of 286 segments, including 129 segments in Xintiandi, 60 segments in Zhongshan Park, and 97 segments in Lianhua Road.

Health Survey

A shortened version of the 2012 China Health and Nutrition Survey was conducted in the three districts to collect information on physical activity and health. The survey measured rates of walking and bicycling for travel and recreation, rates of other forms of physical activity, health outcomes (such as BMI and the presence of various health conditions), and demographic information. Research assistants surveyed residents in public spaces in the three districts. A total of 633 resident surveys were completed, including 129 in Xintiandi, 243 in Zhongshan Park, and 291 in Lianhua Road. However, not all respondents answered all survey questions, so depending on the specific statistical model, the sample size varies. The minimum required sample size to detect a small-effect size (0.10) at a 0.80 power level, with 10 predictors, using a 0.05 alpha, is 172.

> "Based on input from a literature review, observations of built environments in Shanghai, Guangzhou, and Beijing, and interviews with six experts on Chinese urban development, the IMI was expanded from 162 to a total of 286 items. The new audit tool is called the Irvine-Minnesota Inventory-China (IMI-C)."

Analysis and Results

This section reports findings on the characteristics of the built environment in the three districts. This section also reports findings on associations between built environment characteristics and physical activity, including walking and bicycling.

Analysis of Built Environment Characteristics of Three Districts

The first step of the analysis was to characterize the built environment of these three districts, using data from the environmental audit. Data from the environmental audit were analyzed using the State of Place Index, a proprietary algorithm that calculates an overall "walkability" score, composed of 11 sub-scores that measure urban design dimensions empirically tied to walking and bicycling. Each of the 11 dimensions is composed of a subset of the 286 individual built environment items contained in the IMI-C (see Table 3). The Index is calculated for each block and then aggregated at the district level. Individual *t*-tests, which examine whether the mean scores of two groups are statistically different from each other, were run to analyze whether there were significant differences in the Index (including the sub-scores) across the three districts. General descriptive analysis (percentage of blocks containing key IMI-C items, such as building height) were run to further analyze the built environmental differences between the three districts.

The following tables show the results of the analysis of the built environment characteristics for the three districts. Figure 4 shows the individual State of Place profiles for the three districts, where 100% signifies the maximum observed State of Place score at the block level among the 286 blocks for which data were collected. It also shows the differences among the three districts across the eleven State of Place dimensions. Overall, Xintiandi has a significantly higher Index than do Zhongshan Park and Lianhua Road. There is no significant difference between the latter pair in terms of overall State of Place Index. Figure 5 shows the

State of Place Index dimensions	Description/Example items
Density/building height	Measure of density based on building concentration and heights
Proximity/land-use mix	Presence of non-residential land uses
Connectivity	Measure of disconnectivity, potential barriers (e.g., six lane roads)
Form	Measure of streetscape discontinuity (e.g., driveways, podium buildings)
Parks and public space	Presence, quality of parks, playgrounds, plazas, etc.
Pedestrian infrastructure/ amenities	Features that provide pedestrian comfort (e.g., sidewalk widths, street furniture)
Bike infrastructure/amenities	Features that provide bicyclist comfort (e.g., bike lanes, bike racks, bike parking)
Personal safety	Features related to perceived safety (e.g., graffiti, litter, bars on windows)
Traffic safety	Features intended to increase traffic safety (e.g., traffic signals, traffic calming measures)
Aesthetics (pleasurability and maintenance)	Measures of pleasurability and maintenance (e.g., outdoor dining, building transparency)
Recreational facilities	Presence of gyms and fitness facilities and other recreational uses

Table 3. State of Place dimensions and how they were measured.

