行政院國家科學委員會專題研究計畫 成果報告

高密度建成環境中提升住宅可居住性的都市設計元素研究
研究成果報告(精簡版)

計 畫 類 別 ： 個別型
計 畫 編 號 ： NSC 98-2410-H-004-150-
執 行 期 間 ： 98 年 08 月 01 日至 100 年 07 月 31 日
執 行 單 位 ： 國立政治大學地政學系

計 畫 主 持 人 ： 蔡育新

報 告 附 件 ： 出席國際會議研究心得報告及發表論文

處 理 方 式 ： 本計畫涉及專利或其他智慧財產權，1 年後可公開查詢

中 華 民 國 100 年 10 月 30 日

行政院國家科學委員會補助專題研究計畫 ■ 成 果 報 告 □期中進度報告

（計畫名稱）

高密度建成環境中提升住宅可居住性的都市設計元素研究

（Simulation Analysis of Urban Planning/Design Elements for Improving “Physical” Livability in High-Density Neighborhoods）

計畫類別：■ 個別型計畫　　□ 整合型計畫

計畫編號：NSC 98-2410-H-004-150

執行期間：2009/08/01~2011/07/31

計畫主持人：蔡育新

共同主持人：無

計畫參與人員：黃鈺雯、吳孟亭

成果報告類型(依經費核定清單規定繳交)：■精簡報告　□完整報告

本成果報告包括以下應繳交之附件：

□赴國外出差或研習心得報告一份

□赴大陸地區出差或研習心得報告一份

■出席國際學術會議心得報告及發表之論文各一份

□國際合作研究計畫國外研究報告書一份

處理方式：除產學合作研究計畫、提升產業技術及人才培育研究計畫、列管計畫及下列情形者外，得立即公開查詢

□涉及專利或其他智慧財產權，□一年□二年後可公開查詢

執行單位：國立政治大學地政學系

（二）中、英文摘要及關鍵詞(keywords)

高密度都市建成環境(Built environment)是近年永續發展（Sustainable development）等概念的重要實施工具；但高密度住宅社區，其可居住性可能因高人口與建物密度所帶來的採光、通風、隱私性、開放空間、景觀的衝擊而降低。過去文獻已有些就都市設計面向或元素、都市設計對*實質*環境(Physical environment)的改變、其對使用者*感官*(Perception)所造成的影響進行研究。然而，個別都市設計面向或元素對於實質環境不同面向的影響，仍不盡然清楚。又此類研究受限於空間變數、與空間分析軟體的發展，因此研究較為缺乏。本研究目的有三：（1）解析都市計畫與設計元素（2）剖析可居住性的不同面向，及建立其量性指標。（3）衡量都市計畫與設計元素對實質環境可居住性的影響。研究方法包括以 SketchUp、ArcGIS 等空間分析軟體，模擬不同都市設計面向的改變。分析工具包括以彈性係數比較不同都市計畫或設計元素，對於都市實質可居住性影響效率的大小，以斜率分析同一元素的建議情境、以及以總體實質環境指標分析最佳情境。模擬分析結果顯示，建蔽率對於風道、居民隱私性、與友善步行空間塑造的效率高；建物退縮則對於提昇友善步行空間的效率高；高度比則對於增加風道空間與提高隱私性具有較高效率。

關鍵詞：高密度、建成環境、可居住性、都市計畫、都市設計

Abstract

High-density built environment has been one primary policy to promote sustainability in terms of smaller per capita land consumption, travel energy consumption, and tailpipe emission. However, downgraded livability in high-density communities possibly lowers residents' standard of living and willingness to live in dense neighborhoods. Nonetheless, little research provides knowledge about the extent to which the tools of urban planning ordinances can raise physical livability in high-density built environment. This paper aims to first compile an inventory of urban planning/design tools for arranging buildings or space, as well as the aspects and indexes of "physical" livability. The second purpose is to examine the impacts of planning/design tools on physical livability. To assess the efficiency of planning/design tools towards more livable city, a simulation analysis is conducted in a hypothetical high-density city. Two analysis techniques are adopted: elasticity to compare relative efficiency of planning/design tools, and slope to identify recommended scenario. Research results show that planning/design elements include such element as building coverage percentage (BCR), various ways of building setback, and building types. Physical livability are composed of spatial openness at the ground level, room for fresh air to float, natural light exposure, sky view openness, and residential privacy, which are evaluated for from within the buildings as well as on street level. The simulation analysis suggests that BCR is relatively effective in affecting three sub-livability indexes—breezeway, residential privacy and pedestrian-friendly environment. Building setback contributes rather effectively in improving pedestrian environment. And increasing height distance ratio is relatively effective in providing more breezeway and residential privacy.

Keywords: *High density, built environment, livability, urban planning, urban design*

（三）報告內容

In the wake of pursuing sustainability, high-density built environment policy has gained momentum in a great many countries and cities, such as Melbourne, Australia, and as a significant element in such policy as compact city, transit-oriented development (TOD), and encouraged by a great many of academics (Costello, 2005) However, the social benefit of sustainability from denser living settings is likely to conflict individual or residents' interest due to concern on relatively low level of residential built environment quality (livability) in denser communities such as perceived density, low visibility, insufficient breezeway between buildings, Radiation, blocked sky view, and less residential privacy. As a result, the success of high density policy may depend largely on urban planning or design tools to reduce physical negative impacts of high-density settings at the least, or even to improve the physical environment at the best, and in turn, to hope for better perception, acceptance, or even demand for high-density living in the market.

Among numerous urban planning and design tools (planning/design tools in short hereafter), including most probed floor area ratio (FAR), distance height ratio (DHR), building coverage rate (BCR), building setback from the street, or from neighboring buildings, the degree to which they affect residential environment quality is barely examined, including perceivable density, visibility, daylight exposure. For practical purposes, planners need guidelines for selecting best planning/design tools or building shape to improve environmental quality, in particular, in high-density neighborhood. However, little knowledge has been revealed from past research in this regard. Hence, this paper aims to first compile an inventory of urban planning/design tools for arranging buildings or space in a community, as well as the aspects and indexes of "physical" livability of built environment, as opposed to social, cultural, and economic side of livability. The second purpose is to examine the impacts of planning/design tools on physical livability. The following sections are literature review on planning/design tools, aspects and indexes of physical livability, and current knowledge on the efficiency of planning/design tool in affecting livability, research methods describing the simulation analysis and analysis methods, the results of simulation analysis, and conclusions and policy implications.

1. Literature Review （Still in process）

In urban areas wind speed and direction can be affected by buildings in terms of mass, layout, height, and alignment. Most of past research has been addressing environment comfort issue affected by gust and strong wind in urban environment (ASCE, 1999; Ng, 2009). However, recently a great bulk of research, on the contrary, address weak wind in densely populated cities with public health issue such as air-borne contagious disease and urban heat island (UHI) effect (Oke, 1982; Ng, 2009; Wong et al., 2010). Improved urban wind environment can improve physical livability of high-density built environment in the regards of mitigating UHI effect, washing away air pollutants (Wong and Yu, 2005) and providing a more natural wind environment less blocked by dense buildings.

Four principle measures have been applied to gauge wind speed in urban settings: field survey, wind tunnel modeling (Mfula, 2005), numerical models including computational fluid dynamics (CFD) modeling (Blocken, 2007), and morphometric method or urban-form-based indexes. Field survey labor intensive, and requires instruments to measure wind speed and may suffer from sufficient variations of scenarios, and lack of controlled environment. The wind tunnel is the most accurate (Ng, 2009) but complex, technology-demanding and costly (Wong et al., 2010). CFD is appropriate for simulations for various scenarios but also engineering-expertise demanding. For these three methods, wind velocity ratio, the ratio of wind velocity at certain height above roof tops to that on the ground level is applied (Ng, 2009). Several indexes measuring the degree of surface roughness in urban setting (Lettau, 1969; Counihan, 1975; Grimmond and Oke, 1999; Wong et al., 2010), which affects ground wind velocity.

Frontal area index, defined as the ratio of building facets facing the particular wind direction to plane area is mostly used to gauge district-base area average (Grimmond and Oke, 1999; Wong et al., 2010; Chao et al., 2010). Building coverage rate (BCR) or ground coverage ratio, highly positively correlated with frontal area ratio, is proposed as a proxy of frontal area ratio to measure pedestrian-level wind environment due to its simplicity (Ng et al., 2011). However BCR is not able to measure micro-level wind permeability (Ng et al., 2011) such as building level. Theoretically, viewshed from one test point could be used as a proxy since it can be applied to quantify the degree to which it is close to a plane without buildings on the ground on the one hand or the permeability on the ground level to allow wind travelling along breezeways to the test point; and it is theoretically affected by BCR in theory and could be highly correlated on the other hand.

2. Research Methods

To assess the efficiency of planning/design tools towards more livable city, a simulation analysis will be conducted in a hypothetical high-density city. The high-density urban setting is selected since livability is of more concern than in low-density setting. In assessing the efficiency of planning/design tools, hypothetical community simulation analysis is adopted over empirical study of practical cases for two reasons: on the one hand, a hypothetical community provides all possible variations of various planning/design tools as needed. On the other hand, in practical cases, factors affecting built environment per se are barely understood and intermingled, and hence hard to identify, not to mention the difficulty to measure. The hypothetical residential community hence provides a test bed for comparative analysis with built environment controlled for to allow changes in one single planning/design tool; all the scenarios are developed given the same density level, uniform building shapes, road systems, for example, to evaluate the impacts planning tools on livability indexes.

To facilitate the simulation analysis, this section first develops a hypothetical high-density residential community, and then an inventory of the planning/design tools and scenarios derived from their various setups, and the indexes for livability. Two analysis techniques are adopted: elasticity to compare relative efficiency of planning/design tools to improve livability, and slope to identify recommended scenario for each of the planning/design tools. The software packages applied are

Google SketchUp, AutoCAD, ArcGIS and Excel.

2.1 Base Maps of Hypothetical Residential Community

A hypothetical high-density residential community[1] is developed based on two primary guidelines: On the one hand, the spatial scale of the community is as small as possible for calculation purpose, but large enough where the livability indexes can be measured as in a large community with as less distortion as possible. On the other hand, it mimics Taipei, Taiwan in order to embed such concern over livability issues due to high-density development, lack of sidewalk, which is probably also true in many cities in Taiwan and Japan since the major land use plans in Taiwan were developed during the Japanese colonial periods between 1895-1945. Taipei is selected due to its high density of some 9,600 persons per square kilometer in 2011 (Taipei City Government, 2011), where street layouts, sites are mostly developed leaving little room for major modification but urban renewal of buildings.

This hypothetical community is composed of 16 50-meter by 50-meter identical blocks, surrounded by eight-meter wide road, which is the most popular road width in residential communities in Taipei, Taiwan (Figure 1). These eight-meter roads mostly are not equipped with sidewalk (Figure 2), or come along with traditional arch sidewalks attached to the front of the buildings. Within each block lies four identical 50%-BCR and 300%-FAR buildings (i.e., residential type IV[2] of Taipei city zoning ordinance (Taipei City Government, 2002)) are equally scattered and centered in their own quadrant; the FAR of 300% is selected because it is the highest cap of all four stereotypes of residential areas in Taipei as well as Taiwan, formulating the highest population density residential communities. The buildings are all set to be north-south-oriented, as preferred by the locals according to the traditional wisdom and to avoid bright, hot sun lights in the afternoon in the sub-tropical regions. The floor-to-floor height of all the buildings is three meters. Within this hypothetical residential community, the population, building, and activity densities are fixed.

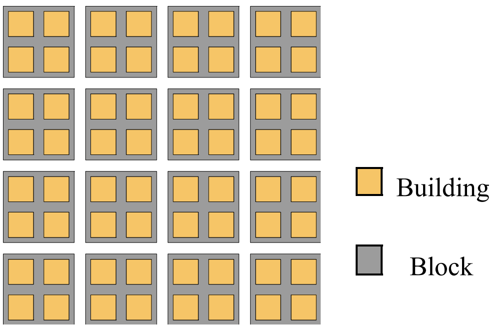


Figure 1. Base Map of Hypothetical Community

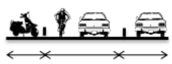


Figure 2 Profile of Eight-Meter Road of Hypothetical Community

2.2 Urban Planning/Design Tools and Scenarios

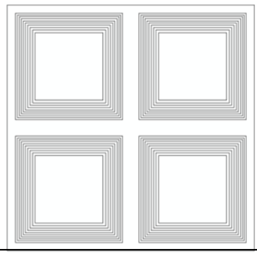
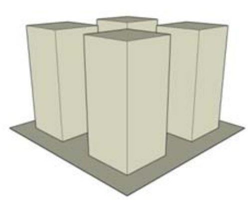
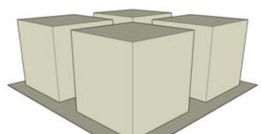
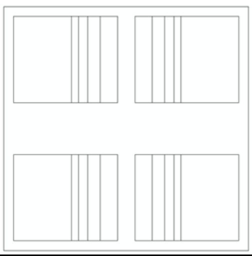
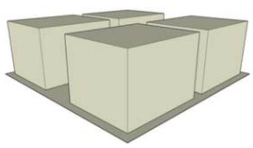
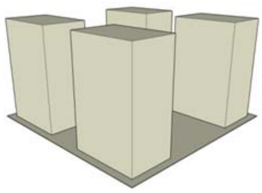
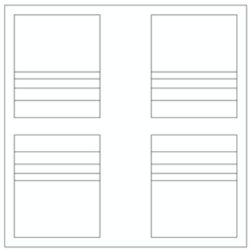
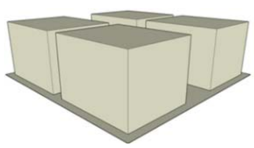
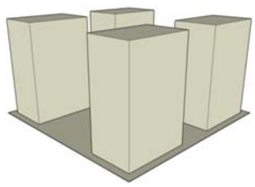
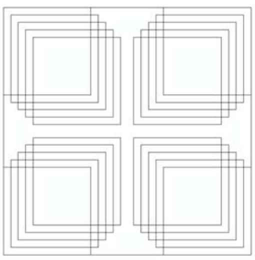
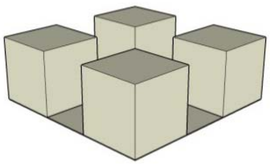
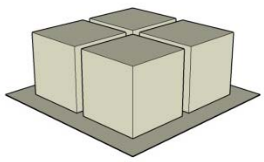
---

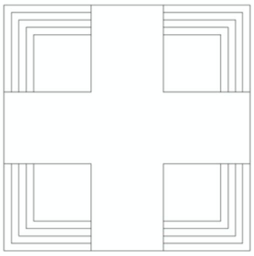
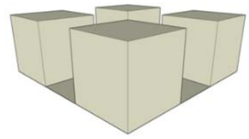
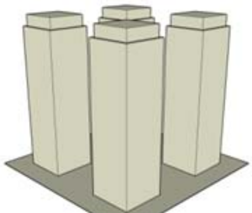
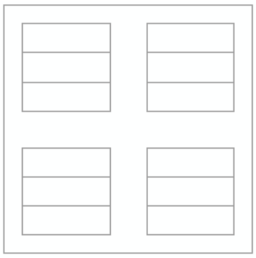
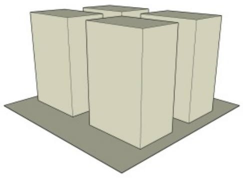
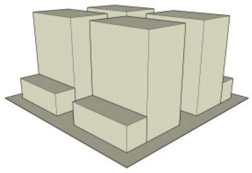
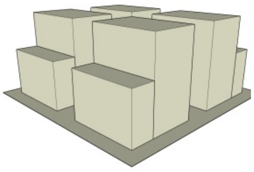
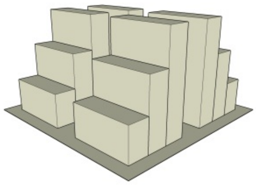
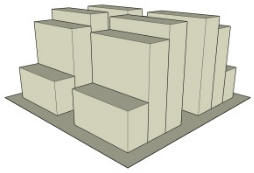
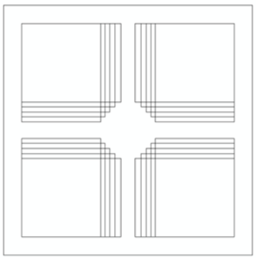
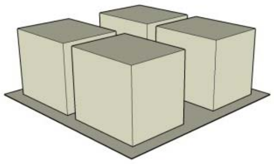
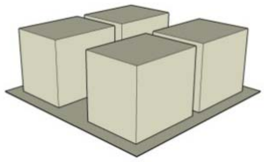
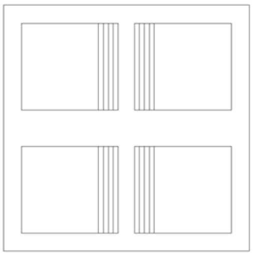
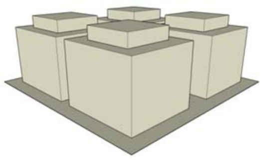
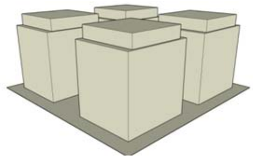
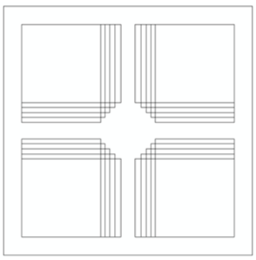
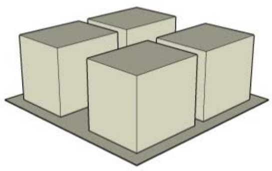
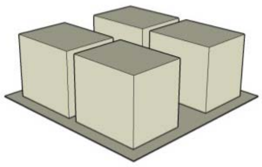
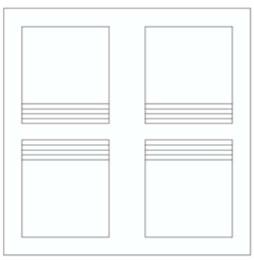
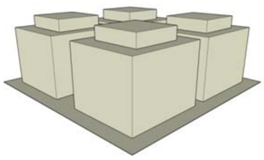
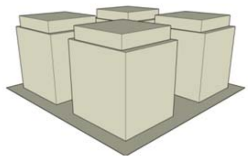
[1] Other land uses, such as commercials, industries, are not incorporated in the hypothetical community since their planning and design concerns are likely to be different Furthermore, neither do public facilities, such as parks, plazas because they may also affect the impact assessment due to their different settings or locations.

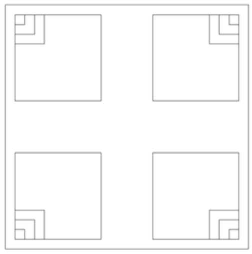
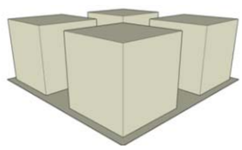
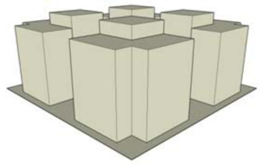
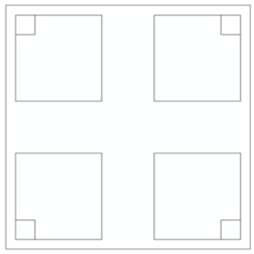
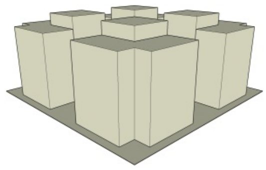
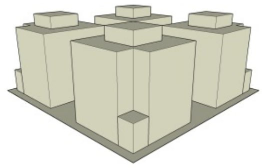
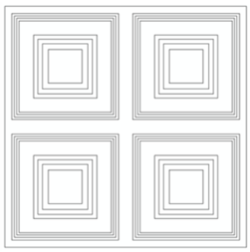
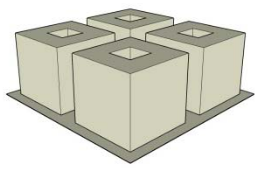
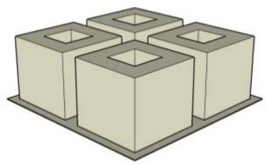
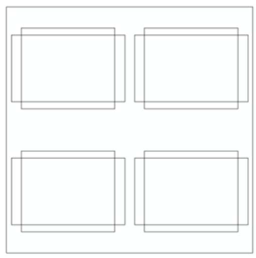
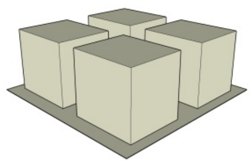
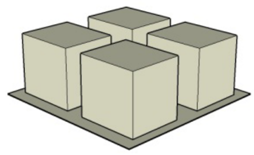
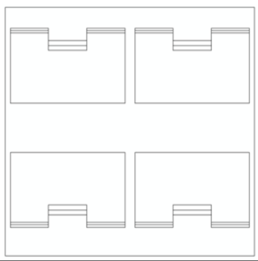
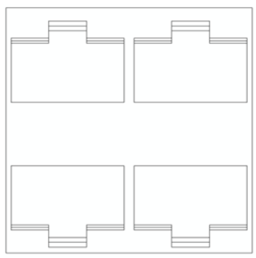
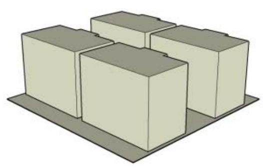
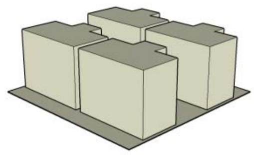
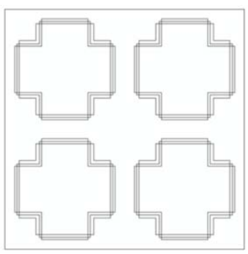
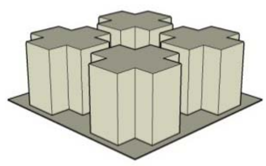
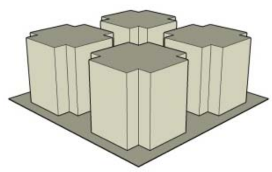
[2] The BCRs and FARs of the other three residential types are 30%-60%, 35%-120%, 45%-225%, respectively.

