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Abstract
Urban density policy, usually implemented through a floor area ratio (FAR) plan, may become increasingly important in achieving such goals as environmental sustainability or acting as an incentive to promote transit-orientated development. Nonetheless there seems a lack of guidance on FAR distribution. In order to provide FAR distribution guidelines, in particular with the goal of incorporating sustainability and market demand, this paper develops a step-by-step, quantitative residential FAR distribution alternative based on both the advantages of the location and the market demand for the locations. It consists of two major steps: floor area generation and FAR distribution; the latter being the focus of this paper. The methods applied involve the measurement of accessibility within geographic information systems and the hedonic price model. A simulation analysis of this FAR distribution method is conducted to develop a FAR plan for a plan area, and is then applied to demonstrate how the FAR plan can be modified if mass rapid transit stations are introduced.

Keywords
accessibility, amenities, density, floor area ratio, sustainability

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Introduction

Density policy or vision of land use planning, usually implemented through floor area ratio (FAR) measures (Bertaud and Brueckner, 2005), is becoming increasingly important in achieving various goals, including a minimum level of service or the efficient use of public facilities and transportation, for amenities, urban design purposes and sustainable development such as in the compact city (Gordon and Vipond, 2005) and transit-orientated development (TOD). The transfer of development rights (TDR) may also rely on it to direct where the floor area can be relocated. Unfortunately, in practice, objective FAR distribution guidelines may not exist, possibly because complex planning perspectives and goals are involved.

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This paper develops a step-by-step, quantitative residential FAR distribution method, which is capable of incorporating sustainability as a goal and objectively assigning floor area according to a variety of location advantages/disadvantages. In addition, it should be able to integrate market demand for locations of different levels of advantage (Cervero and Duncan, 2002), to reduce the risk of possible failure of oversupply or the 'zoned out' effect owing to the undersupply of floor area (Levine, 2005).

The remainder of this paper first reviews the factors affecting FAR plans and the relationship of accessibility to market demand. Then a step-by-step location-demand-based residential FAR distribution method is presented, followed by a simulation analysis. The final section concludes with examples of its application and the limitations of this method.

Factors affecting density/floor area ratio plans

Goals such as sustainable development, combined with constraint factors such as the capacity of natural resources, affect density/FAR plans. These factors can be classified into two spatial tiers: those associated with the overall density/FAR of a plan area and the FAR distribution plan within it. Determination of the overall FAR level may incorporate supply limitations of natural resources of growth management or smart growth (Knaap and Moore, 2000: 3), and the demand side of minimum floor area per capita and projected population size; and then the level of land consumption per capita or degree of compactness/'sprawl' of the city is determined (Churchman, 1999). Rationally, the supply level of public facilities and transportation can be determined at this point to resolve *area-wide*'congestion' issues.

Factors affecting FAR distribution plans include the limitations of natural resources, capacity of public facilities, location advantages, fostering of certain types of urban settings, social equality goals, urban design and being used as an incentive to promote other policies. First, limitations of natural resources include slope and the 'geological-environmental capacity' (e.g. FAR that the ground can sustain) (Cui et al., 2010). Second, considering the capacities of each public facility and transportation, such as park and road capacity, FAR is contemplated to diminish the externality of congestion at the neighbourhood scale. Then location advantages can be gauged for the purpose of maximising the efficient use of land and public facilities (Ho, 1994), and the residents' overall accessibility and liveability. However, the operational process of FAR distribution based on efficiency of land use is not clear. In addition, higher FAR is a significant tool to achieving TOD for sustainable transportation purposes (Cervero and Guerra, 2011).

Of the factors affecting FAR distribution plans, some are more general factors that may apply to all cities, such as location advantages and the capacity of public facilities. Theoretically, a trade-off relationship exists between the efficiency and the level of service: the higher the FAR, the greater the efficiency of use, but the lower the level of service, and vice versa (Figure 1). Conventionally and conceptually, maximum FAR can be imposed to avoid congestion issues (Fujita, 1989), but is regarded as a second-best tool when pricing is not politically workable (Kono et al., 2010). While simultaneously taking both location advantages and the capacity of public facilities into consideration, urban planners may make the most efficient use of the location advantage by increasing FAR or adopting minimum FAR, and maintaining the minimum acceptable level of service by reducing FAR.