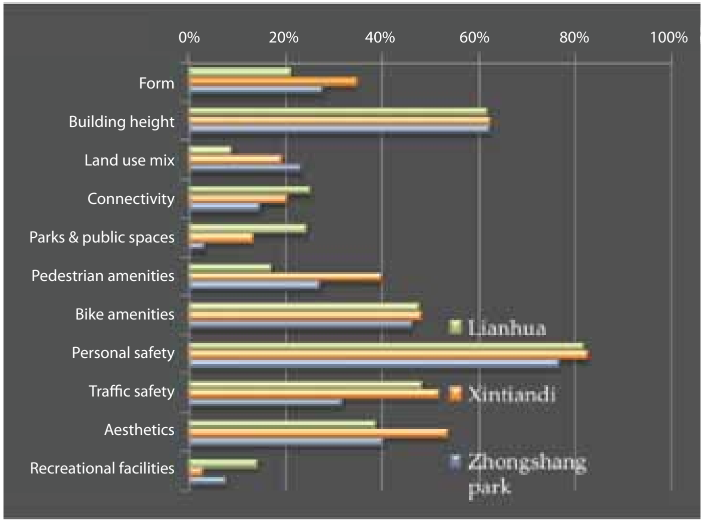

Figure 4. Overall distribution of State of Place dimensions for Xintiandi, Zhongshan Park, and Lianhua Road area. One hundred percent represents the total of each dimension for all three districts.

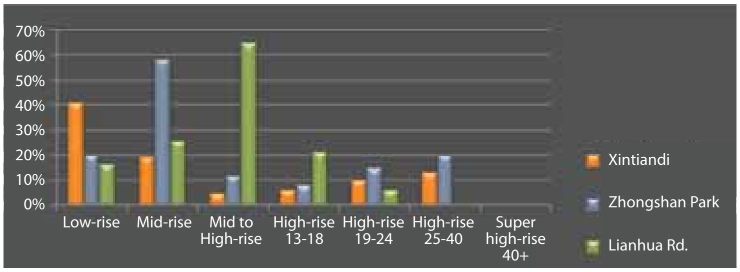

Figure 5. Building height in the three districts.

Figure 6. Average State of Place Index for each block is associated with the number of observed pedestrians on each block.

distribution of building heights throughout the three districts.

The environmental audit and State of Place analysis tells us more about the characteristics of the built environment than about its use. At the same time, the State of Place Index is associated with the number of observed pedestrians. Figure 6 shows the relationship between the average State of Place score for each block, and the number of pedestrians sitting, walking, or standing during the time the environmental audit took place. Blocks with a higher Index have higher volumes of pedestrians. This relationship is statistically significant.

Discussion: Characteristics of the Built Environment in the Three Districts

As expected, Xintiandi is more "walkable" than both Zhongshan Park and Lianhua Road, in terms of having more of the built environment characteristics that had been linked to walking and bicycling in existing research. Compared to the other two districts, Xintiandi offers:

- a more diverse environment in terms of available destinations and amenities
- a more inviting pedestrian realm
- fewer barriers for pedestrians, which makes it easier to navigate
- a more aesthetically pleasing environment in terms of upkeep and character
- a more continuous, activated streetscape with a better sense of enclosure.

While Zhongshan Park and Lianhua Road do not differ from each other overall in terms of the walkability of their built environments, there are important differences in their urban design dimensions that relate to walking and physical activity. Compared to the Lianhua Road area, Zhongshan Park offers a more diverse environment in terms of destinations and amenities; has fewer barriers to connectivity and more pedestrian amenities; has a more continuous streetscape and a better sense of enclosure; and offers a more enhanced pedestrian realm. In contrast, Lianhua Road offers more recreational facilities and parks and public spaces than do Xintiandi and Zhongshan Park, which is line with Lianhua Road's more suburban nature.

Interestingly, Xintiandi and Lianhua Road both have more features associated with a higher perception of personal safety and traffic safety than does Zhongshan Park. This is consistent with the more "planned" nature of the former pair of districts, as opposed to the more organic nature of Zhongshan Park. Further, Zhongshan Park was undergoing much construction during the observation period, which may have impacted its score along these two dimensions.

It is not surprising that there were no differences among the three districts with respect to either building height or bike amenities. All three districts are relatively dense and contain many tall buildings. Xintiandi contains a large number of both low-rise and tall buildings, so its average building height parallels the other two neighborhoods. With respect to bike amenities, there is no reason to believe there would be a difference among these neighborhoods. In particular, suburban Lianhua Road offers one of the only bike-share programs in Shanghai.