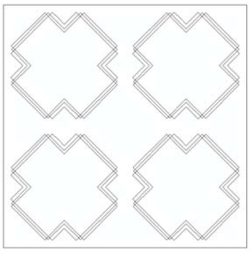
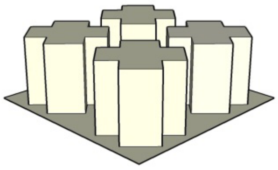
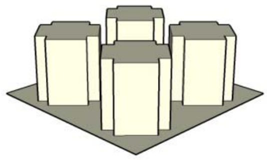
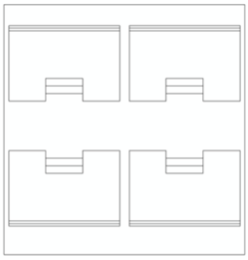
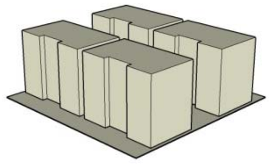
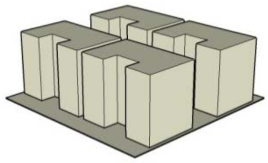
Based on literature review on urban plan regulations or ordinances in Taiwan and practical cases in Taiwan, New York city and Vancouver from Google map, six urban planning/design tools are pooled together to develop various scenarios for baseline building shape (i.e., tower): BCR, height distance ratio (HDR), building setback (SB), side yard width (SW), backyard depth (BD), street-corner building setback (SCBS)(Table 2). Additionally, seven other building shapes are developed for comparative analysis of different building shapes: tower (BS1), enclosing court (BS2), slab (BS3), U-shaped (BS4), convex-shaped (BS5), cross-shaped (BS6), X-shaped (BS7); and reverse U-shaped (BS8)(Table 2). Within each planning/design tools (including building shapes), a set of various scenarios are develop to access the impacts of setup changes within the tool in question. With the same 300% FAR, scenarios of each tool are developed to cover the largest, reasonable variation range, within which scenarios are created at fixed interval and in principle to obtain five scenarios if possible in order to calculate its efficiency/elasticity (refer to evaluation techniques below). Descriptions, two- and three-dimensional concept graphics of all the planning tools and scenarios are presented in Table 1.

Table 1 Urban Planning/Design Tools and Scenarios

Urban Planning/Design Tools: Scenarios Descriptions[1]	2-D Concept Graphics: Overlay of Scenarios	3-D Concept Graphics	
1. Building Coverage Percentage (BCR) ● Scenario: BCR30, 35, 40, 45.....75 (%) ● Buildings shrink inward or expand outwards around building central point as BCR changes.		BCR 75 	BCR30 
2. Height Distance Ratio (HDR) 2-1 HDR-S: FA[1] from Side ● Scenario: HDR-S1.25, 1.50,….2.25 ● The distance between buildings (south and north sides) is fixed with height varies for different scenarios at 0.25 ratio interval. The floor area for the increased height/stories is shift from the side of the building		HDR-S1.25 	HDR-S2.25 
2-2 HDR-B: FA[1] from Back ● Scenario: HDR-B1.25, 1.50,….225 ● The distance is fixed with height varies for different scenarios at 0.25 ratio interval. The floor area for the increased height/stories is shift from the back of the building.		HDR-B1.25 	HDR-B2.25 
3. Building Setback (SB) 3-1 SB-B: Moving Backwards ● Scenario: SB-B0, 1.5, 3, 4.5, 6(M) ● The whole building moves backwards towards block center at 1.5-meter for various scenarios.		SB-B0 	SB-B6 

3-2 SB-T: FA[1] to Top ● Scenario: SB-T0, 1.5, 3, 4.5, 6(M) ● The whole building shrinks towards south-east corner of the building at 1.5-meter interval for various scenarios, and the cutoff floor area is shift to the top of the building.		SB-T0 	SB-T6 
3-3 Stair-Shaped Setback (SSB) ● Scenarios: SSB_Base, _1(Step), _2(Steps)2(Setback on 2F), _2(Steps)4(Setback on 4F), _3(Steps)1(Type 1), 3(Steps)2(Type 2)		SSB_1 	SSB_2_2 
	SSB_2_4 	SSB_3_1 	SSB_3_2 
4. Side Yard Width (SW) 4-1 SW-B: FA1 to Back ● Scenario: SW-B1.5,2.5, 3.5, 4.5, 5.5(M) ● The side yard width is increased at one-meter interval, and the cutoff floor area is shift to the back of the building.		SW-B1.5 	SW-B5.5 
4-2 SW-T: FA[1] to Top ● Scenario: SW-T1.5,2.5, 3.5, 4.5, 5.5(M) ● The side yard width is increased at one-meter interval, and the cutoff floor area is shift to the top of the building.		SW-T3 	SW-T11 
5. Backyard Depth (BD) 5-1 BD-S: FA1 to Side ● Scenario: BD-S1.5,2.5, 3.5, 4.5, 5.5(M) ● The backyard depth is increased at one-meter interval, and the cutoff floor area is shift to the right side of the building.		BD-S1.5 	BD-S5.5 
5-2 BD-T: FA1 to Top ● Scenario: BD-T1.5,2.5, 3.5, 4.5, 5.5(M) ● The backyard depth is increased at one-meter interval, and the cutoff floor area is shift to the top of the building.		- BD T3 	BD-T11 

6.Street-Corner Building Setback (SCBS) 6-1 SCBS-H-1F: Horizontal setbacks on 1F ● Scenario: SCBS-1F0M, 2M, 4M, 6M ● The building corner at the intersection is set back from the ground level and above for 0, 2M, 4M and 6M for various scenarios, respectively, and the cutoff floor area is shift to the top of the building. This can also be called horizontal setback.		SCBS-1F0M 	SCBS-1F4M 
6-2 SCBS-V-4M: Vertical 4-Meter Setbacks ● Scenario: SCBS-4M, -3F, 2F, 1F ● The building corner at the intersection is set back for 4M starting from 1F, 2F, 3F and above for various scenarios, respectively, and the cutoff floor area is shift to the top of the building. This can also be called vertical setback.		SCBS-4M1F 	SCBS-4M3F 
7. Building Shape (BS) BS2:Enclosing Court ● Scenario: BS2-1.5, 2, 2.5, 3 (M) ● The front yard depths of various scenarios are 1.5, 2, 2.5, and 3 meters, respectively.		BS2-1 	BS2-2.5 
BS3: Slab (Baseline) ● Scenario: BS3-1, 2(M) ● The side yard widths of various scenarios are 1 and 2 meters, respectively.		BS3-1 	BS3-2 
BS4: U-Shaped ● Scenario: BS4-1, 2, 3 ● The depths of the dent parts of the buildings vary at one-meter interval.		BS4-1 **(Being revised)**	BS4-3 **(Being revised)**
BS5: Convex-Shaped ● Scenario: BS5-1, 2, 3 ● The depths of the bump parts of the buildings vary at one-meter interval.		BS5-1 	BS5-3 
BS6: Cross-Shaped ● Scenario: BS6-2, 2.5, 3 ● The lengths of the leg parts of the buildings vary at 0.5-meter interval.		BS6-2 	BS6-3 

BS7: X-Shaped ● Scenario: BS7-2, 2.5, 3 ● The lengths of the leg parts of the buildings vary at 0.5-meter interval.		BS7-2 	BS7-3 
BS8: Reverse U-Shaped ● Scenario: BS8-1, 2, 3 ● The depths of the dent parts of the buildings vary at one-meter interval.		BS8-1 	BS8-3 

1. Upper-left building in the block is taken as the example for the scenario description.

2.3 "Physical" Livability Aspects and Indexes

The physical livability of residential built environment to be evaluated is delineated by four major characteristics: first, it will evaluate the quality affected by space-related planning/design only, given other non-space factors the same, such as building materials, colors, detailed design, and landscaping. Secondly, this research limits the evaluation of livability to physical quality, as opposed to societal, economic quality to be more focused on the "hardware" aspect of built environment. Thirdly, this research concerns perceivable quality for both when residents stay in the residence (facing outdoor from windows or balcony) and on the street of the neighborhood as pedestrians, which collectively will make up a more complete residential built environment evaluation.

Finally, the evaluation of residential built environment of this research concerns *"perceivable"* quality, instead of *"perceived"* quality primarily for objective evaluation purposes. Perceivable quality in this research refers to built environment that can play as input factors to human perception, but not necessarily perceived by individuals. In a technical explanation, perceivable quality is measured without concerning weightings by individuals, leading to the advantage of a more generic evaluation version of residential built environment, and in contrast it is not tailored for suiting the special needs of one specific community.

The aspects of residential physical livability to be evaluated are composed of five aspects: pedestrian-friendly environment, space-derived amenities or perceivable density, daylight exposure, breezeway, and residential privacy, each of which is represented by corresponding indexes (Table 2). First, pedestrian-friendly environment is represented by the availability of side walk and green sidewalk when residents walk in the street. Secondly, space-derived amenities or perceivable density is represented by a combination of space/density on the ground (i.e., viewshed) and in the sky (i.e., SVF) perceivable to residents. A better variable is volumetric-space index, but such software being able to calculate it is not commercially available yet. Thirdly, solar radiation measures the day light exposure, affected by sky view and sunlight direction. Then, breezeway aspect is to measure the room where air can blow directly to a vantage point. It is noteworthy that this breezeway does not have the ability to calculate the exact breeze that a person at a vantage point can get since it is much more complicated. With this idea in mind, this aspect of breezeway adopts viewshed ratio as the variable. Finally, residential privacy is to quantify the extent to which residents can seclude themselves from others, or the extent one cannot be seen by neighbors and pedestrians. This research adopts mean of the closest distances to buildings across the street and in the back.

Table 2 Aspects and indexes of "Physical" Livability

Impact Aspect	Index
1. Pedestrian-Friendly Environment	$\text{Sidewalk Percentage} = \frac{\text{Sidewalk Length}^{*}}{\text{Street Length}^{**}}$
	$\text{Green Sidewalk Percentage} = \frac{\text{Green Sidewalk Length}^{***}}{\text{Street Length}^{**}}$
	Overall Index = Mean of above Two Indexes
2. Space-derived Amenities or Perceivable Density	$\text{Viewshed Percentage} = \frac{\text{Viewshed Area}}{\text{Total Land Area}}$
	$\text{Sky View Factor (Percentage)} = \frac{\text{Visible Sky Area}}{\text{Total Sky Area}}$
	Overall Index = Mean of above Two Indexes
3. Daylight Exposure	$\text{Solar Radiation Percentage} = \frac{\text{Solar Radiation of Scenario (Watts/M}^2)^{****}}{\text{Solar Radiation without Buildings}}$
4. Breezeway	$\text{Viewshed Percentage} = \frac{\text{Viewshed Area}}{\text{Total Land Area}}$
5. Residential Privacy	Average Distance to Neighboring Buildings in the Front and Back $\text{Standardized Residential Privacy Index} = 1 - \frac{\text{Average Distance}}{}$
Overall Livability Index	Mean of above Five Indexes

* Sidewalk length is the total length of the street segments where the width between curb and front wall of the building is larger than 1.5 meters for installation of minimal sidewalk.

** The street length excludes the intersection segments, where sidewalk cannot be implemented.

*** Greened sidewalk length is the total length of the street segments where the width between curb and front wall of the building is larger than three meters for growing trees or turf on the sidewalk.

**** The location setting is Taipei city, and time period setting is the second half of year 2011, between the first day of summer and the last day of fall.)

The two less commonly used indexes--viewshed area and solar radiation--are calculated with ArcGIS at selected sample points of one of the four central blocks in the community to represent the whole community. Viewshed is calculated as the weighted mean magnitude of that at nine points denoted by numbers to represent the viewshed around the block when residents walk on the street (Figure 4). Similarly, solar radiation is measured at the nine points denoted by numbers and four points denoted by alphabets for residents when they walk on the street and at the front and back of the building measured on the ground level, respectively. All the variables are standardized (see ..) to be within the range of one and zero, representing highest and lower levels, respectively.

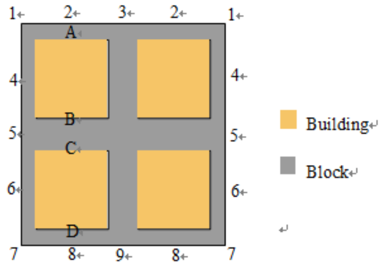


Figure 3　Sampling Points for Measuring Viewshed and Solar Radiation

2.4 Evaluation Techniques: Elasticity and Slopes

To evaluate the efficiency of urban planning/design tools on livability indexes, slope and mid-point elasticity are both adopted; the former is primarily used to identify where environmental quality jumps or drops, while the latter is used for cross-examining the relative effects of various planning tools due to its unit-free capacity.　Due to the units across various planning tools are possibly different, the concept of price-elasticity of demand, popularly used by economists to measure the impact of price on quantity,[3] is adopted and modified to measure the *percentage* change of performance indicator as a response to *percentage* change of planning/design tool (Equation 1). Besides, mid-point/arc elasticity (Equation 2-1) is applied to acquire the average elasticity since scenarios of one planning tool cover certain range.

$$E_{PL,Tool} = \frac{\partial PL / PL}{\partial Tool / Tool}$$ ……………………………………………………………….*Equation 1*

Where $E_{PL,\ Tool}$ is urban planning/design tool elasticity of physical livability;
PL is magnitude of physical livability index;
∂PL is change in magnitude of physical livability index;
Tool is magnitude of urban planning/design tool; and
∂Tool is change in magnitude of urban planning/design tool

The impacts of Urban Planning/Design Tools on "Physical" Livability Indexes

This section reveals the impacts of urban planning/design tools and building types on livability indexes. All the scenarios of urban design/planning tools are developed and extended from the base tower building type to provide a comparative base.　The impacts of buildings types, consisting of the base tower building type and seven other types, are further analyzed.　The impact analysis of urban planning/design tools focuses on both the overall livability index as well as each of the five individual livability aspects.　With the above information put together, the relative significance of each planning/design tool in improving overall livability or its sub-aspect, and the most livable scenarios are analyzed.

3-1 Building Coverage Percentage (BCR)

Table 3-1 provides the original index values of all seven indexes of the five aspects, composed of pedestrian-friendly environment, space-derived amenities or perceivable density, daylight exposure,

[3] Price-elasticity of demand allows comparing price-sensitivity of different products in terms of market demand.

breezeway and residential privacy. For comparative purposes, index values are standardized (refer to the notes of Table 3-1) to the range of between one and zero, indicating highest and lowest levels, respectively. For pedestrian-friendly environment and space-derived amenities aspects, their overall index is the mean of their two constituent indexes, representing two alternative indexes. Furthermore, the overall livability index is the mean of the six aspect indexes, assuming the six aspects contributing equally to livability quality; the reason for the equal weighting is that any types of weightings of the six aspects may differ from city to city, from time to time, or even from people to people, and unavoidably involves certain degree of arbitrary judgment, and it may also be hard to justify one aspect's dominance over others in terms of contribution to livability.

The statistics of pedestrian-friendly environment indexes indicate that when BCR falls under 55%, the overall index value jump significantly, suggesting BCR 55% as the cap in this regard. The index values in Table 3-1 show that there is enough room to build sidewalk on both sides of the streets for all BCR scenarios.[4] However, the sidewalk can only be greened when BCR is reduced to 55% and below, when the space between curb and building wall is wider than three meters to allow growing trees or turf. Due to the same fact, the

Table 3-1 "Physical" Livability Indexes, BCR scenarios

BCR	Pedestrian-Friendly Environment		Space-derived amenities or Perceivable Density		Daylight Exposure	Breezeway	Residential Privacy	Overall Livability (Mean)
	Sidewalk Percentage	Green Sidewalk Percentage	Viewshed Percentage	Sky View Factor	Solar Radiation[2] (Watts/M^2)	Viewshed Percentage	Average Distance[3] (M)	
30%	100.0%	100.0%	8.5%	27.7%	395,808 (49.7%)	8.5%	15.3 (96.8%)	0.55
35%	100.0%	100.0%	7.5%	30.4%	423,215 (53.1%)	7.5%	14.2 (89.9%)	0.54
40%	100.0%	100.0%	6.9%	33.7%	432,619 (54.3%)	6.9%	13.2 (83.4%)	0.53
45%	100.0%	100.0%	6.4%	31.4%	430,112 (54.0%)	6.4%	12.2 (77.4%)	0.51
50%[1]	100.0%	100.0%	6.1%	30.9%	425,599 (53.4%)	6.1%	11.3 (71.6%)	0.50
55%	100.0%	100.0%	5.6%	32.5%	449,875 (56.5%)	5.6%	10.5 (66.2%)	0.49
60%	100.0%	0.0%	5.0%	30.1%	404,469 (50.8%)	5.0%	9.6 (61.0%)	0.37
65%	100.0%	0.0%	4.8%	33.9%	454,768 (57.1%)	4.8%	8.8 (55.9%)	0.37
70%	100.0%	0.0%	4.3%	31.8%	425,711 (53.4%)	4.3%	8.1 (51.1%)	0.35
75%	100.0%	0.0%	4.1%	29.7%	393,897 (49.4%)	4.1%	7.4 (46.5%)	0.33
Mean	100.0%	60.0%	5.9%	31.2%	423,607 (53.2%)	5.9%	11.1 (70.0%)	0.46

Note: 1. Baseline scenario.

2. The number in the parentheses is standardized index, obtained with the following equation

$$= \left(1 - \frac{\text{Insolation}}{\text{Insolation without Buildings}}\right) = \left(1 - \frac{\text{Insolation}}{\text{[illegible] (Watts/M}^2)}\right)$$

3. The number in the parentheses is standardized index, obtained with the following equation

$$= \left(1 - \frac{\text{Average Distance}}{\text{Longest Average Distance}}\right) = \left(1 - \frac{\text{Average Distance}}{\text{15.8M}}\right)$$

accumulated percentage change of pedestrian-friendly environment index, with BCR 50% as base scenario,[5] jumps from -50% to 0 when BCR is reduced from 60% to 55%, i.e., the highest slope (Table 3-2).

[4] Sidewalk generally should be built on the side of road, instead on private property. However, due to the non-existence of sidewalk for most of narrow streets in traditional residential areas, private property is encouraged to build sidewalk with density incentive.

[5] BCR 50% is set as base scenario, with which percentage change between scenario in question and base scenario is calculated (Refer to note 1 in Table 3-2). The percentage change statistics are applied to pinpoint the highest slope, where the most significant impact occurs.