For maximising the efficient use of land and public facilities, location advantages need to be taken into account in determining FAR plans. An alternative approach is to assess the accessibility to all public facilities and land use, which can function in two

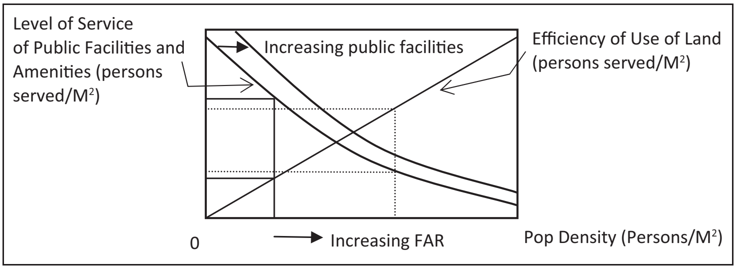

Figure 1. Conceptual trade-off relationship between efficient use of land and level of service of public facilities.

ways: on the one hand, public facilities provide residents with places to fulfil their activities; on the other hand, open space provides amenities in terms of views, lighting and breezeways. Both accessibility and amenities sought by residents trigger market demand and increase the value of the site; hence the better the location characteristics, the higher the market demand (Bertaud and Brueckner, 2005). However, application of land price as a proxy of overall location advantages (Ho, 1994) is inappropriate, since not only location characteristics but also site characteristics, such as FAR cap, affect land prices. If the location demand is taken into account in determining FAR, housing is generally more affordable for places assigned a higher FAR, reinforcing the expectation that housing demand for higher accessibility can be met. Under these circumstances, travel behaviour is more efficient because of shorter trips, increased walking and cycling, and more people living in neighbourhoods with available amenities, all of which contribute to a better quality of life and sustainability.

Relationship of accessibility to market demand and land price

In general, public facilities and certain land use types (e.g. commercial) provide utilities and disutilities to residents, and as a whole compose the overall utilities of a residential location and affect their market demand. Public facilities are generally dichotomised into 'Yes, In My Backyard (YIMBY)' and 'Not In My Backyard (NIMBY)'. The overall total utilities of a public facility differ by being in a more continuous format, however, and can be characterised by four alternative archetypal forms – 'the closer the better', 'close, but not too close', 'far, but not too far', 'the farther the better'. 'The closer the better' public facilities provide the highest utilities with the highest proximity, and decline with distance (Figure 2a); a YIMBY public facility is an example of this type. A special extension of this type is 'Being across the street', such as homes with a park view. Another type at the other end of the spectrum is the 'the farther the better' category, where the greatest negative impact on land price occurs at the closest proximity (Figure 2d); the NIMBY facility well represents this type. The other two types, 'close, but not too close' (Figure 2b) and 'far, but not too far' (Figure 2c) characterise the spatial relationship whereby the highest net impact occurs at some distance from home, for example households with children may prefer to live within a certain proximity to school, but may also prefer not to live too live close to it because of the noise.

Method of location-demand-based FAR allocation

To fill in the gaps of the lack of objective guidelines, and of the incorporation of sustainability as a goal in allocating FAR, a location-demand-based FAR *allocation*

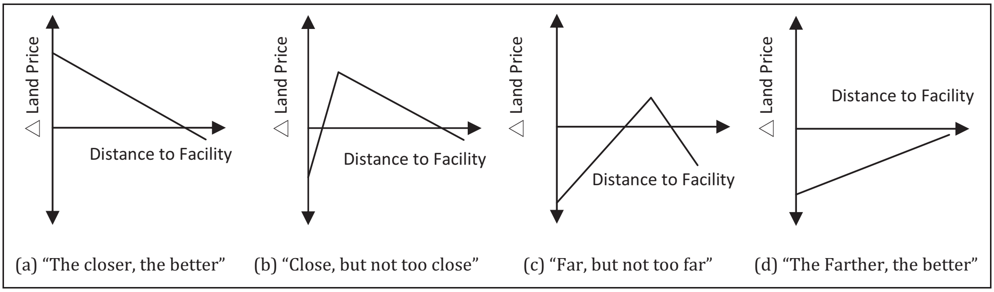

Figure 2. Four archetypal relationships between accessibility and land price.