With respect to building height specifically, the patterns that emerge are also expected. Xintiandi contains a high number of both 2-to-3-story and 13-to-39-story buildings. This reflects the newer, high-end development that characterizes this district, juxtaposed with older, more historic buildings. The building data for Zhongshan Park reflects its varied nature. It mostly contains 4-to-8-story buildings, but also has many 2-to-3-story and 13-to-39-story buildings. Zhongshan Park's residential stock includes primarily mid-rise buildings that are mostly condominiums or apartment buildings. Lianhua Road has a high number of blocks with 8-to-12-story buildings, and most blocks contain mid-to-high-rise residential buildings, almost all of which are apartments and condominiums, with a small percentage of single-family detached units.

When analyzing the mix of uses, and in particular whether buildings vertically integrate more than one use, Lianhua Road has significantly fewer mixed-use blocks than do either Zhongshan Park or Xintiandi. This is consistent with Lianhua's lower score on the "proximity" dimension. Proximity to destinations and the vertical integration of uses have been shown to be key factors of walkability in existing research, as these features allow walking to various amenities within a relatively short distance, and also activate the street to create a more attractive pedestrian realm.

Findings confirm that the higher the State of Place score of a block, the more likely there will

District	N	% Respondents	Low-rise (1–3 stories)	Mid-rise (4–8 stories)	High-rise (9–15 stories)	High-rise (16+ stories)	Average # of Stories
Lianhua	291	0.62	0.15	0.56	0.20	0.09	7.91
Xintiandi	129	0.74	0.33	0.44	0.14	0.09	6.92
Zhongshan	243	0.69	0.19	0.53	0.10	0.19	9.02
P-value			0.0001	0.771	0.118	0.014	0.027

Table 4. Building height for respondents to the health survey.

District	N	BMI	Age	Years Lived in Neighborhood	Income	Years of Education	% Female	Married	Rural resident Status	Household Size	Own Auto	Work for Wage
Lianhua	291	24.06	33.76	6.16	2.50	4.17	0.40	0.67	0.19	3.68	0.39	0.59
Xintiandi	129	22.62	42.45	11.14	1.99	3.18	0.53	0.71	0.24	2.79	0.19	0.45
Zhongshan	243	22.10	32.60	6.48	2.44	4.02	0.39	0.48	0.27	3.38	0.35	0.68
P-value		0.003	0.000	0.000	0.002	0.000	0.025	0.000	0.092	0.273	0.000	0.000

Table 5. Demographic characteristics and BMI for respondents in the three districts.

be high pedestrian activity. It is likely that built environment features that are determined to support physical activity are also related to pedestrian volumes in Shanghai.

Analysis and Results: Relationship Between Built Environment Characteristics, Walking, and Bicycling

The second stage of the analysis involved an examination of the relationship between aspects of the built environment, as measured in the health survey, and physical activity levels and other health outcomes (including BMI). To examine this question, data from the health survey were analyzed in two steps. The first step was a descriptive analysis of the data quality, the differences among the three districts, and the bivariate relationship between key variable pairs, such as building height and walking. The second step was multivariate statistical analysis, primarily using ordinary least square (OLS) regression. The dependent variables are BMI and walking/biking activities. The independent variables include building height, demographic, and neighborhood characteristics, physical activity patterns, and diseases.

Descriptive Analysis

In the health survey, 554 respondents provided sufficient information to calculate their BMI. A BMI of 25 or higher is considered "overweight," while BMI of 30 or higher is considered "obese." Ninety-nine respondents had a BMI equal or greater than 25, which represents an overweight rate of 17.9%. The rate varies across the three districts, with 14.2% in Zhongshan Park, 14.05% in Xintiandi, and 23.5% in the Lianhua Road area.

Respondents to the health survey reported the height of the building in which they lived (see Table 4). For those who reported the height of their building, 19% of residents' buildings in Zhongshan were taller than 16 stories. This share was only 9% for both Lianhua and Xintiandi. The share of low-rise buildings was much higher in Xintiandi (33%) than in the other two districts (15 and 19%). Note that a majority of respondents in all three districts who responded to this question lived in mid-rise (4-to-8-story) buildings.