Table 3-2 Accumulated Percentage Change,[1] Elasticity and Slope of "Physical" Livability, Building Coverage Rate Scenarios

BCR	Pedestrian-Friendly Environment	Space-derived amenities or Perceivable Density[2]	Daylight Exposure[2]	Breezeway	Residential Privacy	Overall Livability (Mean)
30%	0%	-2%	-7%	41%	35%	9%
35%	0%	3%	-1%	25%	26%	8%
40%	0%	10%	2%	14%	17%	6%
45%	0%	2%	1%	5%	8%	3%
50% (Baseline)	--	--	--	--	--	--
55%	0%	3%	6%	-8%	-8%	-1%
60%	-50%	-5%	-5%	-17%	-15%	-26%
65%	-50%	5%	7%	-20%	-22%	-25%
70%	-50%	-2%	0%	-29%	-29%	-29%
75%	-50%	-9%	-7%	-33%	-35%	-33%
Elasticity	-0.56	N/A[1]	N/A[1]	-0.82	-0.78	-0.47
Highest Slope(s)	BCR60→55	BCR40[1]	BCR65, 55[1]	BCR35→30	BCR35→30	BCR60→55

Note: 1. Percentage change = $\frac{(Index_{target\ scenario} - Index_{base\ scenario})}{Index_{base\ scenario}} \times 100\% = \frac{(Index_{target\ scenario} - Index_{BCR50\%})}{Index_{BCR50\%}} \times 100\%$.

2. The impact is not linear, hence only the peak, instead of highest slope, is presented to show the scenario with the highest livability. For the same reason, it is not reasonable to calculate elasticity.

Then, with the same analysis framework as above, the impacts of BCR on the other four livability indexes are presented below. First, the statistics of Tables 3-1 and 3-2 show the impact of space-derived amenities is not linear and the best scenario is BCR 40%, which reflect the tradeoff between sky view and ground-level viewshed as BCR changes. Secondly, the daylight exposure index shows that the impact is not linear; the highest level occurs at BCR65% (7%), and 55% (6%)(Table 3-2), and the worst happens at both the highest and lowest BCRs, which reflects that fact that tallest buildings of lowest BCR 30%, and most reduced open space due to highest BCR of 75% both block sunlight the most. Thirdly, both the trends of index values of Tables 3-1 and accumulated percentages of Table 3-2 show that the lower the BCR, the higher the level of breezeway and residential privacy due to more space between buildings; additionally, the highest slopes suggest the caps are both BCR 30%.

Overall, BCR is an moderately efficient planning tool for developing livable built environment, and the lower the BCR, the more livable the city; furthermore, BCR is most efficient in improving pedestrian-friendly environment, breezeway and residential privacy, all of which involving more space on the ground level. First, the elasticity of overall livability index of -0.47 indicates BCR is moderately inelastic or inefficient in affecting livability (Table 3-2). Furthermore, the trend of percentage changes of overall livability index show that the livable level increases as BCR decreases and BCR 55% is the suggested cap, where the highest slope occurs. Conceptually, reducing BCR moves open space from top of the building (or sky) to the ground level, and hence enhances such ground-based livability quality as residential privacy and breezeway, but its impact on such sky-view-based livability quality as sky view and daylight exposure is complicated by whether sky view is block more by high building with more open space on the ground or low buildings with less open space.

3-2 Height Distance Ratio (HDR)

HDR-S and HDR-B, representing the floor area added to the top of the building shift from the side and back of the building, respectively, are both minimally effective livability planning tools; the higher the HDR, the more livable the city is, and the minimum HDR is suggested to be set at 1.75 and 1.5 for HDR-S and HDR-B, respectively; among the five livability aspects, HDR is effective in affecting residential privacy and breezeway. The elasticity of HDR-S and HDR-B, are 0.18 and 0.20, respectively (Table 4), smaller than the medium level of 0.5. The trend of accumulated percentage change of overall livability index shows the higher the HDR, and more livable the city is. The most efficient point (i.e., the highest slope) takes place at from HDR-S1.50 to 1.75 and from HDR-B1.25 to 1.50, respectively, and hence HDR-S 1.75 and HDR-B 1.50 are recommended as the minimum levels. Similar to the impact of increasing BCR, increasing HDR moves open space from the sky to the ground, and hence affects such ground-based livability quality as residential privacy and breezeway, and such sky-view-based livability quality, as sky view and daylight exposure.[6]

Table 4 Accumulated Percentage Change, Elasticity and Slope of "Physical" Livability Index, Height Distance Ratio Scenarios, Floor Area Shift from Side (-S) and from Back (-B)

HDR Scenario	Pedestrian-Friendly Environment	Space-derived amenities or Perceivable Density	Daylight Exposure	Breezeway	Residential Privacy	Overall Livability (Mean)
HDR-S1.25	0%	0%	8%	-4%	-16%	-4%
HDR-S150 (Baseline)	--	--	--	--	--	--
HDR-S1.75	0%	-2%	-1%	5%	11%	4%
HDR-S2.00	0%	-3%	-3%	10%	20%	6%
HDR-S2.25	0%	-4%	-5%	17%	26%	8%
Elasticity	0.00	-0.06	-0.19	0.31	0.62	0.18
Highest Slope(s)	N/A[3]	HDR-S1.75→150	HDR-S1.50→1.25	HDR-S2.00→2.25	HDR-S1.25→1.50	1.HDR-S1.50→1.75 2. HDR-S1.25→1.50[1]
HDR-B1.25	0%	-5%	-7%	-15%	-16%	-8%
HDR-B150 (Baseline)	--	--	--	--	--	--
HDR-B1.75	0%	2%	2%	12%	11%	5%
HDR-B2.00	0%	-1%	-22%	20%	20%	2%
HDR-B2.25	0%	1%	-21%	31%	25%	5%
Elasticity	0.00	N/A[2]	N/A[2]	0.69	0.62	0.20
Highest Slope(s)	N/A[3]	HDR-B1.75, 1.50[2]	HDR-B1.75, 1.50[2]	HDR-B1.25→1.50	HDR-B1.25→1.50	HDR-B1.25→1.50

Note: 1. For those with two highest slopes, the one with higher index value is prioritized due to better livability.
2. The impact is not linear, hence only the peak, instead of highest slope, is presented to show the scenario with the highest livability. For the same reason, it is not reasonable to calculate elasticity.
3. The highest slope is not available since planning tool in question has no impact on livability index.

3-3 Building Setback (SB)

This section presents the impacts of the three types of building setbacks—moving backwards (SB-B), shifting floor area to the top (SB-T), and stair-shaped setback (SSB), of which SSB is analyzed independently because the variations of its scenarios are not linear as SB-B and SB-T. Both SB-B and SB-T are not very efficient planning tools towards livability development; 3-meter setback (i.e., SB-B3) is the suggested minimum setback for both, and shifting floor are to the top is slightly more efficient than moving backwards setback. For each livability aspect, both types are moderately efficient in improving pedestrian-friendly environment, and minimally efficient in upgrading street level breezeway and space-derived amenities. Table 5-1 shows the elasticity values of overall livability indexes of both SB-B and SB-T are positive but minimal, but shifting floor area to the top is slightly more elastic primarily because more open space is left on the ground. The most efficient function of setback lies in providing more sidewalk space to pedestrians, and hence the accumulated percentage change of pedestrian-friendly environment jumps when the setback increases from zero to three meters. SB can also be used to improve breezeway, but only at elasticity levels of 0.22 and 0.39 for moving backwards and shifting floor area to the top, respectively.

Table 5-1 Accumulated Percentage Change, Elasticity and Slope of "Physical" Livability Index, Building Setback

[6] HDR does not affect pedestrian-friendly environment in this research due to the design setting that distance between buildings across the street is fixed.

Scenarios, Moving Backwards (B) and Floor Area Shift to the Top (T)

Building Setback Scenario	Pedestrian-Friendly Environment	Space-derived amenities or Perceivable Density	Daylight Exposure	Breezeway	Residential Privacy	Overall Livability (Mean)
SB-B0	-100%	-12%	-6%	-19%	0%	-43%
SB-B1.5	-50%	-6%	-1%	-10%	0%	-21%
SB-B3 (Baseline)	--	--	--	--	--	--
SB-B4.5	0%	4%	-2%	11%	0%	0%
SB-B6	0%	7%	-5%	24%	0%	0%
Elasticity	0.50	0.10	N/A	0.22	0.00	0.22
Highest Slope(s)	1. SB-B1.5→3 2. SB-B0→1.5	1. SB-B1.5→3 2. SB-B0→1.5	SB-B3	SB-B4.5→6	N/A	1. SB-B1.5→3 2. SB-B0→1.5
SB-T0	-100%	-10%	-7%	-33%	-12%	-46%
SB-T1.5	-50%	-4%	-3%	-18%	-6%	-23%
SB-T3 (Baseline)	--	--	--	--	--	--
SB-T4.5	0%	1%	-3%	19%	6%	2%
SB-T6	0%	8%	-2%	45%	12%	5%
Elasticity	0.50	0.25	0.02	0.39	0.12	0.25
Highest Slope(s)	1. SB-B1.5→3 2. SB-B0→1.5	SB-T4.5→ 6	SB-T3	SB-T 4.5→6	1. SB-T 4.5→6	1. SB-B1.5→3 2. SB-B0→1.5

Buildings with stair-shape setback are more "physically" livable than tower shape building without setback; three-step-shaped building is more livable than the rest with fewer steps; and even-step setback is more livable than non-even-step setback. First of all, all the values of SSB_1, 2_2, 2_4, 3_1, and 3_2 are higher than those of SSB_Base (i.e., tower without setback) in terms of overall livability, viewshed percentage, sky view factor, solar radiation, viewshed percentage and residential privacy (Table 5-2). Secondly, the two three-step scenarios (i.e., SSB_3_1, 3_2) are better than the rest in overall livability and a few aspect indexes. Finally, the two even-step scenarios (SSB3-1, and SSB2_2) are superior than their counterparts with uneven-step shape (i.e., SSB3-2, and SSB2_4) in overall livability and all aspects expect for pedestrian environment indexes. Figure 3 virtually shows perceivable space and vertical angle block by buildings from a vantage point for all scenarios; the former is related to space-derived amenities, and the later affects both sky view and insolation. The two three-step scenarios again are superior, and the two even-step scenarios are superior than their counterparts in terms of perceivable space and block angle.

Table 5-2 "Physical" Livability Indexes, Stair-Shaped Setback Scenarios

Building Setback Scenario	Pedestrian-Friendly Environment		Space-derived amenities or Perceivable Density		Daylight Exposure	Breezeway	Residential Privacy	Overall Livability[4]
	Sidewalk Percentage	Green Sidewalk Percentage	Viewshed Percentage	Sky View Factor	Solar Radiation[1] (Watts/M^2)	Viewshed Percentage	Average Distance[1] (M)	
SSB_Base	100.0%	100.0%	5.8%	30.9%	425,599 (53.4%)	5.8%	72.0% (11.4)	0.50
SSB_1	100.0%	100.0%	8.7%	29.6%	422267 (53.0%)	8.7%	91.0% (14.4)	0.54
SSB_2_2	100.0%	100.0%	6.4%	33.8%	430234 (54.0%)	6.4%	86.3% (13.6)	0.53
SSB_2_4	100.0%	100.0%	5.9%	32.4%	438201 (55.0%)	5.9%	80.1% (12.7)	0.52
SSB_3_1	100.0%	100.0%	6.5%	36.5%	454136 (57.0%)	6.5%	87.7% (13.9)	0.55
SSB_3_2	100.0%	100.0%	6.4%	35.8%	446168 (56.0%)	6.4%	85.0% (13.4)	0.54
Mean	100.0%	100.0%	6.6%	33.2%	436,101 (54.7%)	6.6%	83.7% (13.2)	0.53

Note: 1. The number in the parentheses is standardized index (Refer to notes in Table 3-1).

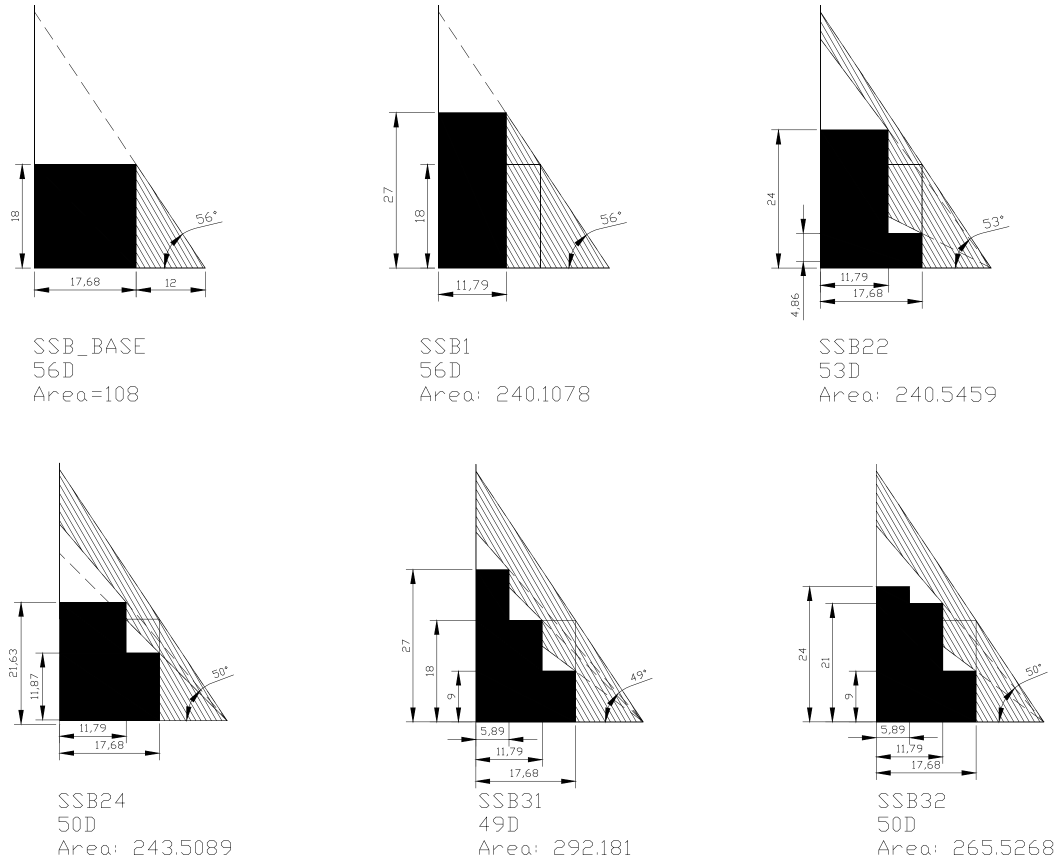


Figure 3 Perceivable 3-D Open Space and Block Angle from Vantage Point, Stair-Shaped Setback Scenarios

3-4 Side Yard Width (SW) and Backyard Depth (BD)

Both the two side yard width types, shifting floor area to the back (SW-B) and top (SW-T) of the buildings, are not efficient planning tool towards livability; the elasticity values of SW-B and top SW-T are -0.02 and 0.1, respectively (Table 6). However, shifting floor are to the top is slightly better than to the back since more open space is left on the ground level.

Backyard depth scenarios affect livability index similar to side yard distance: both the . two types of scenarios, shifting floor to the side (BD-S) and to the top (BD-T) of the building, are not efficient planning tool, and the latter is marginally superior than the former (Table 7)

Table 6 Accumulated Percentage Change, Elasticity and Slope of "Physical" Livability Index, Side Yard Width Scenarios, Floor Area Shift to Back (-B) and Top (-T) of Building

SW Scenario	Pedestrian-Friendly Environment	Space-derived amenities or Perceivable Density	Daylight Exposure	Breezeway	Residential Privacy	Overall Livability (Mean)
SW-B1.5 (Baseline)	--	--	--	--	--	--
SW-B2.5	0%	-8%	-4%	-3%	1%	-1%
SW-B3.5	0%	-5%	-6%	-5%	1%	-2%
SW-B4.5	0%	-10%	-11%	-8%	1%	-3%
SW-B5.5	0%	-13%	-17%	-11%	0%	-5%
Elasticity	0.00	-0.05	-0.06	-0.04	0.00	-0.02
Highest Slope(s)	N/A	SW-B2.5→1.5	SW-B5.5→4.5	SW-B2.5→1.5	SW-B2.5,3.5,4.5	SW-B5.5→4.5
SW-T1.5 (Baseline)	--	--	--	--	--	--
SW-T2.5	0%	-5%	-3%	1%	5%	0%
SW-T3.5	0%	-8%	-10%	2%	10%	0%
SW-T4.5	0%	-6%	-7%	3%	15%	2%
SW-T5.5	0%	-8%	-9%	6%	19%	2%

Elasticity	0.00	-0.03	-0.03	0.02	0.07	0.01
Highest Slope(s)	N/A	SW-B2.5→1.5	SW-T3.5→2.5	SW-T4.5→5.5	1. SW-T5.5	SW-T3.5→4.5

Table 7 Accumulated Percentage Change, Elasticity and Slope of "Physical" Livability Index, Backyard Depth Scenarios, Floor Area Shift to Back (-B) and Top (-T) of Building

SW Scenario	Pedestrian-Friendly Environment	Space-derived amenities or Perceivable Density	Daylight Exposure	Breezeway	Residential Privacy	Overall Livability (Mean)
BD-S1.5 (Baseline)	--	--	--	--	--	--
BD-S2.5	0%	4%	6%	3%	1%	2%
BD-S3.5	0%	10%	12%	6%	0%	3%
BD-S4.5	0%	11%	15%	9%	1%	4%
BD-S5.5	0%	14%	19%	12%	0%	5%
Elasticity	0.00	0.05	0.07	0.05	N/A	0.02
Highest Slope(s)	N/A	BD-S2.5→3.5	1. BD-S2.5→3.5 2. BD-S1.5→2.5	1. BD-S4.5→5.5	BD-S2.5, 4.5	BD-S1.5→2.5
BD-T1.5 (Baseline)	--	--	--	--	--	--
BD-T2.5	0%	4%	5%	5%	5%	3%
BD-T3.5	0%	0%	0%	8%	10%	3%
BD-T4.5	0%	5%	8%	13%	15%	6%
BDT-5.5	0%	4%	7%	19%	19%	8%
Elasticity	0.00	N/A	N/A	0.07	0.07	0.03
Highest Slope(s)	N/A	BD-T4.5	BD-T 4.5	BD-T4.5→5.5	1. BD-T4.5→5.5	1.BD-T3.5→4.5

3-5 Street-Corner Building Setback (SCBS)

The impacts of two types street corner building setback, the horizontal (SCBS-H) and vertical four-meter (SCBS-V) setbacks, on livability development are minimal but buildings with street corner setback is more livable than those without; for horizontal setback, the more the street corner setback, the more livable the city in terms of pedestrian-friendly environment, and breezeway; and for the vertical street corner setback, building with setback at the first floor is more pedestrian-friendly. Both the elasticity values of overall livability index for both SCBS-H and –V are positive but almost indifferent from zero (Table 8); this type of setback, specifically designed for more spacious street corner in a small spatial scale, is reasonable to have limited impact. In addition, horizontal setback does have certain degree of impact on pedestrian-friendly environment with an elasticity value of 0.04, larger breezeway with an elasticity value of 0.02.

Table 8 Accumulated Percentage Change,1 Elasticity and Slope of Livability Index, Street Corner Building Setback (SCBS) Scenarios, Horizontally (-H) and Vertically (-V)

SW Scenario	Pedestrian-Friendly Environment	Space-derived amenities or Perceivable Density	Daylight Exposure	Breezeway	Residential Privacy	Overall Livability (Mean)
SCBS-1F0M (Baseline)	--	--	--	--	--	--
SCBS-H-1F2M	3%	8%	6%	1%	0%	3%
SCBS-H-1F4M	7%	7%	5%	3%	0%	4%
SCBS-H-1F6M	11%	6%	3%	6%	0%	4%
Elasticity	0.04	N/A	0.01	0.02	0.00	0.01
Highest Slope(s)	1. SCBS-H-1F4M →1F6M	SCBS-H-1F2M	SCBS-H-1F0M →1F2M	SCBS-H-1F4M →1F6M	N/A	SCBS-H-1F0M →1F2M
SCBS-4M0F (Baseline)	--	--	--	--	--	--
SCBS-V-4M3F	0%	9%	7%	4%	0%	3%
SCBS-V-4M2F	0%	9%	7%	4%	0%	3%
SCBS-V-4M1F	7%	7%	5%	4%	0%	4%
Elasticity	0.03	N/A	N/A	0.01	0.00	0.01
Highest Slope(s)	SCBS-V-4M0F →4M1F	SCBS-V-4M0F →4M3F	SCBS-V-4M0F →4M3F	SCBS-V-4M0F →4M3F	N/A	SCBS-V-4M0F →4M3F

3-6 Building Shape

Of the selected building shapes, i.e., tower (BS1), enclosing court (BS2), slab (BS3), U-shaped (BS4), convex-shaped (BS5), cross-shaped (BS6), X-shaped (BS7), and reverse U-shaped, in general, the tower shape is superior than others considerably, followed by slab- and X-shaped, but individual variation of one building type may also be physically livable, such as BS2-3. The tower shape is physically more livable because of its capacity of providing wide sidewalk to plant trees, higher viewshed, sky view, solar radiation, and residential privacy derived from concentrated open space around its compact building shape. The slab shape is relatively livable in terms wide sidewalk for planting trees, better solar radiation through concentrated open space in the front and back yards. The X-shaped is supreme due to its capacity of providing greened sidewalk, and larger spacing between buildings. Table 9 shows that the tower, slab, and X-shaped have the three highest overall livability index values, i.e., 0.50, 0.42, and 0.41, respectively, as opposed to the rest with the values in the 0.3s, suggesting being avoided in practice. The green sidewalk percentage index reflects that these three building shapes plus cross-shaped provide sidewalk wider than three meters to grow plants; most of their scenarios have the index values larger than zero. The tower and slab communities provide better viewshed, sky view, and solar radiation than the rest; their viewshed values are 6.1% and 6.3%, respectively; their solar radiation values are 53.4% and 54.4%, higher than the rest in the lower 40% or below.