method (to be distinguished from FAR *distribution* in the second step below) is developed. On the one hand, for achieving sustainability via FAR allocation, this method targets increasing the overall accessibility of a plan area to public facilities and land uses that are likely to result in more sustainable transportation behaviour, as a result of shorter trips, more walking and biking, and to make more efficient utilisation of the facilities. Given that the facilities are provided in the land use plan to serve all the residents within the service shed to achieve the planned level of service and are generally evenly distributed, the undersupply of public facilities or the 'congestion' issue is hence taken care of in this planning process; consequently the higher the number of users, the more efficient the utilisation of the facilities. By the same token, greater accessibility to amenities, such as parks and open space, can also make for a more efficient utilisation of the amenities. For the residents, higher accessibility can raise their quality of life in terms of a more convenient life and more amenities. On the other hand, to provide a more objective FAR allocation guideline, market demand for public facilities and land uses is incorporated. The incorporation of market demand can also better match the supply and demand of floor area, as well as provide an alternative of objective weighting on the significance of different types of accessibility. With the above accessibility and market demand targets, the FAR allocation criteria are developed: to allocate higher floor area ratios to locations with better accessibility, which takes advantage of the results of evaluating the impacts of various accessibilities on land values.

This location-demand method can be broken down into two major steps – floor area generation and FAR distribution. Conceptually, the total floor area for a plan area is first generated by considering such factors as the capacities of natural resources, projected population, and/or the minimum service level of public facilities at city and community levels. This is followed by the FAR distribution step, assigning floor area to all FAR distribution units, such as city blocks. This paper, however, concentrates on the FAR distribution step, since its application is likely to be more universal and objective.

This two-step FAR allocation method is designed for a situation where the land use plan, including public facilities and transportation, is already first developed, and the residential FAR for each block is to be determined. Hence, it can be applied for new urban plans and urban renewal areas, or where FAR is to be adjusted, such as the introduction of mass rapid transit stations.

Step 1: Floor area generation

The first step is to obtain the lump sum residential floor area for a plan area.

An alternative is presented below; however it is not the focus of this paper since it is rather case-based, as detailed below. This setup fundamentally decides the overall level of service, for the plan area as a whole, of public facilities and transportation, land consumption and urban form, influencing travel patterns in general and subsequently affecting the degree of environmental sustainability. In practice, the area-wide undersupply or ‘congestion’ issue of public facilities is taken care of in this step with the delicately planned population size, as well as spatially scattered public facilities.

One alternative for developing total floor area is to obtain planned population and floor area per capita. Planned population may generally consider such limitations of natural resources as water, energy and land, and such constraints of public facilities and transportation as parks and open spaces on the supply side, as well as growth factors such as population growth trends on the demand side. Planned floor area per capita may involve cultural, societal, economic, political and geographical factors, which may differ from place to place and from time to time.

Step 2: Floor area ratio distribution

In this step we obtain the total floor area, to which a block is assigned according to both location dis/advantages and their market demand as a whole, benefiting from the measurement of impacts of two types of location characteristics, accessibility and location-derived amenities, on land value. Location-derived amenities are defined as amenities deriving from the *location* advantage, such as facing open space, as opposed to such *design*-derived amenities such as beautified streetscape.[1] The analysis unit of floor area distribution is suggested as blocks primarily because it is a complete spatial unit that is widely used, and is more flexible for urban planning and design purposes than larger units. This floor area assignment is composed of the following three operational substeps.

Step 2-1: Measuring accessibility and amenities-related location characteristics. This substep measures the accessibility and amenities-related location characteristics for all the FAR assignment units (FAR assignment location characteristics for short). Public facilities and land use, such as commercial areas, may trigger residents’ location demand since they can provide places to fulfil residents’ activities or trips, and hence sites with better accessibility have higher value (accessibility characteristics for short) (Table 1). The open space of the public facilities provides amenities in terms of views, lighting and breezeways (amenities-related location characteristics for short), and hence facing a view and having a wide front road can increase land value.