Respondents in the three districts differed in their demographic characteristics (see Table 5). Many respondents in the Xintiandi area appeared to be relatively less affluent, long-time residents who were older and less educated. Lianhua Road and Zhongshan respondents represented new middle-class suburban and inner-suburban residents, and included many young, single, well-educated newcomers to Shanghai. More respondents in Xintiandi did not work for wages and did not own automobiles. The household size in Zhongshan Park and Lianhua Road was larger than in Xintiandi, compared to the other two districts. Zhongshan Park respondents included significantly more single residents (not married) than did Lianhua Road. Note that a significant share of respondents had rural household status, indicating that they were migrant workers from rural inland China living in Shanghai. The highest share of rural resident status was in Zhongshan Park (27%), while the lowest share was in Lianhua Road (19%).

Respondents in the three districts differed in their levels of physical activity. Xintiandi respondents reported that they normally spend 55 minutes every day on physical exercise, 53% higher than respondents from Lianhua Road and 12% higher than respondents from Zhongshan Park. In particular, Xintiandi respondents spend an average of 25.5 minutes each day on walking-related exercise, which is 74% higher than for respondents in both Lianhua Road and Zhongshan Park. Respondents in all three districts perceived a high importance of being physically active (P-value 0.506).

In terms of travel mode, Xintiandi respondents relied more on walking and regular (non-electric) bicycles and less on cars and public transit. Lianhua Road and Zhongshan Park respondents differed in minor ways. Lianhua Road respondents used less public transit and walked less than did Zhongshan Park respondents (see Table 6). The amount of time spent on travel varied for residents in the three districts. Xintiandi respondents walked for longer amounts of time for commuting, compared to respondents in the other two districts. Xintiandi respondents walked for less time for non-commuting activities compared to Lianhua Road respondents. Zhongshan Park respondents rode bicycles for longer amounts of time for commuting compared to respondents in the other districts. Regarding car usage, Xintiandi respondents drove the least amount of time and rode public transit for durations that were equal to or less than those

Mode Share	Walk 1	Walk 2	Rode Bike 1	Rode Bike 2	Rode e-Bike 1	Rode e-Bike 2	Car 1	Car 2	Bus 1	Bus 2
Lianhua	0.14	0.13	0.04	0.04	0.09	0.04	0.12	0.10	0.28	0.35
Xintiandi	0.25	0.35	0.10	0.05	0.03	0.04	0.02	0.03	0.25	0.27
Zhongshan	0.24	0.17	0.08	0.05	0.05	0.03	0.09	0.08	0.37	0.41
P value	0.005	0.000	0.026	0.684	0.029	0.785	0.008	0.054	0.030	0.026
Average Time Spent in Travel	**Walk 1**	**Walk 2**	**Rode Bike 1**	**Rode Bike 2**	**Rode e-Bike 1**	**Rode e-Bike 2**	**Car 1**	**Car 2**	**Bus 1**	**Bus 2**
Lianhua	17.63	38.08	16.36	21.82	16.65	24.85	38.12	48.33	47.00	49.17
Xintiandi	26.72	30.71	15.77	60.83	23.75	44.00	25.00	20.25	45.97	39.60
Zhongshan	15.69	30.54	25.15	45.46	33.64	26.25	34.57	49.79	41.21	45.66
P value	0.016	0.008	0.050	0.235	0.480	0.524	0.042	0.007	0.407	0.003

1 = travel mode for commuting; 2 = travel mode for non-commuting.

Table 6. Travel mode and time spent in active and non-active travel modes by respondents in the three districts.