Table 9 "Physical" Livability Indexes, Building Shape (BS) Scenarios

Building Shape	Pedestrian-Friendly Environment		Space-derived amenities or Perceivable Density		Daylight Exposure	Breezeway	Residential Privacy	Overall Livability (Mean)[4]
	Sidewalk Percentage	Green Sidewalk Percentage	Viewshed Percentage	Sky View Factor	Solar Radiation (Watts/M²)	Viewshed Percentage	Average Distance (M)	
BS1: Tower	100.0%	100.0%	6.1%	30.9%	425,599 (53.4%)	6.1%	71.6% (11.3)	0.50
BS2-1.5:Enclosing Court	100.0%	0.0%	3.9%	21.8%	253,693 (31.8%)	3.9%	44.3%(7.0)	0.29
BS2-2 (Baseline)	100.0%	0.0%	4.3%	24.0%	343,132 (43.1%)	4.3%	50.6%(8.0)	0.32
BS2-2.5	100.0%	0.0%	4.8%	26.1%	293,552 (36.8%)	4.8%	56.9%(9.0)	0.33
BS2-3	100.0%	100.0%	5.3%	27.7%	389,512 (48.9%)	5.3%	63.6%(10.0)	0.47
Mean	100.0%	25.0%	4.6%	24.9%	319,972 (40.2%)	4.6%	53.8%(8.5)	0.35
BS3-1: Slab (Baseline)	100.0%	100.0%	6.1%	31.3%	421,792 (52.9%)	6.1%	56.0%(8.9)	0.47
BS3-2	100.0%	0.0%	6.4%	32.2%	445,727 (55.9%)	6.4%	57.8%(9.1)	0.38
Mean	100.0%	50.0%	6.3%	31.7%	433,760 (54.4%)	6.3%	56.9%(9.0)	0.42
BS4-1: U-Shaped	100.0%	0.0%	5.3%	29.0%	406,114 (51.0%)	5.3%	70.9%(11.2)	0.39
BS4-2 (Baseline)	100.0%	0.0%	4.6%	27.2%	287,033 (36.0%)	4.6%	74.1%(11.7)	0.36
BS4-3	100.0%	0.0%	4.4%	26.1%	280,281 (35.2%)	4.4%	77.2%(12.2)	0.36
Mean	100.0%	0.0%	4.8%	27.5%	324,476 (40.7%)	4.8%	74.1%(11.7)	0.37
BS5-1: Convex-Shaped	100.0%	0.0%	6.1%	31.5%	300,123 (37.7%)	6.1%	64.6%(10.2)	0.35
BS5-2 (Baseline)	100.0%	0.0%	5.9%	31.1%	294,317 (36.9%)	5.9%	61.4%(9.7)	0.35
BS5-3	100.0%	0.0%	5.6%	30.4%	285,602 (35.8%)	5.6%	58.2%(9.2)	0.34
Mean	100.0%	0.0%	5.8%	31.0%	293,348 (36.8%)	5.8%	61.4%(9.7)	0.34
BS6-2: Cross-Shaped	100.0%	23.7%	4.9%	28.0%	309,999 (38.9%)	4.9%	50.6%(8.0)	0.35
BS6-2.5 (Baseline)	100.0%	21.7%	5.3%	28.9%	319,580 (40.1%)	5.3%	56.9%%(9.0)	0.36
BS6-3	100.0%	100.0%	5.7%	29.9%	416,884 (52.3%)	5.7%	63.3%(10.0)	0.48
Mean	100.0%	48.5%	5.3%	28.9%	348,821 (43.8%)	5.3%	56.9%%(9.0)	0.39
BS7-2: X-Shaped	100.0%	24.6%	3.5%	22.4%	277,266 (34.8%)	3.5%	100%(15.8)	0.36
BS7-25 (Baseline)	100.0%	26.1%	4.0%	24.6%	292,795 (36.7%)	4.0%	96.7%(15.3)	0.37
BS7-3	100.0%	100.0%	4.6%	27.3%	312,421 (39.2%)	4.6%	90.5(14.3)	0.49
Mean	100.0%	50.2%	4.0%	24.8%	294,161 (36.9%)	4.0%	95.7%(15.1)	0.41
BS8-1: Reverse U-Shaped	100.0%	0.0%	5.4%	29.5%	301,562 (37.9%)	5.4%	70.9%(11.2)	0.36
BS8-2 (Baseline)	100.0%	0.0%	5.2%	28.2%	287,446 (36.1%)	5.2%	74.1%(11.7)	0.36
BS8-3	100.0%	0.0%	5.1%	27.2%	272,552 (34.2%)	5.1%	77.2%(12.2)	0.37
Mean	100.0%	0.0%	5.2%	28.3%	287,186 (36.0%)	5.2%	74.1%(11.7)	0.36

3-7 Relative Efficiency of Community Design Tools

3-7-1. Best Urban Planning/Design Tool for Overall Livable Built Environment: To improve the livability performance of the base scenario, BCR is the most efficient too, though only intermediately elastic, that is the percentage performance improvement is around half the percentage planning/design change. The elasticity of BCR is -0.47, followed by the second tier of efficient tools composed of building setbacks and height distance ratio with elasticity value around 0.2s (Table 10).

Table 10 The Elasticity of "Physical" Livability Indexes, By Aspect

Community Design Tools		Pedestrian-Friendly Environment	Space-derived amenities or Perceivable Density	Daylight Exposure	Breezeway	Residential Privacy	Overall Livability (Mean)
1. Building Coverage Percentage (BCR)	1 BCR	**-0.56**[2]	-0.07	0.00	**-0.82**	**-0.78**	-0.47
2. Height Distance Ratio (HDR)	2-1 HDR-S: FA[1] from Side	0.00	-0.06	-0.19	0.31	**0.62**	0.18
	2-2 HDR-B: FA from Back	0.00	N/A	N/A	**0.69**	**0.62**	0.20
3. Building Setback (SB)	3-1 SB-B: Moving Backwards	**0.50**	0.10	N/A	0.22	0.00	0.22
	3-2 SB-T: FA to Top	**0.50**	0.25	0.02	0.39	0.12	0.25
4. Side Yard Width (SW)	4-1 SW-B: FA to Back	0.00	-0.05	-0.06	-0.04	0.00	-0.02
	4-2 SW-T: FA to Top	0.00	-0.03	-0.03	0.02	0.07	0.01
5. Backyard Depth (BD)	5-1 BD-S: FA to Side	0.00	0.05	0.07	0.05	N/A	0.02
	5-2 BD-T: FA to Top	0.00	N/A	N/A	0.07	0.07	0.03
6. Street-Corner Building Setback (SCBS)	6-1 SCBS-H-1F: Horizontal Setbacks on 1F	0.04	0.02	0.01	0.02	0.00	0.01
	6-2 SCBS-V-4M: Vertical 4-Meter Setbacks	0.03	N/A	N/A	0.01	0.00	0.01

Note: 1. Floor Area
2. The highlighted are those with elasticity of .5 or higher.

3-7-2 Best Urban Planning/Design Tool for Individual Aspect of Livability: In certain cases, attention may be drawn to improvement of certain aspect of livability. This section puts together the above impact analysis to list the most efficient urban planning/design tool in each of the five aspects. First, to improve pedestrian-friendly environment, the most effective tools are lower building coverage percentage (1 BCR), higher building setback, either moving the whole building backwards (3-1 SB-B) or shifting floor area to the top (3-2 SB-T) of the buildings; the elasticity values of BCR, SB-B, and SB-T are -0.56, 0.5, and 0.5, respectively (Table 10). Secondly, to improve space-derived amenities or reduce perceivable density, the most efficient tools is to implement building setback by shifting floor area to the top of the building, and followed by moving-backwards building setback; the indexes values are 0.25 and 0.10, respectively.

Thirdly, if solar radiation is an issue for a community, in accordance with existing planning knowledge, reducing height distance radio by shifting floor area from the top of building to the side(2-1 HDR-S) is the most efficient tool, with the elasticity value of -0.19 (Table 10). Then, street-level breezeway can be most efficiently enlarged by reducing BCR or increasing height distance ratio by shifting floor area from the back (2-2 HDR-B) of the building, with elasticity values of -0.82 and 0.69, respectively. Finally, if residential privacy is the target issue, then reducing building coverage rate, increasing HDR by shifting floor area from the back and side of the building are most effective.

In sum, BCR is relatively effective in affecting three sub-livability indexes—breezeway, residential privacy and pedestrian-friendly environment. Building setback contributes rather effectively in improving pedestrian environment. And increasing height distance ratio is relatively effective in providing more breezeway and residential privacy. Finally, it may be inferred shakily that shifting floor area to the top of the building generally improves livability quality better than shifting it to the side, then back of the building, and moving backwards; increasing side yard width, and backyard depth by shifting floor area to the top (i.e., 4-2 SW-T and 5-2 BD-T, respectively) are more efficient than their counterparts of shifting floor area to the back or side of the building (i.e., 4-1 SW-B and 5-1 BD-S, respectively) (Table 10); implementing building setback by shifting floor area to the top (3-1 SB_T) is more efficient than moving backwards (3-2 SB_B); and to increase HDR by shifting floor area from the back of the building (2-2 HDR_B) is more effective than from the side (2-1

HDR_S). This finding, combined with impact of reducing BCR leading to tall buildings, indicates leaving more open space on the ground by shifting floor area on the top may be more "physically" livable; in other words, skinny, tall building may bring in more livable community than fat, short buildings given the circumstances of this research.

3-8 Most Livable Scenarios

Of the all of the scenarios across the six planning tools and eight building shapes, twelve are more livable with overall livability index values over 0.52 (Table 11). All the twelve scenarios area variations of tower shape buildings across three planning/design tools, consisting of stair-shaped setback (i.e., SSB_3_1, _1, 3_2, 2_2, 2_4), large building setback with floor area shift to the top (i.e., SB-T6 and T4.5), smaller building coverage percentages (i.e., BCR-30%, 35%, and 40%), and increasing backyard depth by shifting floor area to top (BD_T5.5, and T_4.5). Of all these scenarios, streets come along with greened sidewalk on both sides the whole length. These scenarios vary in indexes of livability aspects, but generally derived from the tradeoff between leaving more open space on the street level and leaving space in the sky by lowering buildings, and hence reflected on the tradeoff between such sky-based aspects as sky view and such ground-based aspects as viewshed.

Table 11 Most Physically Livable Scenarios

Scenario	Pedestrian-Friendly Environment		Space-derived amenities or Perceivable Density		Daylight Exposure	Breezeway	Residential Privacy	Overall Livability (Mean)[4]
	Sidewalk Percentage	Green Sidewalk Percentage	Viewshed Percentage	Sky View Factor	Solar Radiation	Viewshed Percentage	Average Distance	
BCR30%	100.0%	100.0%	8.5%	27.7%	395,808 (49.7%)[2]	8.5%	96.8% (15.3)[3]	0.55
SSB_3_1	100.0%	100.0%	6.5%	36.5%	454136 (57.0%)[1]	6.5%	87.7%[2] (13.9)[3]	0.55
SSB_1	100.0%	100.0%	8.7%	29.6%	422267 (53.0%)[1]	8.7%	91.0%[2] (14.4)[3]	0.54
SB-T6	100.0%	100.0%	10.0%	26.2%	411,808(51.7%)	10.0%	90.6%(14.3)[3]	0.54
BCR35%	100.0%	100.0%	7.5%	30.4%	423,215 (53.1%)[2]	7.5%	89.9% (14.2)[3]	0.54
SSB_3_2	100.0%	100.0%	6.4%	35.8%	446168 (56.0%)[1]	6.4%	85.0%[2] (13.4)[3]	0.54
SSB_2_2	100.0%	100.0%	6.4%	33.8%	430234 (54.0%)[1]	6.4%	86.3%[2] (13.6)[3]	0.53
BCR40%	100.0%	100.0%	6.9%	33.7%	432,619 (54.3%)[2]	6.9%	83.4% (13.2)[3]	0.53
SSB_2_4	100.0%	100.0%	5.9%	32.4%	438,201 (55.0%)[1]	5.9%	80.1%[2] (12.7)[3]	0.52
BDT-5.5	100.0%	100.0%	6.6%	31.8%	454,101(57.05)	6.6%	77.9% (12.3)	0.52
SB-T4.5	100.0%	100.0%	8.2%	25.0%	408,192 (51.2%)[2]	4.6%	85.9% (13.8)	0.52
BD-T4.5	100.0%	100.0%	6.3%	32.4%	459,056 (57.6%)[2]	6.3%	74.8% (11.8)	0.52

4. Conclusions and Policy Implications

This paper examines the impacts of the tools on livability, generally employed by urban planners and/or designers. Through simulation analysis in a hypothetical dense community, the roles of a range of eight planning/design tools are revealed in affecting livability in the regards of visible horizontal space, breeze way, visible sky, Radiation, and residential privacy. The results suggest that overall, reducing BCR decreasing BCR brings space to the ground at the cost of more building mass in the sky may be worthy since the magnitudes of beneficiary visible horizontal space, breeze way, and privacy is larger than that of loss of visible sky and Radiation on the one hand, and the level of sky view and Radiation seems at a higher level than visible horizontal space and breezeway, which may lessen the negative impact but weighting the positive gain. Besides, more space on the ground provides the potential of more green open space within close proximity to pedestrians, as well as plants, insects, and birds. Building setback plays the role of moving space from backyard to front yard, and hence enhances both ground-based and sky-based livability at the front of the building at the cost of less space in the backyard. It can be a more politically feasible tool since it adds no extra cost to developers, as opposed to lowering BCR resulting in higher cost due to taller buildings, and provides more space along the street, which is tangible to all users. However, the impacts in terms of downgrade of Radiation, breeze way, privacy in the backyard, which is barely measured in the paper, cannot be ignored, and deserver further analysis.

In addition, in pursuing certain aspect of livability, the most effective tools are also identified, which may be applicable in different urban settings. In a neighbourhood where visible space on the ground or breeze is of most concern, or even providing more space for eco-community, low BCR is the most effective tool to adopt, and building setback but shifting floor area to the top of the building, and the conventional building setback come after. Furthermore, in a neighbourhood where visible space in the sky or Radiation is of most concern, building setback and increasing BCR are the two most effective tools. To pursuing residential privacy alone, p reducing BCR, back setback and setback and shift up tools are the top three effective tools.

References

Costello, L., 2005. From Prisons to Penthouses: The Changing Images of High-Rise Living in Melbourne. Housing Studies, 20(1), pp. 49-6.

Taipei City Government, 2002. Taipei City Plan Ordinance (In Chinese).

Marshall, Alfred. [1890] 1997. Principles of Economics. Prometheus Books.

Wong, N. H., and C. Yu, 2005. Study of Green Areas and Urban Heat Island in A Tropical City. *Habitat Internationa*l, 29)(3), pp. 547-558

Wong, M. S., J. E. Nichol, P. H. To, and J. Wang, 2010. A Simple Method for Designation of Urban Ventilation Corridors and Its Application to Urban Heat Island Analysis. Building and Environment, 45, pp.1880-89.

Oke, TR., 1982. The Energetic Basis of The Urban Heat Island. *Quarterly Journal of The Royal Meteorological Society*, 108:1-24.

Grimmond, CSB, and TR. Oke, 1999. Aerodynamic Properties of Urban Areas Derived From Analysis of Surface Form. *Journal of Applied Meteorology*, 34, pp.1262-92.

Lettau, H, 1969. Note on Aerodynamic Roughness-Parameter Estimation on The Basis of Roughness-Element Description. *Journal of Applied Meteorology,*8: pp. 828-32.

Counihan, J.. 1975. Adiabatic Atmospheric Boundary Layers: a Review and Analysis of Data from the Period 1880-1972. Atmospheric Environment, 9: pp. 871-905.

Mfula, A. M., V. Kukadia, R. F. Griffiths, and Hall D. J., 2005. Wind Tunnel Modeling of Urban Building Exposure to Outdoor Pollution. *Atmospheric Environment*, 39(15): 2737-45.

Blocken, B., J.,Carmeliet, T., and Stathopoulos. 2007. CFD Evaluation of The Wind Speed Conditions In Passages Between Buildings E Effect of Wall-Function Roughness Modifications on the Atmospheric Boundary Layer Flow. *Journal of Wind Engineering and Industrial Aerodynamics*. 95: pp. 941-62.

Ng., E., 2009. Policies and Technical Guidelines for Urban Planning of High-Density Cities – Air Ventilation Assessment (AVA) of Hong Kong. *Building and Environment*, 44, pp.1478–88.

ASCE, 1999. *American Society of Civil Engineers (ASCE) manuals and reports on engineering* *practice No. 67: wind tunnel studies of buildings and structures*. Virginia.

Chao, R., Y.-Y. E. Ng, and L. Katzschner, 2010. Urban Climatic Map Studies: A Review. *International Journal of Climatology*. Published online in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/joc.2237.

Ng, E., Chao Y., C. Liang, R. Chao, C.H. F., Jimmy, 2011. Improving the Wind Environment in High-Density Cities By Understanding Urban Morphology and Surface Roughness: A Study In Hong Kong. Landscape and Urban Planning, 101, pp. 59–74

出席國際學術會議心得報告

日期：2011 年 10 月 30 日

計畫編號	NSC 98-2410-H-004-150		
計畫名稱	高密度建成環境中提升住宅可居住性的都市設計元素研究		
出國人員姓名	蔡育新	服務機構及職稱	國立政治大學地政系 副教授
會議時間	2011 年 1 月 28 日至 29 日	會議地點	*Beppu, Oita, Japan.*
會議名稱	（中文）2011 冬季環境創新與永續研討會 （英文）*The 2011 Winter Conference on Environmental Innovations and Sustainability*		
發表論文題目	(中文)高密度建成環境中提升住宅可居住性的都市設計元素研究 (英文)Simulation Analysis of Urban Planning/Design Elements for Improving "Physical" Livability in High-Density Neighborhoods		

一、參加會議經過：

研究者此次參加位於北九州大分縣 *Beppu 都市*的 Ritsumeikan Asia Pacific University 的 *The 2011* Winter Conference on Environmental Innovations and Sustainability 國際研討會，會期共兩天，會議地點於此大學內，與會學者以亞洲國家研究者為多，少數來自加拿大、澳洲。本研究者的發表時間是首日下午 3:30 – 1700。

二、與會心得：

研究者除個人發表論文外，亦於會場的兩個發表場地聆聽較有興趣的題目。但由於此研討會的規模較小，研討會主軸亦較為廣泛，因此與個人研究領域重疊者數量較少，是較為可惜的地方。

由於個人的專長是都市規劃，因此，也藉此機會，對於此研討會所在的溫泉都市、大學城、鐵路與公車系統、觀光國際化的部份進行觀察，稍有所得。

三、建議

受限於出國經費，因此可選擇的研討會較為有限。又現有國科會對於出國經費，似乎以同年度參加國際會議精神為主，然而，社會科學論文的於一年內的完成度通常較為不足，因此於預算時間內參加會議的發表成果，效果可能較不理想。

四、攜回資料名稱及內容

研討會論文集，部分其他發表者論文全文或相關簡報資料。

研討會論文被接受發表之大會證明文件：

Prof. Yu-Hsin Tsai 蔡育新

Department of Land Economics
National Chengchi University
Taiwan

Re: INVITATION LETTER FOR Prof. Yu-Hsin Tsai

Dear Prof. Tsai:

Greetings from the Graduate School of Management of Ritsumeikan Asia Pacific University.