Site characteristics, including building coverage rate (BCR) and FAR, and whether or not a site is improved, are not suggested for consideration as FAR assignment variables primarily because they do not necessarily serve sustainability purposes or amenities-seeking purposes, since their functions are not clear and their market demand varies. BCR and mixed use may affect land value, primarily owing to consumers’ subjective preferences. A higher FAR cap may affect land prices positively because of more permitted developed space, but negatively because of unattractive landscape (Gao et al., 2006). Whether or not sites are improved can cause cost reductions/increases in site development (Lin and Jhen, 2009).

A range of accessibility variables of location characteristics with different emphases and meanings and different levels of measurement can be chosen. First, Euclidian distance, network distance, or travel time to the closest public facility is the basic type, suitable for emphasising that the closest one is

Table 1. Characteristics/variables affecting demand/land value of a residential site, by site and location characteristics.

Characteristics		Variable (impact)	Causes of impact
Location characteristics (FAR assignment)			
To public facilities	Accessibility characteristics	• Distance to public facilities: parks and open space, schools, mass rapid transit stations, highway interchanges (−)	• Activities/trips fulfilling purposes
	Amenities-related location characteristics	• Open space view: facing parks (0/1) (+), width of front road (+)	• Location-derived amenities-seeking purposes
To land use	Accessibility characteristics	• Distance to commercial areas: CBD (−), local commercial area (−) • District (0/1)(+/−)	• Activities/trips fulfilling purposes
Site characteristics			
		• Building coverage rate cap (?)	• Preferences
		• Floor area ratio cap (+/−)	• Profit chasing
		• Improved site (−)	• Cost increase/reduction
Neighbourhood characteristics		• Density (+/−)	• Preferences, activities/ trips fulfilling purposes
Mixed land use		• Mixed land use (in-building, block: −) (across-street: +)	• Preferences, activities/ trips fulfilling purposes

of the most significance. A special type of closest-opportunity accessibility is a dummy variable representing whether or not a residence faces a public facility. If opportunities within a certain distance, such as a five-minute walking distance, affect people the most, then the cumulative-opportunities variable is a good candidate. More delicate but also more difficult accessibility variables include weighted-distance gravity-based accessibility, utilities-based accessibility (Geurs and van Wee, 2004), and level-of-service accessibility indexes, taking both supply and demand into consideration.

Step 2-2: Assessing the relative significance of accessibility and amenities-related location characteristics. With the FAR assignment variables measured, the purpose of step 2-2 is to gauge their relative significance as represented by their impacts on land prices (a_{FAR} in equation (1)), which in combination can be applied to predict the overall significance level of a location, represented by a predicted unit area land value (equation (1)). This step jumps from the plan-orientated or supply-based FAR assignment of step 2-1, since only physical location characteristics are considered, to a demand-orientated base by incorporating consumers' demand for different aspects of location characteristics, hence constituting a location-demand FAR distribution ground.

$$V_{LU} = a_{LU} + a_{FAR}X_{FAR} \quad (1)$$

where V_{LU} is the price per unit land area for each FAR assignment unit; X_{FAR} is an array of FAR assignment location variables; a_{LU} is constant.

The coefficients of FAR assignment variables can be calculated with a unit land area hedonic price model, with site, neighbourhood and mixed land use characteristics as control variables:

$$V_{LU} = a_{LU} + a_{FAR}X_{FAR} + a_S X_S + a_N X_N + a_{MU}X_{MU} + \varepsilon \quad (2)$$

where X_S is an array of site variables, X_N is an array of block/neighbourhood characteristic variables, and X_{MU} is an array of mixed-use variables; a_S, a_N, and a_{MU} are respective coefficients for the above variables; ε is residual.

For the purpose of plausible application for urban planners, the ideal data for application in equation (2) are unimproved land sales in the FAR distribution plan area in a mature real estate market. A pre-mature real estate market may not provide demand levels closer to conditions when the city is fully developed, such as new towns around newly established high-speed rail stations. If the plan area does not provide mature real estate sales data, a reference area may be considered. The reference area is suggested to have a similar physical environment (e.g. population size, density and transportation systems) and socioeconomic characteristics (e.g. income) with a mature real estate market. Additionally, to avoid bias caused by outliers, the collection of sales data is suggested to avoid periods of unstable real estate market, and sales prices more than three standard errors and a Cook distance no less than 1 can be eliminated (Cook, 1977). In addition, unimproved land sales data are recommended for incorporation, to improve prediction accuracy (Guerin, 2000).