D Variable = BMI	Coefficient	Standard Error	t	P-value
Constant	26.43	1.56	16.91	0
Demographic				
Income level (1 to 6)*	−0.61	0.24	−2.52	0.012
Education level (0 to 6)**	−0.53	0.24	−2.22	0.027
Female (yes/no)	−2.35	0.58	−4.02	0
Middle age (26–55 years) (yes/no)	1.10	0.61	1.81	0.071
Number of years lived in current residence	−0.04	0.03	−1.31	0.19
Work for wage (yes/no)	−1.27	0.81	−1.56	0.12
Neighborhood				
Building 4–8 stories (yes/no)	−1.08	0.64	−1.69	0.091
Building 9–15 stories (yes/no)	−1.72	0.93	−1.84	0.067
Lianhua Road neighborhood (yes/no)[a]	3.18	0.91	3.48	0.001
Zhongshan Park neighborhood (yes/no)[a]	0.99	0.69	1.43	0.152
Prefer suburban (yes/no)	0.67	0.59	1.14	0.253
Physical Activities				
Changed behavior due to air pollution (yes/no)	0.95	0.56	1.69	0.092
Job involves heavy labor (yes/no)[b]	3.68	2.82	1.30	0.193
Job involves moderate labor (yes/no)[b]	−1.47	0.87	−1.68	0.093
Total time spent on transit (minutes)	−0.02	0.01	−2.35	0.019
Total time spent on bicycle[c]	0.02	0.01	1.08	0.281
Physically active not important (rank 1–5)	0.72	0.35	2.07	0.039
Healthy diet not important (rank 1–5)	−0.52	0.43	−1.20	0.229
Diseases				
High blood pressure (yes/no)	3.17	1.44	2.20	0.029
Diabetes (yes/no)	−1.49	1.12	−1.33	0.184
Chest wheezing (yes/no)	−1.66	0.90	−1.84	0.066
Number of observations	423 individuals			
F(20, 402)	3.39			
Prob > F	0.00			
R-squared	0.1749			
Root MSE	5.9085			

[a]reference is Xintiandi neighborhood; [b]reference is job involves light labor; [c]both regular and electronic bikes
*per month 1 = ¥2000, 2 = ¥2,000–7,999, 3 = ¥80,00–14,999, 4 = ¥15,000–29,999, 5 = ¥30,000–59,000, 6 = ¥60,000
**0 = did not graduate from primary school, 1 = primary school, 2 = lower middle school, 3 = upper middle school, 4 = technical/vocational school, 5 = university/college degree, 6 = masters degree or higher

Table 7. Factors associated with higher BMI.

Stories (yes/no)	Walk 1	Walk 2	Walk Exercise	Physical Exercise	Sedentary Time	Bike 1	Bike 2
Building 1–3 stories	5.21**	–	5.12	9.68	–	–	–
Building 4–8 stories	–	−1.68	–	14.04**	−16.9	1.05	–
Building 9–15 stories	–	−5.27**	−6.09	17.28*	–	2.47	–
Building 16+ stories	–	–	–	–	–	–	–
District	**Walk 1**	**Walk 2**	**Walk Exercise**	**Physical Exercise**	**Sedentary Time**	**Bike 1**	**Bike 2**
Lianhua	−1.88*	–	–	−9.61*	51.36**	–	–
Xintiandi	–	–	–	–	–	–	–
Zhongshan	–	–	−4.13	–	–	1.61	–

* 0.10> p >0.05; ** p<0.05
For each category, 1 = travel mode for commuting and 2 = travel mode for non-commuting

Table 8. Association of building height and district with physical activity.

of respondents in the other two neighborhoods.

OLS Regressions

The above bivariate statistics do not capture the true relationships between individual variables, so Ordinary Least Squares (OLS) regression was estimated. The correlation matrix was first tested, and no two variables were highly correlated with each other. Most pairs had an R-value smaller than 0.3.

The first model is BMI (dependent variable = BMI). This model estimated the effect of building height on BMI while controlling for other variables; it indicates that demographic characteristics, neighborhood, physical activities, and diseases all matter for BMI. Respondents with a higher income, better education, and female gender tended to have a lower BMI. Middle-aged respondents tended to have a higher BMI than did young adults and older respondents. Duration of residence and employment status had little impact on BMI.

Respondents who were more likely to change their behavior to avoid air pollution tended to have a higher BMI, suggesting a possible multiplier health effect of air pollution, though the effect is only significant at the 10% level. Those who spent more time on public transit, worked for labor-intensive jobs, and viewed being physically active as important had a lower BMI.

In terms of the effect of neighborhood, Lianhua Road respondents had a higher BMI than did Xintiandi respondents, consistent with the earlier analysis. Building height mattered for BMI, even when excluding the effect of demographics, physical activities, neighborhood unique features, and diseases, but only at the 10% level. Living in a 4-to-15-story building was associated with a lower BMI, compared to living in 1-to-3 or 16-story and taller buildings (see Table 7).[2]

To better understand the relationship between building height, physical activities, and BMI, seven OLS regressions were estimated, with the dependent variables being commuting walking time (walk 1), non-commuting walking time (walk 2), walk as exercise, physical exercise time, sedentary time, commuting biking time (bike 1), and non-commuting biking time (bike 2). Table 8 summarizes these results. Control variables are not presented.