We are pleased to invite you to the 2011 International Winter Conference on Environmental Innovations and Sustainability to be held in our campus on January 28 to 29, 2011.

We look forward to the presentation of your paper entitled, "A Simulation Analysis of Urban Design Elements for Improving Livability in High Density Neighborhoods Towards Sustainable City". Outstanding papers shall be considered for publication in the Asia Pacific World, the journal of the International Association of Asia Pacific Studies (IAAPS) and other academic journals that will be showcased during the conference days.

Thank you very much for completing the registration process and we eagerly await to meeting you in Beppu soon.

With best regards,

YOKOYAMA, Kenji, PhD.
Dean, Graduate School of Management
Ritsumeikan Asia Pacific University
yokoyama@apu.ac.jp

THE ORGANIZING COMMITTEE
gsm.apu.conference2011@apu.ac.jp
+81 977 78 1232

會議議程：

2011 International Winter Conference on Environmental Innovations and Sustainability

Session 2A - January 28, 2011 1530 - 1700

1530 - 1600	*A simulation analysis of urban design elements for improving physical livability in high-density neighborhoods towards sustainable city* Yu-Hsin Tsai, PhD., Department of Land Economics, National Chengchi University, Taiwan
1600 - 1630	*Solar power as sustainable source of energy in 21st century: A study on possibility of solar energy utilization in Beppu City* Faezeh Mahichi, Fan Li, Yangbeibei Liu, Rajeev Kumar Singh, Kanako Ochi and Yasuko Kon, Ritsumeikan Asia Pacific University, Japan
1630 - 1700	*Thermal mass application technique to reduce cooling load, CO2 emission and heat rejection in building design* Nattapon Jirattikalkit, PhD. Candidate, Chulalongkorn University, Thailand

論文：

Simulation Analysis of Urban Planning/Design Elements for Improving "Physical" Livability in High-Density Neighborhoods

Abstract

High-density built environment has been one primary policy to promote sustainability in terms of smaller per capita land consumption, travel energy consumption, and tailpipe emission. However, downgraded livability in high-density communities possibly lowers residents' standard of living and willingness to live in dense neighborhoods. Nonetheless, little research provides knowledge about the extent to which the tools of urban planning ordinances can raise physical livability in high-density built environment. This paper aims to first compile an inventory of urban planning/design tools for arranging buildings or space, as well as the aspects and indexes of "physical" livability. The second purpose is to examine the impacts of planning/design tools on physical livability. To assess the efficiency of planning/design tools towards more livable city, a simulation analysis is conducted in a hypothetical high-density city. Two analysis techniques are adopted: elasticity to compare relative efficiency of planning/design tools, and slope to identify recommended scenario. Research results show that planning/design elements include such element as building coverage percentage (BCR), various ways of building setback, and building types. Physical livability are composed of spatial openness at the ground level, room for fresh air to float, natural light exposure, sky view openness, and residential privacy, which are evaluated for from within the buildings as well as on street level. The simulation analysis suggests that BCR is relatively effective in affecting three sub-livability indexes—breezeway, residential privacy and pedestrian-friendly environment. Building setback contributes rather effectively in improving pedestrian environment. And increasing height distance ratio is relatively effective in providing more breezeway and residential privacy.

Keywords: *High density, built environment, livability, urban planning, urban design*

In the wake of pursuing sustainability, high-density built environment policy has gained momentum in a great many countries and cities, such as Melbourne, Australia, and as a significant element in such policy as compact city, transit-oriented development (TOD), and encouraged by a great many of academics (Costello, 2005) However, the social benefit of sustainability from denser living settings is likely to conflict individual or residents' interest due to concern on relatively low level of residential built environment quality (livability) in denser communities such as perceived density, low visibility, insufficient breezeway between buildings, Radiation, blocked sky view, and less residential privacy. As a result, the success of high density policy may depend largely on urban planning or design tools to reduce physical negative impacts of high-density settings at the least, or even to improve the physical environment at the best, and in turn, to hope for better perception, acceptance, or even demand for high-density living in the market.

Among numerous urban planning and design tools (planning/design tools in short hereafter), including most probed floor area ratio (FAR), distance height ratio (DHR), building coverage rate (BCR), building setback from the street, or from neighboring buildings, the degree to which they affect residential environment quality is barely examined, including perceivable density, visibility, daylight exposure. For practical purposes, planners need guidelines for selecting best planning/design tools or building shape to improve environmental quality, in particular, in high-density neighborhood. However, little knowledge has been revealed from past research in this regard. Hence, this paper aims to first compile an inventory of urban planning/design tools for arranging buildings or space in a community, as well as the aspects and indexes of "physical" livability of built environment, as opposed to social, cultural, and economic side of livability. The second purpose is to examine the impacts of planning/design tools on physical livability. The following sections are literature review on planning/design tools, aspects and indexes of physical livability, and current knowledge on the efficiency of planning/design tool in affecting livability, research methods describing the simulation analysis and analysis methods, the results of simulation analysis, and conclusions and policy implications.

1. Literature Review

In urban areas wind speed and direction can be affected by buildings in terms of mass, layout, height, and alignment. Most of past research has been addressing environment comfort issue affected by gust and strong wind in urban environment (ASCE, 1999; Ng, 2009). However, recently a great bulk of research, on the contrary, address weak wind in densely populated cities with public health issue such as air-borne contagious disease and urban heat island (UHI) effect (Oke, 1982; Ng, 2009; Wong et al., 2010). Improved urban wind environment can improve physical livability of high-density built environment in the regards of mitigating UHI effect, washing away air pollutants (Wong and Yu, 2005) and providing a more natural wind environment less blocked by dense buildings.

Four principle measures have been applied to gauge wind speed in urban settings: field survey, wind tunnel modeling (Mfula, 2005), numerical models including computational fluid dynamics (CFD) modeling (Blocken, 2007), and morphometric method or urban-form-based indexes. Field survey labor intensive, and requires instruments to measure wind speed and may suffer from sufficient variations of scenarios, and lack of controlled environment. The wind tunnel is the most accurate (Ng, 2009) but complex, technology-demanding and costly (Wong et al., 2010). CFD is appropriate for simulations for various scenarios but also engineering-expertise demanding. For these three methods, wind velocity ratio, the ratio of wind velocity at certain height above roof tops to that on the ground level is applied (Ng, 2009). Several indexes measuring the degree of surface roughness in urban setting (Lettau, 1969; Counihan, 1975; Grimmond and Oke, 1999; Wong et al., 2010), which affects ground wind velocity.

Frontal area index, defined as the ratio of building facets facing the particular wind direction to plane area is mostly used to gauge district-base area average (Grimmond and Oke, 1999; Wong et al., 2010; Chao et al., 2010). Building coverage rate (BCR) or ground coverage ratio, highly positively correlated with frontal area ratio, is proposed as a proxy of frontal area ratio to measure pedestrian-level wind environment due to its simplicity (Ng et al., 2011). However BCR is not able to measure micro-level wind permeability (Ng et al., 2011) such as building level. Theoretically, viewshed from one test point could be used as a proxy since it can be applied to quantify the degree to which it is close to a plane without buildings on the ground on the one hand or the permeability on the ground level to allow wind travelling along breezeways to the test point; and it is theoretically affected by BCR in theory and could be highly correlated on the other hand.

2. Research Methods

To assess the efficiency of planning/design tools towards more livable city, a simulation analysis will be conducted in a hypothetical high-density city. The high-density urban setting is selected since livability is of more concern than in low-density setting. In assessing the efficiency of planning/design tools, hypothetical community simulation analysis is adopted over empirical study of practical cases for two reasons: on the one hand, a hypothetical community provides all possible variations of various planning/design tools as needed. On the other hand, in practical cases, factors affecting built environment per se are barely understood and intermingled, and hence hard to identify, not to mention the difficulty to measure. The hypothetical residential community hence provides a test bed for comparative analysis with built environment controlled for to allow changes in one single planning/design tool; all the scenarios are developed given the same density level, uniform building shapes, road systems, for example, to evaluate the impacts planning tools on livability indexes.

To facilitate the simulation analysis, this section first develops a hypothetical high-density residential community, and then an inventory of the planning/design tools and scenarios derived from their various setups, and the indexes for livability. Two analysis techniques are adopted: elasticity to compare relative efficiency of planning/design tools to improve livability, and slope to identify recommended scenario for each of the planning/design tools. The software packages applied are Google SketchUp, AutoCAD, ArcGIS and Excel.

2.1 Base Maps of Hypothetical Residential Community

A hypothetical high-density residential community[1] is developed based on two primary guidelines: On the one hand, the spatial scale of the community is as small as possible for calculation purpose, but large enough where the livability indexes can be measured as in a large community with as less distortion as possible. On the other hand, it mimics Taipei, Taiwan in order to embed such concern over livability issues due to high-density development, lack of sidewalk, which is probably also true in many cities in Taiwan and Japan since the major land use plans in Taiwan were developed during the Japanese colonial periods between 1895-1945. Taipei is selected due to its high density of some 9,600 persons per square kilometer in 2011 (Taipei City Government, 2011), where street layouts, sites are mostly developed leaving little room for major modification but urban renewal of buildings.

This hypothetical community is composed of 16 50-meter by 50-meter identical blocks, surrounded by eight-meter wide road, which is the most popular road width in residential communities in Taipei, Taiwan (Figure 1). These eight-meter roads mostly are not equipped with sidewalk (Figure 2), or come along with traditional arch sidewalks attached to the front of the buildings. Within each block lies four identical 50%-BCR and 300%-FAR buildings (i.e., residential type IV[2] of Taipei city zoning ordinance (Taipei City Government, 2002)) are equally scattered and centered in their own quadrant; the FAR of 300% is selected because it is the highest cap of all four stereotypes of residential areas in Taipei as well as Taiwan, formulating the highest population density residential communities. The buildings are all set to be north-south-oriented, as preferred by the locals according to the traditional wisdom and to avoid bright, hot sun lights in the afternoon in the sub-tropical regions. The floor-to-floor height of all the buildings is three meters. Within this hypothetical residential community, the population, building, and activity densities are fixed.

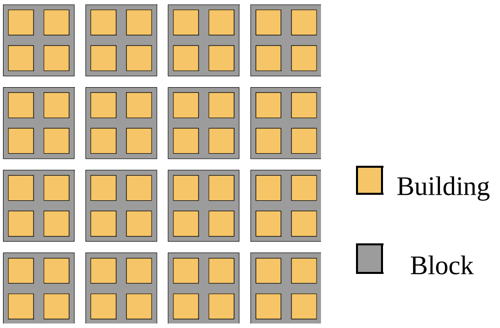


Figure 1. Base Map of Hypothetical Community

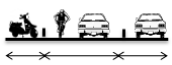


Figure 2 Profile of Eight-Meter Road of Hypothetical Community

2.2 Urban Planning/Design Tools and Scenarios

Based on literature review on urban plan regulations or ordinances in Taiwan and practical cases

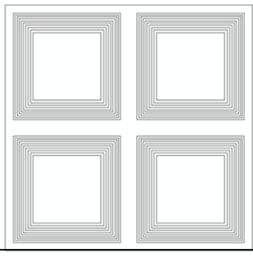
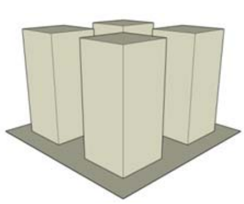
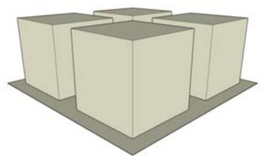
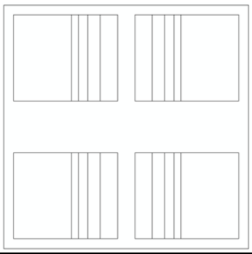
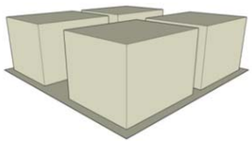
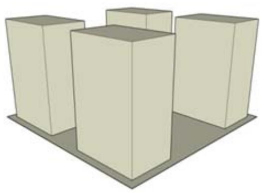
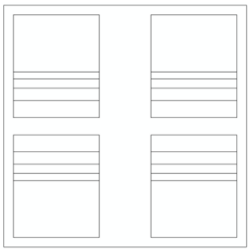
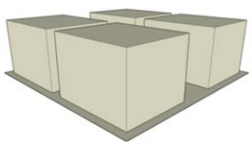
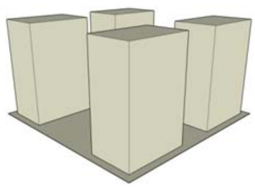
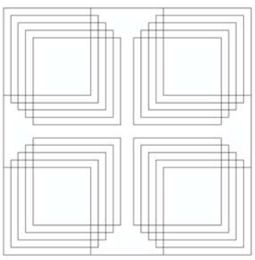
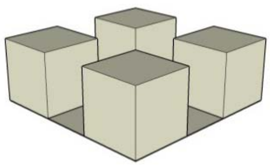
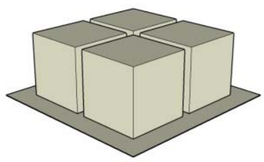
---

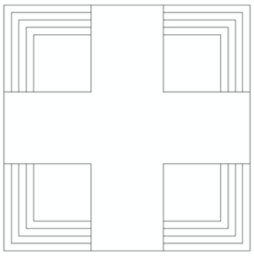
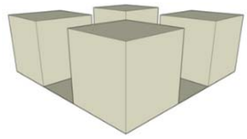
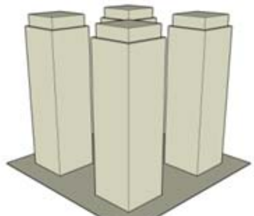
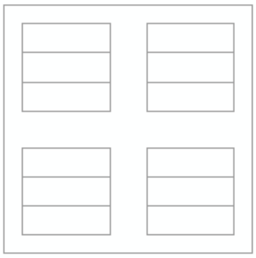
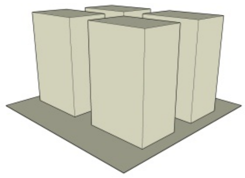
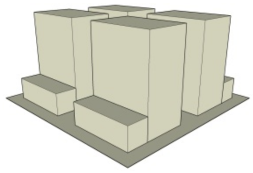
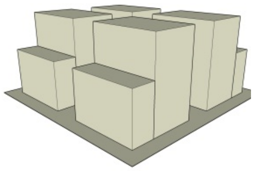
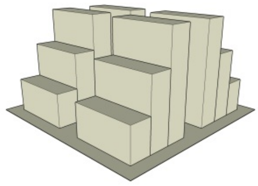
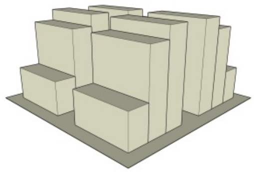
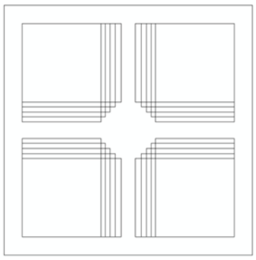
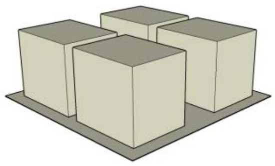
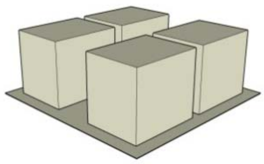
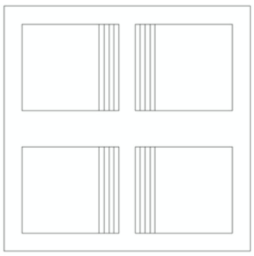
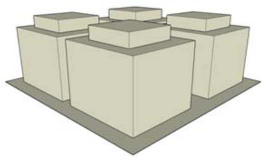
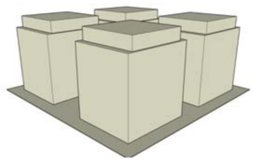
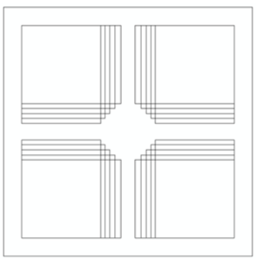
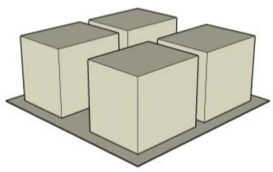
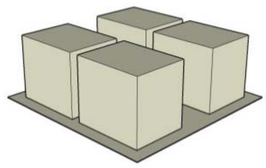
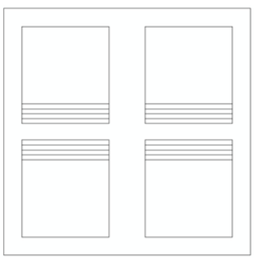
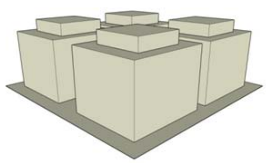
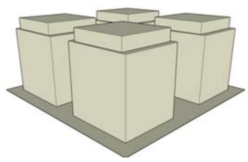
[1] Other land uses, such as commercials, industries, are not incorporated in the hypothetical community since their planning and design concerns are likely to be different Furthermore, neither do public facilities, such as parks, plazas because they may also affect the impact assessment due to their different settings or locations.

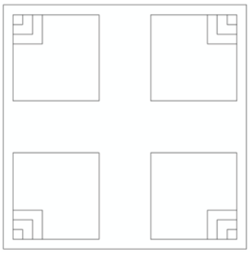
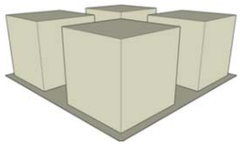
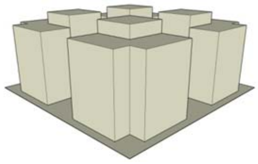
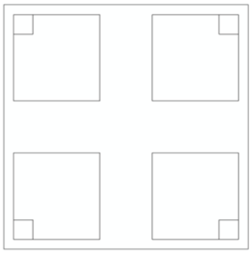
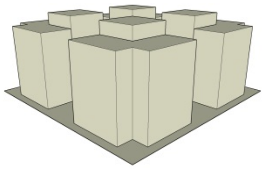
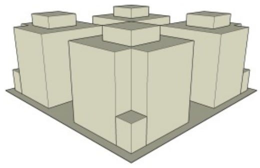
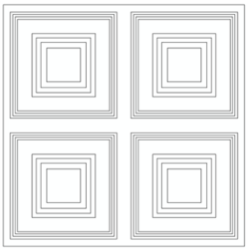
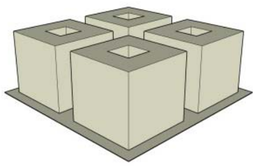
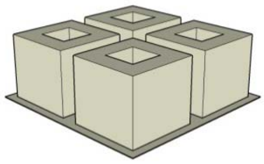
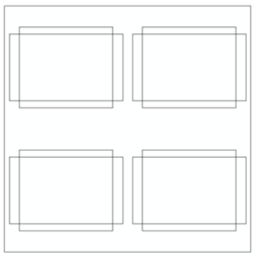
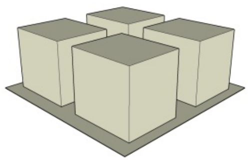
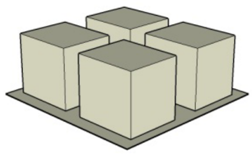
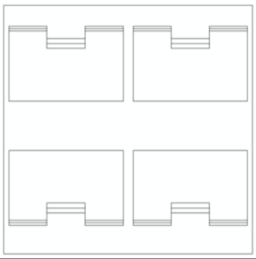
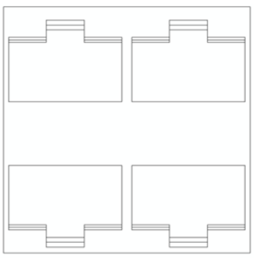
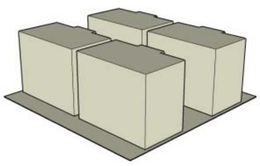
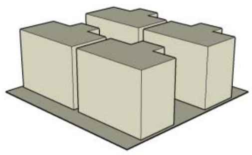
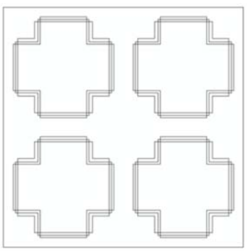
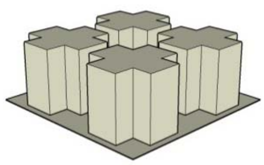
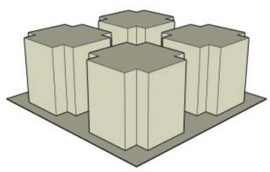
[2] The BCRs and FARs of the other three residential types are 30%-60%, 35%-120%, 45%-225%, respectively.