Nonetheless, the regression land price model is rarely employable in practice since vacant land is scarce in well-developed cities or areas. An alternative method is instead to adopt a *housing* hedonic pricing model, separating land values from housing values to obtain the unit land area price, and finally developing a unit land area hedonic price mode, as detailed below.

Development of a hedonic housing price model. On the basis of the housing sales data, a land price regression model with price per floor area as a dependent variable can be developed (equation (3)). Independent variables include FAR assignment location variables, site and neighbourhood characteristics and mixed land use variables of location characteristics, and residence and building variables; residence variables include size, layout and floor where the residence is located; building variables include number of stories and age.

$$V_{HU} = a_{HU} + (a_{FAR}X_{FAR} + a_S X_S + a_N X_N + a_{MU}X_{MU}) + (a_R X_R + a_B X_B) + \varepsilon \quad (3)$$

where V_{HU} is housing price per floor area, X_R is an array of residence variables and X_B is an array of building variables; a_{HU} is constant, and a_R and a_B are respective coefficients for above variables; ε is residual.

Separating land value from housing value in the hedonic housing price model. With the results from the above hedonic housing price model, land value contributing to unit floor area housing price can be singled out by taking advantage of the knowledge and methods of valuation of land and improvements in real estate appraisal (Sunderman and Birch, 2002: 327). Of the four typical categories of land valuation methods – sales comparison, allocation, income capitalisation and extraction – an extended method of the extraction approach is selected because of its reliability (Sunderman and Birch, 2002: 327) (equation (3-1)); unit floor area housing price contributed by land characteristics (V_L) can be obtained by extracting the improvement value (equations (3-1) and (4)) from the unit floor area value (V_{HU}).

$$V_{HU} = V_L + V_I = a_{HU} + (a_{FAR}X_{FAR} + a_S X_S + a_N X_N + a_{MU}X_{MU}) + (a_R X_R + a_B X_B) + \varepsilon \quad (3-1)$$

where V_L is price per floor area contributed by land characteristic variables; V_I is price per floor area contributed by improvements.

$$V_L = V_{HU} - V_I \tag{4}$$

The above process does not, however, deal with the so-called 'merger value' issue of the constant (i.e. a_{HU} in equation (3-1)) (Gloudemans, 2002; Lin and Jhen, 2009); that is the constant is contributed by both housing and land characteristics (equation (5)), and also has to be resolved. With the real truth not yet known, if it ever is, the best estimation of the constant contributed by land characteristics may rely on a best statistical guess. Of the four possible statistical 'guesses', i.e. zero contribution, perfect contribution, split contribution and proportional contribution, indicating the constant contributed by land characteristics 0%, 100%, 50%, and proportionally to the percentage explanation power of land characteristics to total model explanation power (equation (6)), respectively, none has been proved to be superior to others.

$$a_{HU} = a_{HU-L} + a_{HU-H} \tag{5}$$

where $a_{HU\text{-}L}$ and $a_{HU\text{-}H}$ are parts of the constant a_{HU} contributed by land and housing characteristics, respectively.

$$a_{HU-L} = a_{HU} * \left(R_L{}^2/R^2\right) \tag{6}$$

where $R_L{}^2$ is the variance explained by land characteristics; R^2 is the total variance explained by all variables incorporated.

Theoretically, after selecting from the above the four possible statistical 'guesses' of $a_{HU\text{-}L}$, land value contributing to unit floor area housing price can be calculated with equation (7), where the residual can be omitted from equation (3) since it is assumed to have a mean of zero.

$$V_L = a_{HU-L} + \left(a_{FAR}X_{FAR} + a_S X_S + a_N X_N + a_{MU}X_{MU}\right) \tag{7}$$

Calculating unit land area price for each housing sale case. Land value contributing to unit floor area housing price obtained from equation (7) is not yet unit land area price, since unit floor areas of different housing units share different proportions of unit land areas when their actual floor area ratio varies. For example, the unit floor area values of buildings with 0.6 and 3.6 floor area ratios, respectively, share 1/0.6 and 1/3.6 of the unit land area cost, respectively. To resolve this concern, the unit land area price can be calculated by multiplying V_L by the actual floor area ratio (equation (8)).

$$V_{LU} = V_L * \text{FAR}_{act} \ldots^{2} \tag{8}$$

where V_{LU} is the unit land area price; FAR_{act} is the actual floor area ratio.