The height of the building that respondents lived in did not appear to be directly associated with many physical activities, such as time spent walking and walking as exercise. However, living in a low-rise building was associated with time spent in commuting walking. This might be an effect of living in an inner-city neighborhood where low-rise buildings can be found, and not the effect of building height. Living in a building with 9 to 15 stories was not associated with non-commuting walking, while living in buildings of four to 15 stories was associated with engaging in physical exercise. Clearly, respondents in the suburban Lianhua area are less likely to walk to work, and they also spend less time on physical exercise and more time on sedentary activities.

[2] This response refers to the height of buildings only, and not the floor of the building on which respondents lived

Discussion: Relationship Between Built Environment Characteristics, Walking, and Bicycling

In summary, respondents in the three neighborhoods relied on different travel modes, including primarily walking in Xintiandi, public transit in Zhongshan, and cars in Lianhua Road. Respondents in Xintiandi are the most physically active, spending the longest time on physical activities (including for exercise and transportation). Respondents in the Lianhua Road area were the least active and spent the longest time (51 minutes more) on sedentary activities. Respondents in Zhongshan Park represented a middle ground between the other districts.

These findings are supported by the findings from the environmental audits. Xintiandi, with the highest State of Place score, also had the lowest reported BMI and highest reported rates of physical activity; followed by Zhongshan Park with the next-highest State of Place score, next-lowest BMI and next-highest physical activity rates; and finally Lianhua Road, with the lowest State of Place score, highest BMI, and lowest rates of physical activity. These findings are consistent with the hypotheses about the built environment characteristics linked to walking.

The impact of building height on activity patterns and BMI requires further examination. Building height may impact activity patterns, as respondents in tall buildings tend to walk less; however, these respondents also appear to exercise more, though not necessarily by walking. Even excluding the physical activity effect, living in tall buildings seems to be associated with lower BMI, although the reason for this association is still unclear. The results do not find any evidence that living in tall buildings is associated with reduced time spent on exercise. Future research should explore the mechanisms that link living in tall buildings with more time spent in exercise, and should consider not only building height, but also the story on which an individual resident lives in the building, since the experience of living in tall buildings may vary accordingly.

The research team plans to expand this study to incorporate many more districts and cities throughout China, to allow us to measure the impacts of diverse types of building and urban development types on physical activity. Ideally, future research will focus especially on the Pearl River Delta region of Southern China, which is the most intensely urbanizing region in the world. Next steps will involve directly comparing the experiences of residents living in different types of tall buildings and on different floors within these buildings. These comparison would be made (with and without nearby features such as mixed land uses, ground-floor transparency, walkable and bikeable streetscapes, and nearby recreational facilities). Key outcomes include rates of physical activity and obesity. The research team is also interested in the effect of concern about exposure to air pollution on walking and bicycling among these residents. China should maximize its unique opportunity to shape the character of current and future urban development to promote health and well-being. ■

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

References

BEKEDAM, H. 2006. In his opening remarks at Conference on Obesity and Related Disease Control, November 21–23. http://www.wpro.who.int/china/media_centre/speeches/speech_20061121.htm. Accessed September 11, 2011.

CAROLINA POPULATION CENTER. 2012. "China Health and Nutrition Survey." http://www.cpc.unc.edu/projects/china. Accessed September 12, 2012.

CLIFTON K. & DILL J. 2005. "Women's Travel Behavior and Land Use: Will New Styles of Neighborhoods Lead to More Women Walking?" ***Research on Women's Issues in Transportation. Conference Proceeding.*** Chicago: Transportation Research Board: 89–99.

CTBUH. ***The Skyscraper Center.*** http://skyscrapercenter.com/. Accessed September 12, 2012.