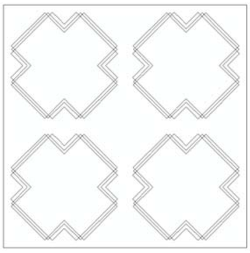
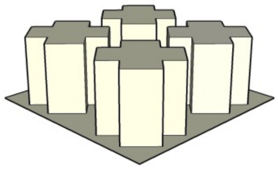
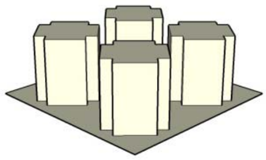
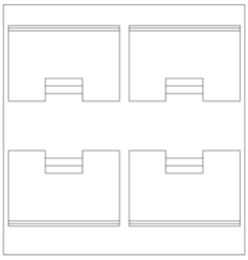
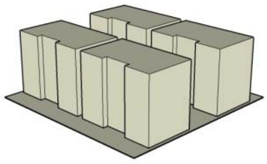
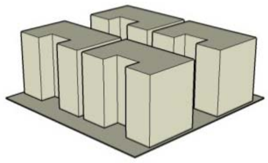
in Taiwan, New York city and Vancouver from Google map, six urban planning/design tools are pooled together to develop various scenarios for baseline building shape (i.e., tower): BCR, height distance ratio (HDR), building setback (SB), side yard width (SW), backyard depth (BD), street-corner building setback (SCBS)(Table 2). Additionally, seven other building shapes are developed for comparative analysis of different building shapes: tower (BS1), enclosing court (BS2), slab (BS3), U-shaped (BS4), convex-shaped (BS5), cross-shaped (BS6), X-shaped (BS7); and reverse U-shaped (BS8)(Table 2). Within each planning/design tools (including building shapes), a set of various scenarios are develop to access the impacts of setup changes within the tool in question. With the same 300% FAR, scenarios of each tool are developed to cover the largest, reasonable variation range, within which scenarios are created at fixed interval and in principle to obtain five scenarios if possible in order to calculate its efficiency/elasticity (refer to evaluation techniques below). Descriptions, two- and three-dimensional concept graphics of all the planning tools and scenarios are presented in Table 1.

Table 1 Urban Planning/Design Tools and Scenarios

Urban Planning/Design Tools: Scenarios Descriptions[1]	2-D Concept Graphics: Overlay of Scenarios	3-D Concept Graphics	
1. Building Coverage Percentage (BCR) ● Scenario: BCR30, 35, 40, 45.....75 (%) ● Buildings shrink inward or expand outwards around building central point as BCR changes.		BCR 75 	BCR30 
2. Height Distance Ratio (HDR) 2-1 HDR-S: FA[1] from Side ● Scenario: HDR-S1.25, 1.50,….2.25 ● The distance between buildings (south and north sides) is fixed with height varies for different scenarios at 0.25 ratio interval. The floor area for the increased height/stories is shift from the side of the building		HDR-S1.25 	HDR-S2.25 
2-2 HDR-B: FA[1] from Back ● Scenario: HDR-B1.25, 1.50,….225 ● The distance is fixed with height varies for different scenarios at 0.25 ratio interval. The floor area for the increased height/stories is shift from the back of the building.		HDR-B1.25 	HDR-B2.25 
3. Building Setback (SB) 3-1 SB-B: Moving Backwards ● Scenario: SB-B0, 1.5, 3, 4.5, 6(M) ● The whole building moves backwards towards block center at 1.5-meter for various scenarios.		SB-B0 	SB-B6 

3-2 SB-T: FA[1] to Top ● Scenario: SB-T0, 1.5, 3, 4.5, 6(M) ● The whole building shrinks towards south-east corner of the building at 1.5-meter interval for various scenarios, and the cutoff floor area is shift to the top of the building.		SB-T0 	SB-T6 
3-3 Stair-Shaped Setback (SSB) ● Scenarios: SSB_Base, _1(Step), _2(Steps)2(Setback on 2F), _2(Steps)4(Setback on 4F), _3(Steps)1(Type 1), 3(Steps)2(Type 2)		SSB_1 	SSB_2_2 
	SSB_2_4 	SSB_3_1 	SSB_3_2 
4. Side Yard Width (SW) 4-1 SW-B: FA1 to Back ● Scenario: SW-B1.5,2.5, 3.5, 4.5, 5.5(M) ● The side yard width is increased at one-meter interval, and the cutoff floor area is shift to the back of the building.		SW-B1.5 	SW-B5.5 
4-2 SW-T: FA[1] to Top ● Scenario: SW-T1.5,2.5, 3.5, 4.5, 5.5(M) ● The side yard width is increased at one-meter interval, and the cutoff floor area is shift to the top of the building.		SW-T3 	SW-T11 
5. Backyard Depth (BD) 5-1 BD-S: FA1 to Side ● Scenario: BD-S1.5,2.5, 3.5, 4.5, 5.5(M) ● The backyard depth is increased at one-meter interval, and the cutoff floor area is shift to the right side of the building.		BD-S1.5 	BD-S5.5 
5-2 BD-T: FA1 to Top ● Scenario: BD-T1.5,2.5, 3.5, 4.5, 5.5(M) ● The backyard depth is increased at one-meter interval, and the cutoff floor area is shift to the top of the building.		- BD T3 	BD-T11 

6.Street-Corner Building Setback (SCBS) 6-1 SCBS-H-1F: Horizontal setbacks on 1F ● Scenario: SCBS-1F0M, 2M, 4M, 6M ● The building corner at the intersection is set back from the ground level and above for 0, 2M, 4M and 6M for various scenarios, respectively, and the cutoff floor area is shift to the top of the building. This can also be called horizontal setback.		SCBS-1F0M 	SCBS-1F4M 
6-2 SCBS-V-4M: Vertical 4-Meter Setbacks ● Scenario: SCBS-4M, -3F, 2F, 1F ● The building corner at the intersection is set back for 4M starting from 1F, 2F, 3F and above for various scenarios, respectively, and the cutoff floor area is shift to the top of the building. This can also be called vertical setback.		SCBS-4M1F 	SCBS-4M3F 
7. Building Shape (BS) BS2:Enclosing Court ● Scenario: BS2-1.5, 2, 2.5, 3 (M) ● The front yard depths of various scenarios are 1.5, 2, 2.5, and 3 meters, respectively.		BS2-1 	BS2-2.5 
BS3: Slab (Baseline) ● Scenario: BS3-1, 2(M) ● The side yard widths of various scenarios are 1 and 2 meters, respectively.		BS3-1 	BS3-2 
BS4: U-Shaped ● Scenario: BS4-1, 2, 3 ● The depths of the dent parts of the buildings vary at one-meter interval.		BS4-1 **(Being revised)**	BS4-3 **(Being revised)**
BS5: Convex-Shaped ● Scenario: BS5-1, 2, 3 ● The depths of the bump parts of the buildings vary at one-meter interval.		BS5-1 	BS5-3 
BS6: Cross-Shaped ● Scenario: BS6-2, 2.5, 3 ● The lengths of the leg parts of the buildings vary at 0.5-meter interval.		BS6-2 	BS6-3 

BS7: X-Shaped ● Scenario: BS7-2, 2.5, 3 ● The lengths of the leg parts of the buildings vary at 0.5-meter interval.		BS7-2 	BS7-3 
BS8: Reverse U-Shaped ● Scenario: BS8-1, 2, 3 ● The depths of the dent parts of the buildings vary at one-meter interval.		BS8-1 	BS8-3 

1. Upper-left building in the block is taken as the example for the scenario description.

2.3 "Physical" Livability Aspects and Indexes

The physical livability of residential built environment to be evaluated is delineated by four major characteristics: first, it will evaluate the quality affected by space-related planning/design only, given other non-space factors the same, such as building materials, colors, detailed design, and landscaping. Secondly, this research limits the evaluation of livability to physical quality, as opposed to societal, economic quality to be more focused on the "hardware" aspect of built environment. Thirdly, this research concerns perceivable quality for both when residents stay in the residence (facing outdoor from windows or balcony) and on the street of the neighborhood as pedestrians, which collectively will make up a more complete residential built environment evaluation.

Finally, the evaluation of residential built environment of this research concerns *"perceivable"* quality, instead of *"perceived"* quality primarily for objective evaluation purposes. Perceivable quality in this research refers to built environment that can play as input factors to human perception, but not necessarily perceived by individuals. In a technical explanation, perceivable quality is measured without concerning weightings by individuals, leading to the advantage of a more generic evaluation version of residential built environment, and in contrast it is not tailored for suiting the special needs of one specific community.

The aspects of residential physical livability to be evaluated are composed of five aspects: pedestrian-friendly environment, space-derived amenities or perceivable density, daylight exposure, breezeway, and residential privacy, each of which is represented by corresponding indexes (Table 2). First, pedestrian-friendly environment is represented by the availability of side walk and green sidewalk when residents walk in the street. Secondly, space-derived amenities or perceivable density is represented by a combination of space/density on the ground (i.e., viewshed) and in the sky (i.e., SVF) perceivable to residents. A better variable is volumetric-space index, but such software being able to calculate it is not commercially available yet. Thirdly, solar radiation measures the day light exposure, affected by sky view and sunlight direction. Then, breezeway aspect is to measure the room where air can blow directly to a vantage point. It is noteworthy that this breezeway does not have the ability to calculate the exact breeze that a person at a vantage point can get since it is much more complicated. With this idea in mind, this aspect of breezeway adopts viewshed ratio as the variable. Finally, residential privacy is to quantify the extent to which residents can seclude themselves from others, or the extent one cannot be seen by neighbors and pedestrians. This research adopts mean of the closest distances to buildings across the street and in the back.

Table 2 Aspects and indexes of “Physical” Livability

Impact Aspect	Index
1. Pedestrian-Friendly Environment	$\text{Sidewalk Percentage} = \frac{\text{Sidewalk Length}^{*}}{\text{Street Length}^{**}}$
	$\text{Green Sidewalk Percentage} = \frac{\text{Green Sidewalk Length}^{***}}{\text{Street Length}^{**}}$
	Overall Index = Mean of above Two Indexes
2. Space-derived Amenities or Perceivable Density	$\text{Viewshed Percentage} = \frac{\text{Viewshed Area}}{\text{Total Land Area}}$
	$\text{Sky View Factor (Percentage)} = \frac{\text{Visible Sky Area}}{\text{Total Sky Area}}$
	Overall Index = Mean of above Two Indexes
3. Daylight Exposure	$\text{Solar Radiation Percentage} = \frac{\text{Solar Radiation of Scenario (Watts/M}^2)^{****}}{\text{Solar Radiation without Buildings}}$
4. Breezeway	$\text{Viewshed Percentage} = \frac{\text{Viewshed Area}}{\text{Total Land Area}}$
5. Residential Privacy	Average Distance to Neighboring Buildings in the Front and Back $\text{Standardized Residential Privacy Index} = 1 - \frac{\text{Average Distance}}{}$
Overall Livability Index	Mean of above Five Indexes

* Sidewalk length is the total length of the street segments where the width between curb and front wall of the building is larger than 1.5 meters for installation of minimal sidewalk.

** The street length excludes the intersection segments, where sidewalk cannot be implemented.

*** Greened sidewalk length is the total length of the street segments where the width between curb and front wall of the building is larger than three meters for growing trees or turf on the sidewalk.

**** The location setting is Taipei city, and time period setting is the second half of year 2011, between the first day of summer and the last day of fall.)

The two less commonly used indexes--viewshed area and solar radiation--are calculated with ArcGIS at selected sample points of one of the four central blocks in the community to represent the whole community. Viewshed is calculated as the weighted mean magnitude of that at nine points denoted by numbers to represent the viewshed around the block when residents walk on the street (Figure 4). Similarly, solar radiation is measured at the nine points denoted by numbers and four points denoted by alphabets for residents when they walk on the street and at the front and back of the building measured on the ground level, respectively. All the variables are standardized (see ..) to be within the range of one and zero, representing highest and lower levels, respectively.

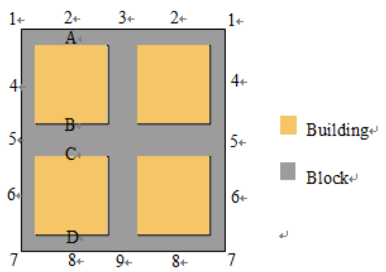


Figure 3 Sampling Points for Measuring Viewshed and Solar Radiation

2.4 Evaluation Techniques: Elasticity and Slopes

To evaluate the efficiency of urban planning/design tools on livability indexes, slope and mid-point elasticity are both adopted; the former is primarily used to identify where environmental quality jumps or drops, while the latter is used for cross-examining the relative effects of various planning tools due to its unit-free capacity. Due to the units across various planning tools are possibly different, the concept of price-elasticity of demand, popularly used by economists to measure the impact of price on quantity,[3] is adopted and modified to measure the *percentage* change of performance indicator as a response to *percentage* change of planning/design tool (Equation 1). Besides, mid-point/arc elasticity (Equation 2-1) is applied to acquire the average elasticity since scenarios of one planning tool cover certain range.

$$E_{PL,Tool} = \frac{\partial PL / PL}{\partial Tool / Tool}$$ ……………………………………………………………*Equation 1*

Where $E_{PL,\,Tool}$ is urban planning/design tool elasticity of physical livability;
PL is magnitude of physical livability index;
∂PL is change in magnitude of physical livability index;
Tool is magnitude of urban planning/design tool; and
∂Tool is change in magnitude of urban planning/design tool

3 Price-elasticity of demand allows comparing price-sensitivity of different products in terms of market demand.

The impacts of Urban Planning/Design Tools on "Physical" Livability Indexes

This section reveals the impacts of urban planning/design tools and building types on livability indexes. All the scenarios of urban design/planning tools are developed and extended from the base tower building type to provide a comparative base. The impacts of buildings types, consisting of the base tower building type and seven other types, are further analyzed. The impact analysis of urban planning/design tools focuses on both the overall livability index as well as each of the five individual livability aspects. With the above information put together, the relative significance of each planning/design tool in improving overall livability or its sub-aspect, and the most livable scenarios are analyzed.

3-1 Building Coverage Percentage (BCR)

Table 3-1 provides the original index values of all seven indexes of the five aspects, composed of pedestrian-friendly environment, space-derived amenities or perceivable density, daylight exposure, breezeway and residential privacy. For comparative purposes, index values are standardized (refer to the notes of Table 3-1) to the range of between one and zero, indicating highest and lowest levels, respectively. For pedestrian-friendly environment and space-derived amenities aspects, their overall index is the mean of their two constituent indexes, representing two alternative indexes. Furthermore, the overall livability index is the mean of the six aspect indexes, assuming the six aspects contributing equally to livability quality; the reason for the equal weighting is that any types of weightings of the six aspects may differ from city to city, from time to time, or even from people to people, and unavoidably involves certain degree of arbitrary judgment, and it may also be hard to justify one aspect's dominance over others in terms of contribution to livability.

The statistics of pedestrian-friendly environment indexes indicate that when BCR falls under 55%, the overall index value jump significantly, suggesting BCR 55% as the cap in this regard. The index values in Table 3-1 show that there is enough room to build sidewalk on both sides of the streets for all BCR scenarios.[4] However, the sidewalk can only be greened when BCR is reduced to 55% and below, when the space between curb and building wall is wider than three meters to allow growing trees or turf. Due to the same fact, the

Table 3-1 "Physical" Livability Indexes, BCR scenarios

BCR	Pedestrian-Friendly Environment		Space-derived amenities or Perceivable Density		Daylight Exposure	Breezeway	Residential Privacy	Overall Livability (Mean)
	Sidewalk Percentage	Green Sidewalk Percentage	Viewshed Percentage	Sky View Factor	Solar Radiation[2] (Watts/M^2)	Viewshed Percentage	Average Distance[3] (M)	
30%	100.0%	100.0%	8.5%	27.7%	395,808 (49.7%)	8.5%	15.3 (96.8%)	0.55
35%	100.0%	100.0%	7.5%	30.4%	423,215 (53.1%)	7.5%	14.2 (89.9%)	0.54
40%	100.0%	100.0%	6.9%	33.7%	432,619 (54.3%)	6.9%	13.2 (83.4%)	0.53
45%	100.0%	100.0%	6.4%	31.4%	430,112 (54.0%)	6.4%	12.2 (77.4%)	0.51

[4] Sidewalk generally should be built on the side of road, instead on private property. However, due to the non-existence of sidewalk for most of narrow streets in traditional residential areas, private property is encouraged to build sidewalk with density incentive.

50%[1]	100.0%	100.0%	6.1%	30.9%	425,599 (53.4%)	6.1%	11.3 (71.6%)	0.50
55%	100.0%	100.0%	5.6%	32.5%	449,875 (56.5%)	5.6%	10.5 (66.2%)	0.49
60%	100.0%	0.0%	5.0%	30.1%	404,469 (50.8%)	5.0%	9.6 (61.0%)	0.37
65%	100.0%	0.0%	4.8%	33.9%	454,768 (57.1%)	4.8%	8.8 (55.9%)	0.37
70%	100.0%	0.0%	4.3%	31.8%	425,711 (53.4%)	4.3%	8.1 (51.1%)	0.35
75%	100.0%	0.0%	4.1%	29.7%	393,897 (49.4%)	4.1%	7.4 (46.5%)	0.33
Mean	100.0%	60.0%	5.9%	31.2%	423,607 (53.2%)	5.9%	11.1 (70.0%)	0.46

Note: 1. Baseline scenario.

2. The number in the parentheses is standardized index, obtained with the following equation

$$= \left(1 - \frac{\text{Insolation}}{\text{Insolation without Building}}\right) = \left(1 - \frac{\text{Insolation}}{\text{[illegible]}}\right)$$

3. The number in the parentheses is standardized index, obtained with the following equation

$$= \left(1 - \frac{\text{Average Distance}}{\text{Longest Average Distance}}\right) = \left(1 - \frac{\text{Average Distance}}{\text{[illegible]}}\right)$$

accumulated percentage change of pedestrian-friendly environment index, with BCR 50% as base scenario,[5] jumps from -50% to 0 when BCR is reduced from 60% to 55%, i.e., the highest slope (Table 3-2).

Table 3-2 Accumulated Percentage Change,[1] Elasticity and Slope of "Physical" Livability, Building Coverage Rate Scenarios

BCR	Pedestrian-Friendly Environment	Space-derived amenities or Perceivable Density[2]	Daylight Exposure[2]	Breezeway	Residential Privacy	Overall Livability (Mean)
30%	0%	-2%	-7%	41%	35%	9%
35%	0%	3%	-1%	25%	26%	8%
40%	0%	10%	2%	14%	17%	6%
45%	0%	2%	1%	5%	8%	3%
50% (Baseline)	--	--	--	--	--	--
55%	0%	3%	6%	-8%	-8%	-1%
60%	-50%	-5%	-5%	-17%	-15%	-26%
65%	-50%	5%	7%	-20%	-22%	-25%
70%	-50%	-2%	0%	-29%	-29%	-29%
75%	-50%	-9%	-7%	-33%	-35%	-33%
Elasticity	-0.56	N/A[1]	N/A[1]	-0.82	-0.78	-0.47
Highest Slope(s)	BCR60→55	BCR40[1]	BCR65, 55[1]	BCR35→30	BCR35→30	BCR60→55

Note: 1. Percentage change = $\frac{(\text{Index}_{\text{target scenario}} - \text{Index}_{\text{base scenario}})}{\text{Index}_{\text{base scenario}}} \times 100\% = \frac{(\text{Index}_{\text{target scenario}} - \text{Index}_{\text{BCR50\%}})}{\text{Index}_{\text{BCR50\%}}} \times 100\%$.

2. The impact is not linear, hence only the peak, instead of highest slope, is presented to show the scenario with the highest livability. For the same reason, it is not reasonable to calculate elasticity.