Development of unit land area in the hedonic price model. This step calculates the coefficient of each FAR assignment location variable and other control variables (equation (2)).

Step 2-3: Predicting collective location demand for each FAR assignment unit and FAR distribution. This step forecasts the overall location-demand value for all FAR assignment units with equation (1) with the results from steps 2-1 and 2-2, in order to assign FAR to each FAR assignment unit. Since the predicted overall location-demand value may constitute a negative value, it is modified into a location-demand value for an 'average' FAR assignment unit with variance caused by FAR assignment variables; technically the unit land area price of an 'average' FAR assignment is calculated by means and/or modes of each non-FAR assignment variable (equation (9)) of the plan area.

$$V_{LU,i} = a_{LU} + a_{FAR}X_{FAR,i} + (a_S X_{S,ave} + a_N X_{N,ave} + a_{MU}X_{MU,ave}) \quad (9)$$

where $V_{LU,i}$ is unit land area price for FAR assignment unit *i;* $X_{FAR,\ i}$ is an array of FAR assignment location variables for FAR assignment unit *i;* $X_{S,\ ave}$ is an array of site variables for an average block, $X_{N,\ ave}$ is an array of block/neighbourhood characteristic variables for an average block, and $X_{MU,\ ave}$ is an array of mixed-use variables for an average block; a_{LU} is constant, and a_{FAR}, a_S, a_N, and a_{MU} are respective coefficients for the above variables.

The value derived from equation (9) represents the demand for the location with their specific accessibility and amenities level, which needs to be taken into account in assigning floor area in order to match the demand for each location. One alternative can be assigning floor area to the FA assignment unit proportionate to their location values to comply with the original mathematical relationship, which can be calculated according to the ratio of its overall location-demand value to the total location-demand value of the plan area (equation (10)). Equation (10), in fact, is a special form of equation (10-1), when the magnitude of parameter (i.e., α) = 1, which controls the extent of difference of floor area ratios between locations with high and low market demands, that is the extent of concentration or compactness. Then its FAR can be calculated with equation (11).

$$FA_i = FA * \frac{V_{LU,i} * A_i}{\sum V_{LU,i} * A_i} \quad (10)$$

where FA is the total planned floor area of plan area, FA_i is the floor area assigned to FAR assignment unit *i*, and A_i is the total land area of FAR assignment unit *i*.

$$FA_i = FA * \frac{{V_{LU,i}}^{\alpha} * A_i}{\sum {V_{LU,i}}^{\alpha} * A_i} \quad (10-1)$$

where α is a parameter and not less than zero.

$$FAR_i = \frac{FA_i}{A_i} \quad (11)$$

Simulation analysis of FAR distribution

The simulation analysis first develops a FAR plan for the Wenshan plan area, a sub-plan area of Taipei city, according to the location-demand-based FAR distribution method, and then demonstrates how the FAR plan is modified if mass rapid transit stations are introduced. The Wenshan plan area, with a population of some 76,000 and population density of 8502 people/km^2 in 2012, is located in southern Taipei city with a population of 2.6 million (Figure 3a) (Taipei City Government, 2012). Taipei city is chosen for the simulation analysis because of its high density and because, since 1996, it is facing urban transformation owing to an emerging urban renewal tide and newly deployed and still-expanding mass rapid transit system, and a burgeoning but premature TDR policy.