DAY, K.; ALFONZO, M.; CHEN, Y.; GUO, Z. & LEE, K. 2013. "Overweight, Obesity, and Inactivity and Urban Design in Rapidly Growing Chinese Cities." ***Health & Place,*** 21: 29–38.

DAY, K.; BOARNET, M.; ALFONZO, M. & FORSYTH, A. 2006. "The Irvine-Minnesota Inventory to Measure Built Environments. Development." ***American Journal of Preventive Medicine,*** 30(2): 144–152.

eChinacities.com. http://www.echinacities.com/. Accessed September 12, 2012.

LEE, C. & MOUDON, A. 2006. "The 3Ds + R: Quantifying Land Use and Urban Form Correlates of Walking." ***Transportation Research,*** 11(3): 204–215.

MOUDON, A.; LEE, C.; CHEADLE, A.; GARVIN, C.; JOHNSON, D.; SCHMID, T.; WEATHERS, R. & LIN, L. 2006. "Operational Definitions of Walkable Neighborhood: Theoretical and Empirical Insights." ***Journal of Physical Activity and Health,*** 3: S99–117.

NG, S.; NORTON, E. & POPKIN, B. 2009. "Why Have Physical Activity Levels Declined among Chinese Adults? Findings from the 1991–2006 China Health and Nutrition Surveys." ***Social Science and Medicine,*** 68(7): 1305–1314.

QUAN, Y. & SUN, M. 2011. "Noticeable Problems of Transportation Development in Large Metropolitan Areas in China." ***Urban Transport of China,*** 9(2): 1–6.

RODRIGUEZ, D.; BRISSON, E. & ESTUPINAN, N. 2009. "The Relationship between Segment-Level Built Environment Attributes and Pedestrian Activity around Bogota's BRT Stations." ***Transportation Research Part D: Transport and Environment,*** 14(7): 470–478.

SAELENS, B. & HANDY, S. 2008. "Built Environment Correlates of Walking: A Review." ***Medicine & Science in Sports & Exercise,*** 40(7S): S550–566.

SHI, J.; LI, Z. & TAO, L. 2011. "Spatial Distribution of Residential Communities and Roadway Planning." ***Urban Transport of China,*** 9(3): 60–64.

UN HABITAT. 2010. ***The State of China's Cities 2010/2011.*** Beijing: Foreign Language Press.

WANG, L.; KONG, L.; WU, F. & BUSTON, R. 2005. "Preventing Chronic Diseases In China." Lancet, 366: 1821–24.

WANG, Y.; MI, J.; SHAN, X.; WANG, Q. & GE, K. 2007. "Is China Facing an Obesity Epidemic and the Consequences? The Trends in Obesity and Chronic Disease in China." ***International Journal of Obesity,*** 31(1): 177–188.

WU, Y.; MA, G.; HU, Y.; LI, Y.; LI, X.; LUI, Z.; CHEN, C. & KONG, L. 2005. "The Current Prevalence of Body Overweight and Obesity in China: Data from the China National Nutrition and Health Survey." ***Zhonghua Yu Fang Yi Xue Za Zhi,*** 39(5): 319–20.

XIAOCHEN, S. & LEI, L. 2013. "Obesity Rate on the Rise in China. Asia News Network." http://www.asianewsnet.net/Obesity-rate-on-the-rise-in-China-49943.html. Accessed on June 8, 2013.

XU, F.; LI, J.; LIANG, Y.; WANG, Z.; HONG, X.; WARE, R.; LESLIE, E.; SUGIYAMA, T & OWEN, N. 2009a. "Associations of Residential Density with Adolescents' Physical Activity in a Rapidly Urbanizing Area of Mainland China." ***Journal of Urban Health,*** 87(1): 44–53.

XU, F.; LI, J.; LIANG, Y.; WANG, Z.; HONG, X.; WARE, R.; LESLIE, E.; SUGIYAMA, T. & OWEN, N. 2009b. "Residential Density and Adolescent Overweight in Rapidly Urbanizing Region of Mainland China." ***Journal of Epidemiological Community Health,*** 64(11): 1017–1021.

XU, H.; ZHANG, X. & LIN, Q. 2011. "Relieving Congestion with Comprehensive Traffic Control System in Shenzhen." ***Urban Transport of China,*** 9(3): 30–36.