Then, with the same analysis framework as above, the impacts of BCR on the other four livability indexes are presented below. First, the statistics of Tables 3-1 and 3-2 show the impact of space-derived amenities is not linear and the best scenario is BCR 40%, which reflect the tradeoff between sky view and ground-level viewshed as BCR changes. Secondly, the daylight exposure index shows that the impact is not linear; the highest level occurs at BCR65% (7%), and 55% (6%)(Table 3-2), and the worst happens at both the highest and lowest BCRs, which reflects that fact that tallest buildings of lowest BCR 30%, and most reduced open space due to highest BCR of 75% both block sunlight the most. Thirdly, both the trends of index values of Tables 3-1 and accumulated percentages of Table 3-2 show that the lower the BCR, the higher the level of breezeway and residential privacy due to more space between buildings; additionally, the highest slopes suggest the caps are both BCR 30%.

Overall, BCR is an moderately efficient planning tool for developing livable built environment, and the lower the BCR, the more livable the city; furthermore, BCR is most efficient in improving pedestrian-friendly environment, breezeway and residential privacy, all of which involving more space on the ground level. First, the elasticity of overall livability index of -0.47 indicates BCR is

[5] BCR 50% is set as base scenario, with which percentage change between scenario in question and base scenario is calculated (Refer to note 1 in Table 3-2). The percentage change statistics are applied to pinpoint the highest slope, where the most significant impact occurs.

moderately inelastic or inefficient in affecting livability (Table 3-2). Furthermore, the trend of percentage changes of overall livability index show that the livable level increases as BCR decreases and BCR 55% is the suggested cap, where the highest slope occurs. Conceptually, reducing BCR moves open space from top of the building (or sky) to the ground level, and hence enhances such ground-based livability quality as residential privacy and breezeway, but its impact on such sky-view-based livability quality as sky view and daylight exposure is complicated by whether sky view is block more by high building with more open space on the ground or low buildings with less open space.

3-2 Height Distance Ratio (HDR)

HDR-S and HDR-B, representing the floor area added to the top of the building shift from the side and back of the building, respectively, are both minimally effective livability planning tools; the higher the HDR, the more livable the city is, and the minimum HDR is suggested to be set at 1.75 and 1.5 for HDR-S and HDR-B, respectively; among the five livability aspects, HDR is effective in affecting residential privacy and breezeway. The elasticity of HDR-S and HDR-B, are 0.18 and 0.20, respectively (Table 4), smaller than the medium level of 0.5. The trend of accumulated percentage change of overall livability index shows the higher the HDR, and more livable the city is. The most efficient point (i.e., the highest slope) takes place at from HDR-S1.50 to 1.75 and from HDR-B1.25 to 1.50, respectively, and hence HDR-S 1.75 and HDR-B 1.50 are recommended as the minimum levels. Similar to the impact of increasing BCR, increasing HDR moves open space from the sky to the ground, and hence affects such ground-based livability quality as residential privacy and breezeway, and such sky-view-based livability quality, as sky view and daylight exposure.[6]

Table 4 Accumulated Percentage Change, Elasticity and Slope of "Physical" Livability Index, Height Distance Ratio Scenarios, Floor Area Shift from Side (-S) and from Back (-B)

HDR Scenario	Pedestrian-Friendly Environment	Space-derived amenities or Perceivable Density	Daylight Exposure	Breezeway	Residential Privacy	Overall Livability (Mean)
HDR-S1.25	0%	0%	8%	-4%	-16%	-4%
HDR-S150 (Baseline)	--	--	--	--	--	--
HDR-S1.75	0%	-2%	-1%	5%	11%	4%
HDR-S2.00	0%	-3%	-3%	10%	20%	6%
HDR-S2.25	0%	-4%	-5%	17%	26%	8%
Elasticity	0.00	-0.06	-0.19	0.31	0.62	0.18
Highest Slope(s)	N/A[3]	HDR-S1.75→150	HDR-S1.50→1.25	HDR-S2.00→2.25	HDR-S1.25→1.50	1.HDR-S1.50→1.75 2. HDR-S1.25→1.50[1]
HDR-B1.25	0%	-5%	-7%	-15%	-16%	-8%
HDR-B150 (Baseline)	--	--	--	--	--	--
HDR-B1.75	0%	2%	2%	12%	11%	5%
HDR-B2.00	0%	-1%	-22%	20%	20%	2%
HDR-B2.25	0%	1%	-21%	31%	25%	5%
Elasticity	0.00	N/A[2]	N/A[2]	0.69	0.62	0.20
Highest Slope(s)	N/A[3]	HDR-B1.75, 1.50[2]	HDR-B1.75, 1.50[2]	HDR-B1.25→1.50	HDR-B1.25→1.50	HDR-B1.25→1.50

Note: 1. For those with two highest slopes, the one with higher index value is prioritized due to better livability.
2. The impact is not linear, hence only the peak, instead of highest slope, is presented to show the scenario with the highest livability. For the same reason, it is not reasonable to calculate elasticity.
3. The highest slope is not available since planning tool in question has no impact on livability index.

3-3 Building Setback (SB)

This section presents the impacts of the three types of building setbacks—moving backwards (SB-B), shifting floor area to the top (SB-T), and stair-shaped setback (SSB), of which SSB is analyzed independently because the variations of its scenarios are not linear as SB-B and SB-T. Both SB-B and SB-T are not very efficient planning tools towards livability development; 3-meter setback

[6] HDR does not affect pedestrian-friendly environment in this research due to the design setting that distance between buildings across the street is fixed.

(i.e., SB-B3) is the suggested minimum setback for both, and shifting floor are to the top is slightly more efficient than moving backwards setback. For each livability aspect, both types are moderately efficient in improving pedestrian-friendly environment, and minimally efficient in upgrading street level breezeway and space-derived amenities. Table 5-1 shows the elasticity values of overall livability indexes of both SB-B and SB-T are positive but minimal, but shifting floor area to the top is slightly more elastic primarily because more open space is left on the ground. The most efficient function of setback lies in providing more sidewalk space to pedestrians, and hence the accumulated percentage change of pedestrian-friendly environment jumps when the setback increases from zero to three meters. SB can also be used to improve breezeway, but only at elasticity levels of 0.22 and 0.39 for moving backwards and shifting floor area to the top, respectively.

Table 5-1 Accumulated Percentage Change, Elasticity and Slope of "Physical" Livability Index, Building Setback Scenarios, Moving Backwards (B) and Floor Area Shift to the Top (T)

Building Setback Scenario	Pedestrian-Friendly Environment	Space-derived amenities or Perceivable Density	Daylight Exposure	Breezeway	Residential Privacy	Overall Livability (Mean)
SB-B0	-100%	-12%	-6%	-19%	0%	-43%
SB-B1.5	-50%	-6%	-1%	-10%	0%	-21%
SB-B3 (Baseline)	--	--	--	--	--	--
SB-B4.5	0%	4%	-2%	11%	0%	0%
SB-B6	0%	7%	-5%	24%	0%	0%
Elasticity	0.50	0.10	N/A	0.22	0.00	0.22
Highest Slope(s)	1. SB-B1.5→3 2. SB-B0→1.5	1. SB-B1.5→3 2. SB-B0→1.5	SB-B3	SB-B4.5→6	N/A	1. SB-B1.5→3 2. SB-B0→1.5
SB-T0	-100%	-10%	-7%	-33%	-12%	-46%
SB-T1.5	-50%	-4%	-3%	-18%	-6%	-23%
SB-T3 (Baseline)	--	--	--	--	--	--
SB-T4.5	0%	1%	-3%	19%	6%	2%
SB-T6	0%	8%	-2%	45%	12%	5%
Elasticity	0.50	0.25	0.02	0.39	0.12	0.25
Highest Slope(s)	1. SB-B1.5→3 2. SB-B0→1.5	SB-T4.5→6	SB-T3	SB-T 4.5→6	1. SB-T 4.5→6	1. SB-B1.5→3 2. SB-B0→1.5

Buildings with stair-shape setback are more "physically" livable than tower shape building without setback; three-step-shaped building is more livable than the rest with fewer steps; and even-step setback is more livable than non-even-step setback. First of all, all the values of SSB_1, 2_2, 2_4, 3_1, and 3_2 are higher than those of SSB_Base (i.e., tower without setback) in terms of overall livability, viewshed percentage, sky view factor, solar radiation, viewshed percentage and residential privacy (Table 5-2). Secondly, the two three-step scenarios (i.e., SSB_3_1, 3_2) are better than the rest in overall livability and a few aspect indexes. Finally, the two even-step scenarios (SSB3-1, and SSB2_2) are superior than their counterparts with uneven-step shape (i.e., SSB3-2, and SSB2_4) in overall livability and all aspects expect for pedestrian environment indexes. Figure 3 virtually shows perceivable space and vertical angle block by buildings from a vantage point for all scenarios; the former is related to space-derived amenities, and the later affects both sky view and insolation. The two three-step scenarios again are superior, and the two even-step scenarios are superior than their counterparts in terms of perceivable space and block angle.

Table 5-2 “Physical” Livability Indexes, Stair-Shaped Setback Scenarios

Building Setback Scenario	Pedestrian-Friendly Environment		Space-derived amenities or Perceivable Density		Daylight Exposure	Breezeway	Residential Privacy	Overall Livability[4]
	Sidewalk Percentage	Green Sidewalk Percentage	Viewshed Percentage	Sky View Factor	Solar Radiation[1] (Watts/M^2)	Viewshed Percentage	Average Distance[1] (M)	
SSB_Base	100.0%	100.0%	5.8%	30.9%	425,599 (53.4%)	5.8%	72.0% (11.4)	0.50
SSB_1	100.0%	100.0%	8.7%	29.6%	422267 (53.0%)	8.7%	91.0% (14.4)	0.54
SSB_2_2	100.0%	100.0%	6.4%	33.8%	430234 (54.0%)	6.4%	86.3% (13.6)	0.53
SSB_2_4	100.0%	100.0%	5.9%	32.4%	438201 (55.0%)	5.9%	80.1% (12.7)	0.52
SSB_3_1	100.0%	100.0%	6.5%	36.5%	454136 (57.0%)	6.5%	87.7% (13.9)	0.55
SSB_3_2	100.0%	100.0%	6.4%	35.8%	446168 (56.0%)	6.4%	85.0% (13.4)	0.54
Mean	100.0%	100.0%	6.6%	33.2%	436,101 (54.7%)	6.6%	83.7% (13.2)	0.53

Note: 1. The number in the parentheses is standardized index (Refer to notes in Table 3-1).

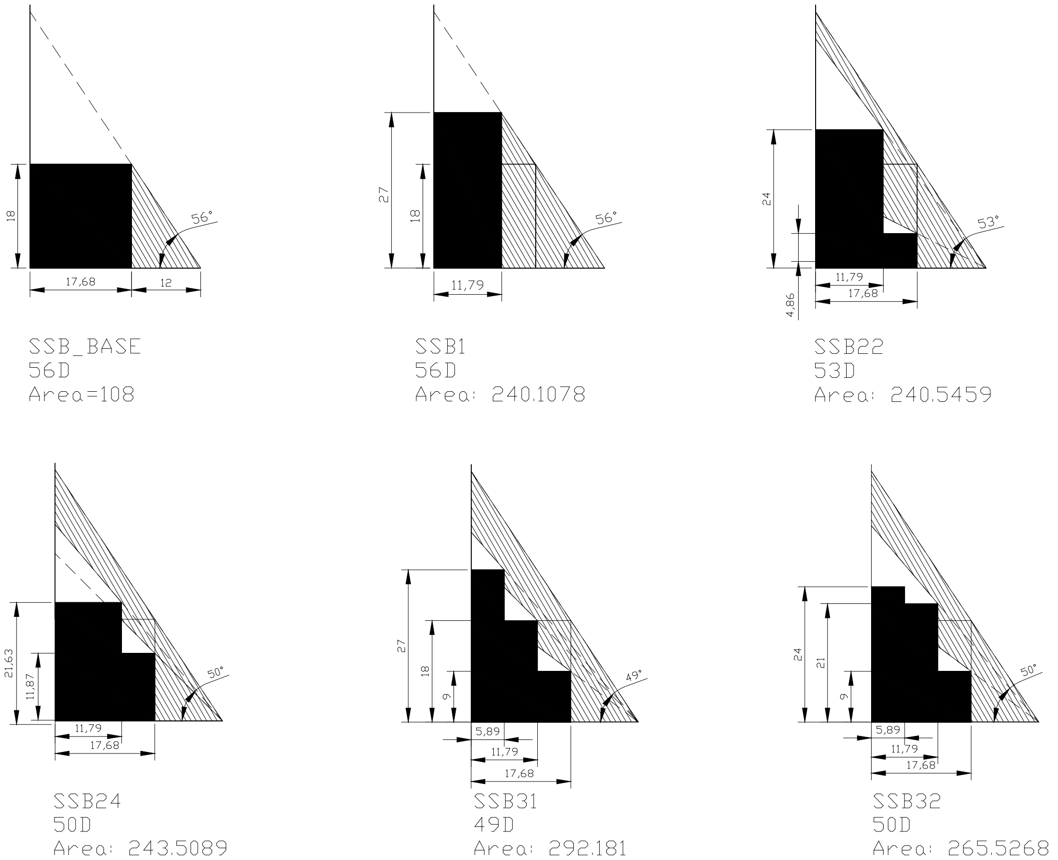


Figure 3 Perceivable 3-D Open Space and Block Angle from Vantage Point, Stair-Shaped Setback Scenarios

3-4 Side Yard Width (SW) and Backyard Depth (BD)

Both the two side yard width types, shifting floor area to the back (SW-B) and top (SW-T) of the buildings, are not efficient planning tool towards livability; the elasticity values of SW-B and top SW-T are -0.02 and 0.1, respectively (Table 6). However, shifting floor are to the top is slightly better than to the back since more open space is left on the ground level.

Backyard depth scenarios affect livability index similar to side yard distance: both the . two types of scenarios, shifting floor to the side (BD-S) and to the top (BD-T) of the building, are not efficient planning tool, and the latter is marginally superior than the former (Table 7)

Table 6 Accumulated Percentage Change, Elasticity and Slope of "Physical" Livability Index, Side Yard Width Scenarios, Floor Area Shift to Back (-B) and Top (-T) of Building

SW Scenario	Pedestrian-Friendly Environment	Space-derived amenities or Perceivable Density	Daylight Exposure	Breezeway	Residential Privacy	Overall Livability (Mean)
SW-B1.5 (Baseline)	--	--	--	--	--	--
SW-B2.5	0%	-8%	-4%	-3%	1%	-1%
SW-B3.5	0%	-5%	-6%	-5%	1%	-2%
SW-B4.5	0%	-10%	-11%	-8%	1%	-3%
SW-B5.5	0%	-13%	-17%	-11%	0%	-5%
Elasticity	0.00	-0.05	-0.06	-0.04	0.00	-0.02
Highest Slope(s)	N/A	SW-B2.5→1.5	SW-B5.5→4.5	SW-B2.5→1.5	SW-B2.5,3.5,4.5	SW-B5.5→4.5
SW-T1.5 (Baseline)	--	--	--	--	--	--
SW-T2.5	0%	-5%	-3%	1%	5%	0%
SW-T3.5	0%	-8%	-10%	2%	10%	0%
SW-T4.5	0%	-6%	-7%	3%	15%	2%
SW-T5.5	0%	-8%	-9%	6%	19%	2%
Elasticity	0.00	-0.03	-0.03	0.02	0.07	0.01
Highest Slope(s)	N/A	SW-B2.5→1.5	SW-T3.5→2.5	SW-T4.5→5.5	1. SW-T5.5	SW-T3.5→4.5

Table 7 Accumulated Percentage Change, Elasticity and Slope of "Physical" Livability Index, Backyard Depth Scenarios, Floor Area Shift to Back (-B) and Top (-T) of Building

SW Scenario	Pedestrian-Friendly Environment	Space-derived amenities or Perceivable Density	Daylight Exposure	Breezeway	Residential Privacy	Overall Livability (Mean)
BD-S1.5 (Baseline)	--	--	--	--	--	--
BD-S2.5	0%	4%	6%	3%	1%	2%
BD-S3.5	0%	10%	12%	6%	0%	3%
BD-S4.5	0%	11%	15%	9%	1%	4%
BD-S5.5	0%	14%	19%	12%	0%	5%
Elasticity	0.00	0.05	0.07	0.05	N/A	0.02
Highest Slope(s)	N/A	BD-S2.5→3.5	1. BD-S2.5→3.5 2. BD-S1.5→2.5	1. BD-S4.5→5.5	BD-S2.5, 4.5	BD-S1.5→2.5
BD-T1.5 (Baseline)	--	--	--	--	--	--
BD-T2.5	0%	4%	5%	5%	5%	3%
BD-T3.5	0%	0%	0%	8%	10%	3%
BD-T4.5	0%	5%	8%	13%	15%	6%
BDT-5.5	0%	4%	7%	19%	19%	8%
Elasticity	0.00	N/A	N/A	0.07	0.07	0.03
Highest Slope(s)	N/A	BD-T4.5	BD-T 4.5	BD-T4.5→5.5	1. BD-T4.5→5.5	1.BD-T3.5→4.5

3-5 Street-Corner Building Setback (SCBS)

The impacts of two types street corner building setback, the horizontal (SCBS-H) and vertical four-meter (SCBS-V) setbacks, on livability development are minimal but buildings with street corner setback is more livable than those without; for horizontal setback, the more the street corner setback, the more livable the city in terms of pedestrian-friendly environment, and breezeway; and for the vertical street corner setback, building with setback at the first floor is more pedestrian-friendly. Both the elasticity values of overall livability index for both SCBS-H and –V are positive but almost indifferent from zero (Table 8); this type of setback, specifically designed for more spacious street corner in a small spatial scale, is reasonable to have limited impact. In addition, horizontal setback does have certain degree of impact on pedestrian-friendly environment with an elasticity value of 0.04, larger breezeway with an elasticity value of 0.02.

Table 8 Accumulated Percentage Change,1 Elasticity and Slope of Livability Index, Street Corner Building Setback (SCBS) Scenarios, Horizontally (-H) and Vertically (-V)

SW Scenario	Pedestrian-Friendly Environment	Space-derived amenities or Perceivable Density	Daylight Exposure	Breezeway	Residential Privacy	Overall Livability (Mean)
SCBS-1F0M (Baseline)	--	--	--	--	--	--
SCBS-H-1F2M	3%	8%	6%	1%	0%	3%
SCBS-H-1F4M	7%	7%	5%	3%	0%	4%
SCBS-H-1F6M	11%	6%	3%	6%	0%	4%
Elasticity	0.04	N/A	0.01	0.02	0.00	0.01
Highest Slope(s)	1. SCBS-H-1F4M →1F6M	SCBS-H-1F2M	SCBS-H-1F0M →1F2M	SCBS-H-1F4M →1F6M	N/A	SCBS-H-1F0M →1F2M
SCBS-4M0F (Baseline)	--	--	--	--	--	--
SCBS-V-4M3F	0%	9%	7%	4%	0%	3%
SCBS-V-4M2F	0%	9%	7%	4%	0%	3%
SCBS-V-4M1F	7%	7%	5%	4%	0%	4%
Elasticity	0.03	N/A	N/A	0.01	0.00	0.01
Highest Slope(s)	SCBS-V-4M0F →4M1F	SCBS-V-4M0F →4M3F	SCBS-V-4M0F →4M3F	SCBS-V-4M0F →4M3F	N/A	SCBS-V-4M0F →4M3F

3-6 Building Shape

Of the selected building shapes, i.e., tower (BS1), enclosing court (BS2), slab (BS3), U-shaped (BS4), convex-shaped (BS5), cross-shaped (BS6), X-shaped (BS7), and reverse U-shaped, in general, the tower shape is superior than others considerably, followed by slab- and X-shaped, but individual variation of one building type may also be physically livable, such as BS2-3. The tower shape is physically more livable because of its capacity of providing wide sidewalk to plant trees, higher viewshed, sky view, solar radiation, and residential privacy derived from concentrated open space around its compact building shape. The slab shape is relatively livable in terms wide sidewalk for planting trees, better solar radiation through concentrated open space in the front and back yards. The X-shaped is supreme due to its capacity of providing greened sidewalk, and larger spacing between buildings. Table 9 shows that the tower, slab, and X-shaped have the three highest overall livability index values, i.e., 0.50, 0.42, and 0.41, respectively, as opposed to the rest with the values in the 0.3s, suggesting being avoided in practice. The green sidewalk percentage index reflects that these three building shapes plus cross-shaped provide sidewalk wider than three meters to grow plants; most of their scenarios have the index values larger than zero. The tower and slab communities provide better viewshed, sky view, and solar radiation than the rest; their viewshed values are 6.1% and 6.3%, respectively; their solar radiation values are 53.4% and 54.4%, higher than the rest in the lower 40% or below.