Step 1: Floor area generation

This step estimates the total floor area, which is assumed to be the same as in the current plan for two reasons: on the one hand, this location-demand-based FAR plan is comparable with the current planned FAR. On the other hand, the limitations of natural resources are beyond the reach of this paper in terms of data. The total floor area to be distributed is calculated by adding

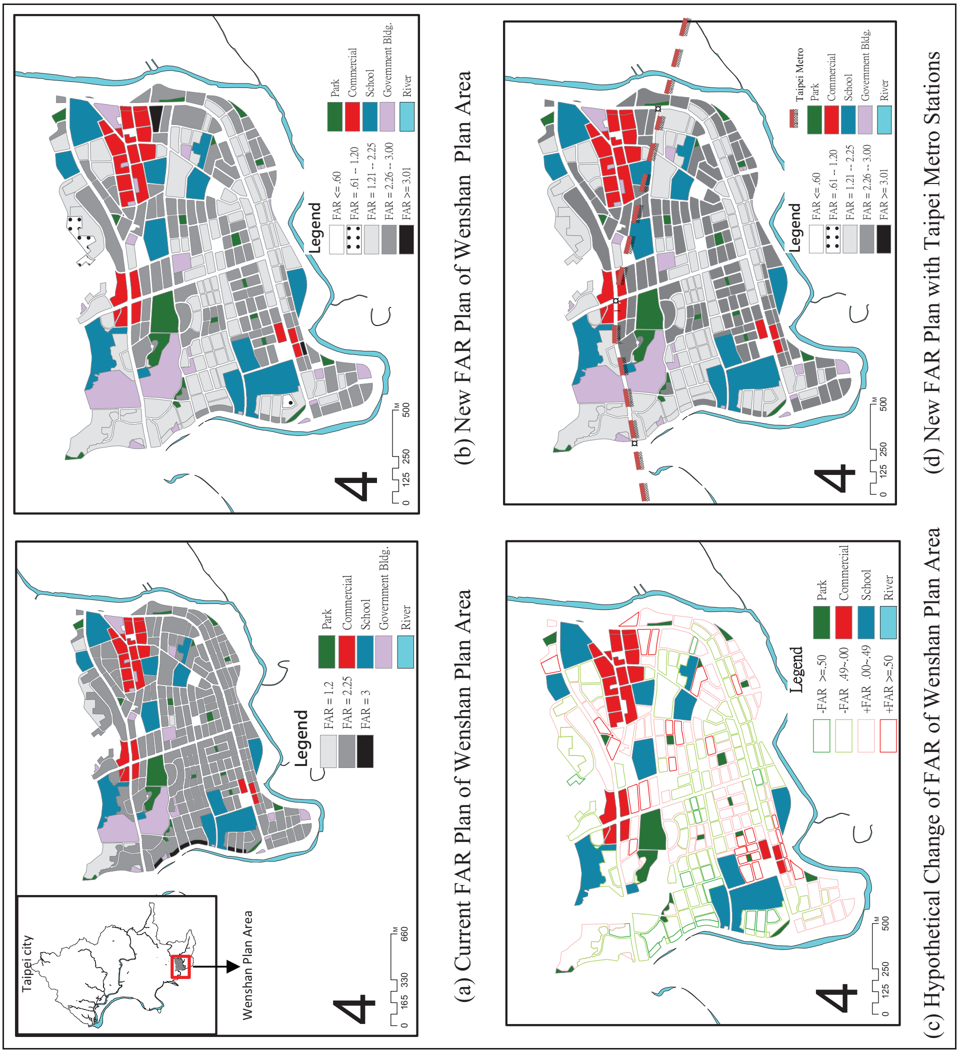

Figure 3. Wenshan Plan Area FAR maps.

the planned floor area of all residential blocks (equation (12)), which is 2,363,843 m^2.

$$FA = \sum FAR_i \times AREA_i \qquad (12)$$

where FAR_i is the planned FAR of block i; $AREA_i$ is the land area of block i.

The total floor area required for an urban plan area in Taiwan is the product of the planned population size and referenced floor area per capita. The planned population size for most urban plans is based on a projected population, but the capacity of life support systems has brought more attention to the concepts of growth management. The referenced floor area per capita in Taiwan used to be 50 m^2 per capita but became unrestricted to cope with population jumps in major metropolitan areas, where unimproved land barely exists today. This simulation analysis adopts the current total floor area of the Wenshan area plan with the planned population of 78,000, providing some 30 m^2 per head (Taipei City Government, 2010).