Table 9 "Physical" Livability Indexes, Building Shape (BS) Scenarios

Building Shape	Pedestrian-Friendly Environment		Space-derived amenities or Perceivable Density		Daylight Exposure	Breezeway	Residential Privacy	Overall Livability (Mean)[4]
	Sidewalk Percentage	Green Sidewalk Percentage	Viewshed Percentage	Sky View Factor	Solar Radiation (Watts/M²)	Viewshed Percentage	Average Distance (M)	
BS1: Tower	100.0%	100.0%	6.1%	30.9%	425,599 (53.4%)	6.1%	71.6% (11.3)	0.50
BS2-1.5:Enclosing Court	100.0%	0.0%	3.9%	21.8%	253,693 (31.8%)	3.9%	44.3%(7.0)	0.29
BS2-2 (Baseline)	100.0%	0.0%	4.3%	24.0%	343,132 (43.1%)	4.3%	50.6%(8.0)	0.32
BS2-2.5	100.0%	0.0%	4.8%	26.1%	293,552 (36.8%)	4.8%	56.9%(9.0)	0.33
BS2-3	100.0%	100.0%	5.3%	27.7%	389,512 (48.9%)	5.3%	63.6%(10.0)	0.47
Mean	100.0%	25.0%	4.6%	24.9%	319,972 (40.2%)	4.6%	53.8%(8.5)	0.35
BS3-1: Slab (Baseline)	100.0%	100.0%	6.1%	31.3%	421,792 (52.9%)	6.1%	56.0%(8.9)	0.47
BS3-2	100.0%	0.0%	6.4%	32.2%	445,727 (55.9%)	6.4%	57.8%(9.1)	0.38
Mean	100.0%	50.0%	6.3%	31.7%	433,760 (54.4%)	6.3%	56.9%(9.0)	0.42
BS4-1: U-Shaped	100.0%	0.0%	5.3%	29.0%	406,114 (51.0%)	5.3%	70.9%(11.2)	0.39
BS4-2 (Baseline)	100.0%	0.0%	4.6%	27.2%	287,033 (36.0%)	4.6%	74.1%(11.7)	0.36
BS4-3	100.0%	0.0%	4.4%	26.1%	280,281 (35.2%)	4.4%	77.2%(12.2)	0.36
Mean	100.0%	0.0%	4.8%	27.5%	324,476 (40.7%)	4.8%	74.1%(11.7)	0.37
BS5-1: Convex-Shaped	100.0%	0.0%	6.1%	31.5%	300,123 (37.7%)	6.1%	64.6%(10.2)	0.35
BS5-2 (Baseline)	100.0%	0.0%	5.9%	31.1%	294,317 (36.9%)	5.9%	61.4%(9.7)	0.35
BS5-3	100.0%	0.0%	5.6%	30.4%	285,602 (35.8%)	5.6%	58.2%(9.2)	0.34
Mean	100.0%	0.0%	5.8%	31.0%	293,348 (36.8%)	5.8%	61.4%(9.7)	0.34
BS6-2: Cross-Shaped	100.0%	23.7%	4.9%	28.0%	309,999 (38.9%)	4.9%	50.6%(8.0)	0.35
BS6-2.5 (Baseline)	100.0%	21.7%	5.3%	28.9%	319,580 (40.1%)	5.3%	56.9%%(9.0)	0.36
BS6-3	100.0%	100.0%	5.7%	29.9%	416,884 (52.3%)	5.7%	63.3%(10.0)	0.48
Mean	100.0%	48.5%	5.3%	28.9%	348,821 (43.8%)	5.3%	56.9%%(9.0)	0.39
BS7-2: X-Shaped	100.0%	24.6%	3.5%	22.4%	277,266 (34.8%)	3.5%	100%(15.8)	0.36
BS7-25 (Baseline)	100.0%	26.1%	4.0%	24.6%	292,795 (36.7%)	4.0%	96.7%(15.3)	0.37
BS7-3	100.0%	100.0%	4.6%	27.3%	312,421 (39.2%)	4.6%	90.5(14.3)	0.49
Mean	100.0%	50.2%	4.0%	24.8%	294,161 (36.9%)	4.0%	95.7%(15.1)	0.41
BS8-1: Reverse U-Shaped	100.0%	0.0%	5.4%	29.5%	301,562 (37.9%)	5.4%	70.9%(11.2)	0.36
BS8-2 (Baseline)	100.0%	0.0%	5.2%	28.2%	287,446 (36.1%)	5.2%	74.1%(11.7)	0.36
BS8-3	100.0%	0.0%	5.1%	27.2%	272,552 (34.2%)	5.1%	77.2%(12.2)	0.37
Mean	100.0%	0.0%	5.2%	28.3%	287,186 (36.0%)	5.2%	74.1%(11.7)	0.36

3-7 Relative Efficiency of Community Design Tools

3-7-1. Best Urban Planning/Design Tool for Overall Livable Built Environment: To improve the livability performance of the base scenario, BCR is the most efficient too, though only intermediately elastic, that is the percentage performance improvement is around half the percentage planning/design change. The elasticity of BCR is -0.47, followed by the second tier of efficient tools composed of building setbacks and height distance ratio with elasticity value around 0.2s (Table 10).

Table 10 The Elasticity of "Physical" Livability Indexes, By Aspect

Community Design Tools		Pedestrian-Friendly Environment	Space-derived amenities or Perceivable Density	Daylight Exposure	Breezeway	Residential Privacy	Overall Livability (Mean)
1. Building Coverage Percentage (BCR)	1 BCR	**-0.56**[2]	-0.07	0.00	**-0.82**	**-0.78**	-0.47
2. Height Distance Ratio (HDR)	2-1 HDR-S: FA[1] from Side	0.00	-0.06	-0.19	0.31	**0.62**	0.18
	2-2 HDR-B: FA from Back	0.00	N/A	N/A	**0.69**	**0.62**	0.20
3. Building Setback (SB)	3-1 SB-B: Moving Backwards	**0.50**	0.10	N/A	0.22	0.00	0.22
	3-2 SB-T: FA to Top	**0.50**	0.25	0.02	0.39	0.12	0.25
4. Side Yard Width (SW)	4-1 SW-B: FA to Back	0.00	-0.05	-0.06	-0.04	0.00	-0.02
	4-2 SW-T: FA to Top	0.00	-0.03	-0.03	0.02	0.07	0.01
5. Backyard Depth (BD)	5-1 BD-S: FA to Side	0.00	0.05	0.07	0.05	N/A	0.02
	5-2 BD-T: FA to Top	0.00	N/A	N/A	0.07	0.07	0.03
6. Street-Corner Building Setback (SCBS)	6-1 SCBS-H-1F: Horizontal Setbacks on 1F	0.04	0.02	0.01	0.02	0.00	0.01
	6-2 SCBS-V-4M: Vertical 4-Meter Setbacks	0.03	N/A	N/A	0.01	0.00	0.01

Note: 1. Floor Area
2. The highlighted are those with elasticity of .5 or higher.

3-7-2 Best Urban Planning/Design Tool for Individual Aspect of Livability: In certain cases, attention may be drawn to improvement of certain aspect of livability. This section puts together the above impact analysis to list the most efficient urban planning/design tool in each of the five aspects. First, to improve pedestrian-friendly environment, the most effective tools are lower building coverage percentage (1 BCR), higher building setback, either moving the whole building backwards (3-1 SB-B) or shifting floor area to the top (3-2 SB-T) of the buildings; the elasticity values of BCR, SB-B, and SB-T are -0.56, 0.5, and 0.5, respectively (Table 10). Secondly, to improve space-derived amenities or reduce perceivable density, the most efficient tools is to implement building setback by shifting floor area to the top of the building, and followed by moving-backwards building setback; the indexes values are 0.25 and 0.10, respectively.

Thirdly, if solar radiation is an issue for a community, in accordance with existing planning knowledge, reducing height distance radio by shifting floor area from the top of building to the side(2-1 HDR-S) is the most efficient tool, with the elasticity value of -0.19 (Table 10). Then, street-level breezeway can be most efficiently enlarged by reducing BCR or increasing height distance ratio by shifting floor area from the back (2-2 HDR-B) of the building, with elasticity values of -0.82 and 0.69, respectively. Finally, if residential privacy is the target issue, then reducing building coverage rate, increasing HDR by shifting floor area from the back and side of the building are most effective.

In sum, BCR is relatively effective in affecting three sub-livability indexes—breezeway, residential privacy and pedestrian-friendly environment. Building setback contributes rather effectively in improving pedestrian environment. And increasing height distance ratio is relatively effective in providing more breezeway and residential privacy. Finally, it may be inferred shakily that shifting floor area to the top of the building generally improves livability quality better than shifting it to the side, then back of the building, and moving backwards; increasing side yard width, and backyard depth by shifting floor area to the top (i.e., 4-2 SW-T and 5-2 BD-T, respectively) are more efficient than their counterparts of shifting floor area to the back or side of the building (i.e., 4-1 SW-B and 5-1 BD-S, respectively) (Table 10); implementing building setback by shifting floor area to the top (3-1 SB_T) is more efficient than moving backwards (3-2 SB_B); and to increase HDR by shifting floor area from the back of the building (2-2 HDR_B) is more effective than from the side (2-1 HDR_S). This finding, combined with impact of reducing BCR leading to tall buildings, indicates leaving more open space on the ground by shifting floor area on the top may be more "physically" livable; in other words, skinny, tall building may bring in more livable community than fat, short buildings given the circumstances of this research.

3-8 Most Livable Scenarios

Of the all of the scenarios across the six planning tools and eight building shapes, twelve are more livable with overall livability index values over 0.52 (Table 11). All the twelve scenarios area variations of tower shape buildings across three planning/design tools, consisting of stair-shaped setback (i.e., SSB_3_1, _1, 3_2, 2_2, 2_4), large building setback with floor area shift to the top (i.e., SB-T6 and T4.5), smaller building coverage percentages (i.e., BCR-30%, 35%, and 40%), and increasing backyard depth by shifting floor area to top (BD_T5.5, and T_4.5). Of all these scenarios, streets come along with greened sidewalk on both sides the whole length. These scenarios vary in indexes of livability aspects, but generally derived from the tradeoff between leaving more open space on the street level and leaving space in the sky by lowering buildings, and hence reflected on the tradeoff between such sky-based aspects as sky view and such ground-based aspects as viewshed.

Table 11 Most Physically Livable Scenarios

Scenario	Pedestrian-Friendly Environment		Space-derived amenities or Perceivable Density		Daylight Exposure	Breezeway	Residential Privacy	Overall Livability (Mean)[4]
	Sidewalk Percentage	Green Sidewalk Percentage	Viewshed Percentage	Sky View Factor	Solar Radiation	Viewshed Percentage	Average Distance	
BCR30%	100.0%	100.0%	8.5%	27.7%	395,808 (49.7%)[2]	8.5%	96.8% (15.3)[3]	0.55
SSB_3_1	100.0%	100.0%	6.5%	36.5%	454136 (57.0%)[1]	6.5%	87.7%[2] (13.9)[3]	0.55
SSB_1	100.0%	100.0%	8.7%	29.6%	422267 (53.0%)[1]	8.7%	91.0%[2] (14.4)[3]	0.54
SB-T6	100.0%	100.0%	10.0%	26.2%	411,808(51.7%)	10.0%	90.6%(14.3)[3]	0.54
BCR35%	100.0%	100.0%	7.5%	30.4%	423,215 (53.1%)[2]	7.5%	89.9% (14.2)[3]	0.54
SSB_3_2	100.0%	100.0%	6.4%	35.8%	446168 (56.0%)[1]	6.4%	85.0%[2] (13.4)[3]	0.54
SSB_2_2	100.0%	100.0%	6.4%	33.8%	430234 (54.0%)[1]	6.4%	86.3%[2] (13.6)[3]	0.53
BCR40%	100.0%	100.0%	6.9%	33.7%	432,619 (54.3%)[2]	6.9%	83.4% (13.2)[3]	0.53
SSB_2_4	100.0%	100.0%	5.9%	32.4%	438,201 (55.0%)[1]	5.9%	80.1%[2] (12.7)[3]	0.52
BDT-5.5	100.0%	100.0%	6.6%	31.8%	454,101(57.05)	6.6%	77.9% (12.3)	0.52
SB-T4.5	100.0%	100.0%	8.2%	25.0%	408,192 (51.2%)[2]	4.6%	85.9% (13.8)	0.52
BD-T4.5	100.0%	100.0%	6.3%	32.4%	459,056 (57.6%)[2]	6.3%	74.8% (11.8)	0.52

4. Conclusions and Policy Implications

This paper examines the impacts of the tools on livability, generally employed by urban planners and/or designers. Through simulation analysis in a hypothetical dense community, the roles of a range of eight planning/design tools are revealed in affecting livability in the regards of visible horizontal space, breeze way, visible sky, Radiation, and residential privacy. The results suggest that overall, reducing BCR decreasing BCR brings space to the ground at the cost of more building mass in the sky may be worthy since the magnitudes of beneficiary visible horizontal space, breeze way, and privacy is larger than that of loss of visible sky and Radiation on the one hand, and the level of sky view and Radiation seems at a higher level than visible horizontal space and breezeway, which may lessen the negative impact but weighting the positive gain. Besides, more space on the ground provides the potential of more green open space within close proximity to pedestrians, as well as plants, insects, and birds. Building setback plays the role of moving space from backyard to front yard, and hence enhances both ground-based and sky-based livability at the front of the building at the cost of less space in the backyard. It can be a more politically feasible tool since it adds no extra cost to developers, as opposed to lowering BCR resulting in higher cost due to taller buildings, and provides more space along the street, which is tangible to all users. However, the impacts in terms of downgrade of Radiation, breeze way, privacy in the backyard, which is barely measured in the paper, cannot be ignored, and deserver further analysis.

In addition, in pursuing certain aspect of livability, the most effective tools are also identified, which may be applicable in different urban settings. In a neighbourhood where visible space on the ground or breeze is of most concern, or even providing more space for eco-community, low BCR is the most effective tool to adopt, and building setback but shifting floor area to the top of the building, and the conventional building setback come after. Furthermore, in a neighbourhood where visible space in the sky or Radiation is of most concern, building setback and increasing BCR are the two most effective tools. To pursuing residential privacy alone, p reducing BCR, back setback and setback and shift up tools are the top three effective tools.

References

Costello, L., 2005. From Prisons to Penthouses: The Changing Images of High-Rise Living in Melbourne. Housing Studies, 20(1), pp. 49-6.

Taipei City Government, 2002. Taipei City Plan Ordinance (In Chinese).

Marshall, Alfred. [1890] 1997. Principles of Economics. Prometheus Books.

Wong, N. H., and C. Yu, 2005. Study of Green Areas and Urban Heat Island in A Tropical City. *Habitat Internationa*l, 29)(3), pp. 547-558

Wong, M. S., J. E. Nichol, P. H. To, and J. Wang, 2010. A Simple Method for Designation of Urban Ventilation Corridors and Its Application to Urban Heat Island Analysis. Building and Environment, 45, pp.1880-89.

Oke, TR., 1982. The Energetic Basis of The Urban Heat Island. *Quarterly Journal of The Royal Meteorological Society*, 108:1-24.

Grimmond, CSB, and TR. Oke, 1999. Aerodynamic Properties of Urban Areas Derived From Analysis of Surface Form. *Journal of Applied Meteorology*, 34, pp.1262-92.

Lettau, H, 1969. Note on Aerodynamic Roughness-Parameter Estimation on The Basis of Roughness-Element Description. *Journal of Applied Meteorology*,8: pp. 828-32.

Counihan, J.. 1975. Adiabatic Atmospheric Boundary Layers: a Review and Analysis of Data from the Period 1880-1972. Atmospheric Environment, 9: pp. 871-905.

Mfula, A. M., V. Kukadia, R. F. Griffiths, and Hall D. J., 2005. Wind Tunnel Modeling of Urban Building Exposure to Outdoor Pollution. *Atmospheric Environment*, 39(15): 2737-45.

Blocken, B., J.,Carmeliet, T., and Stathopoulos. 2007. CFD Evaluation of The Wind Speed Conditions In Passages Between Buildings E Effect of Wall-Function Roughness Modifications on the Atmospheric Boundary Layer Flow. *Journal of Wind Engineering and Industrial Aerodynamics*. 95: pp. 941-62.

Ng., E., 2009. Policies and Technical Guidelines for Urban Planning of High-Density Cities – Air Ventilation Assessment (AVA) of Hong Kong. *Building and Environment*, 44, pp.1478–88.

ASCE, 1999. *American Society of Civil Engineers (ASCE) manuals and reports on engineering* *practice No. 67: wind tunnel studies of buildings and structures*. Virginia.

Chao, R., Y.-Y. E. Ng, and L. Katzschner, 2010. Urban Climatic Map Studies: A Review. *International Journal of Climatology*. Published online in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/joc.2237.

Ng, E., Chao Y., C. Liang, R. Chao, C.H. F., Jimmy, 2011. Improving the Wind Environment in High-Density Cities By Understanding Urban Morphology and Surface Roughness: A Study In Hong Kong. Landscape and Urban Planning, 101, pp. 59–74

國科會補助計畫衍生研發成果推廣資料表

日期:2011/10/30

國科會補助計畫	計畫名稱: 高密度建成環境中提升住宅可居住性的都市設計元素研究
	計畫主持人: 蔡育新
	計畫編號: 98-2410-H-004-150- 學門領域: 都市及區域

無研發成果推廣資料

98 年度專題研究計畫研究成果彙整表

計畫主持人：蔡育新			計畫編號：98-2410-H-004-150-				
計畫名稱：高密度建成環境中提升住宅可居住性的都市設計元素研究							
成果項目			量化			單位	備註（質化說明：如數個計畫共同成果、成果列為該期刊之封面故事...等）
			實際已達成數（被接受或已發表）	預期總達成數(含實際已達成數)	本計畫實際貢獻百分比		
國內	論文著作	期刊論文	0	0	0%	篇	
		研究報告/技術報告	1	1	100%		
		研討會論文	0	0	100%		
		專書	0	0	100%		
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（本國籍）	碩士生	2	2	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		
國外	論文著作	期刊論文	0	1	100%	篇	
		研究報告/技術報告	1	1	100%		
		研討會論文	1	1	100%		
		專書	0	0	100%	章/本	
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（外國籍）	碩士生	0	0	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		

其他成果 (無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)	無

	成果項目	量化	名稱或內容性質簡述
科教處計畫加填項目	測驗工具(含質性與量性)	0	
	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數	0	

國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

   ■達成目標

   □未達成目標（請說明，以 100 字為限）

      □實驗失敗

      □因故實驗中斷

      □其他原因

   說明：

2. 研究成果在學術期刊發表或申請專利等情形：

   論文：□已發表 □未發表之文稿 ■撰寫中 □無

   專利：□已獲得 □申請中 ■無

   技轉：□已技轉 □洽談中 ■無

   其他：（以 100 字為限）

   已發表於國際研討會 （The 2011 Winter Conference on Environmental Innovations and Sustainability. January 28 and 29, 2010. Beppu, Oita, Japan.）

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限）

   本研究以都市計畫的角度，分析個別都市計畫與設計元素，對於高密度住宅區可居住性的個別元素與總體效果的影響，此方面理論探討似乎於過去國際文獻中尚未發現，又以彈性係數比較不同都市計畫與設計元素的效率高低似乎也是第一次，因此，或許是一個還算創新的研究。

   本計畫進行過程碰到一些理論與軟體使用上的挑戰，主要原因是此類研究尚屬發展初期：如計算觀察點與建物間所形成三度空間大小，其軟體雖有國際學者開發出，但仍未商業化，無法取得；又如影響風道環境的都市計畫空間指標於今（2011）年又有數篇新文獻發表，因此，本研究又進行修正。

   本計畫挑戰性高、所花的時間與精力也多，但伴隨著不斷的挫折，是研究過程中柳暗花明的欣喜與成果取得的滿足感。研究的初步成果已於 2011 年出於日本發表，完稿也已預計於為一個月完成，之後預計投稿 SSCI 國際期刊(如 Environment and Planning B: Planning and Design、或 Building and Environment)。

   經由此一年期的研究計畫經驗，研究者陸續發現相關研究題目仍待近一步研究，如本文中的都市計畫元素對於生態都市建置的（量性、效率性）影響分析，或對於風道環境的建置影響以減低熱島效應，研究者將陸續進行相關研究。