Step 2: FAR distribution

Step 2-1: Measuring accessibility and amenities-related location characteristics for each block in the Wenshan plan area. Variables quantifying accessibility to all public facilities and local commercial districts and measuring space-derived amenities in front of the block and district dummy variables are selected as FAR assignment location variables (Table 2). Public facilities included are not limited to those within the Wenshan plan area, since residents' activities naturally occur beyond it. The public facilities and transportation incorporated are parks and open spaces, schools, mass rapid transit stations and arterials. Accessibility to the closest commercial area is included, but not the CBD, primarily because in Taipei city and in Taiwan in general there is a barely visible, subjective CBD. Dummy variables of districts are chosen as latent variables to quantify levels of accessibility, public facilities, amenities, etc.

Furthermore, among the different forms of accessibility variables proposed in the FAR assignment guideline above, Euclidian distance is chosen primarily because of its easy application in planning practice in terms of data availability and expertise required. The median distances from the block to the closest park or open space, school, mass rapid transit station, collector or arterial, and commercial area are 101, 136, 1506, 27 and 237 m, respectively; and the majority of blocks do not face parks or open spaces (Table 2).[3]

Step 2-2: Assessing the significance level of each FAR assignment location characteristic based on housing sales data from Taipei city. In order to assess the significance level of each FAR assignment location characteristic for the Wenshan plan area, a hedonic *land* price model (i.e. equation (9)) of the plan area is developed from a hedonic *housing* price model (i.e. equation (3)) of Taipei city. Taipei city is selected for the collection of sales data to develop the housing price model since the Wenshan plan area per se is too small to compile a statistically large enough sample size. The data set contains 2001 housing sales data (Taipei City Government, 2001), and 2000 land use data for each residential unit (Taipei Revenue Service, 2000). Most of the data are transformed into Geographic Information System (GIS) layers to derive land use characteristics with the assistance of ArcGIS and Excel. SPSS is applied to develop regression models.

Development of a hedonic housing price model for the reference area – Taipei city. In this model the price per square metre (NT$[4]1000/$m^2$) is chosen as the dependent

Table 2. Descriptive statistics of FAR assignment location variables for FAR distribution area – Wenshan Plan Area.

FAR assignment location characteristics		Variables	Statistics	
			Mean/mode	Standard deviation
To public facilities	Accessibility characteristics	Distance to closest park/open space (m)	101	68.5
		Distance to closest school (m)	136	86.0
		Distance to closest mass rapid transit stations (m)	1506	302.0
		Distance to closest collector/arterial (m)	27	17.3
	Amenities-related location characteristics	Facing parks (0/1)	0	N/A
		Width of front road (m)	9	7.3
To land use	Accessibility characteristics	Districts (0/1)	1 (Wenshan Dist.)	N/A
		Distance to closest commercial area (m)	237	141

variable (equation (3)). Independent variables are composed of land and improvements/housing variables (Table 3). Control variables include the BCR and FAR permitted, the total floor area of the block and neighbourhood defined as the target block plus surrounding blocks in this research, and a group of mixed land use variables. The mixed-use variables are classified into quantity and types at the first tier and further classified by spatial scale into building, block and neighbourhood characteristics. For example, the quantity aspect includes the total floor area of non-residential land which is useful for residents[5] and the total floor area of commercial land useful for residents at building, block and neighbourhood scales; type aspect variables include percentage floor area of non-residential use useful for residents at the building, block and neighbourhood scales, number of land use types useful for residents, entropy and HHI[6] at the neighbourhood scale. Improvement characteristics, also acting as control variables in this model, are composed of residence and building characteristics, such as the floor area of the residence characteristics, and the age and number of floors of the building characteristics.

Two approaches are taken to avoid the potential bias caused by quality issues regarding housing sales data. First, to avoid bias owing to unstable markets such as a real estate bubble, the 2001 sales data set is confirmed as appropriate since the real estate market of Taipei city started to rocket around 2003. Then, to avoid such individual outliers as sales suspected of being deliberately boosted by developers or opportunists, sales prices with more than three standard errors or a Cook's distance no less than 1 are eliminated.

The most appropriate forms of each variable are selected on theoretical and statistical considerations. First, bivariate analysis is conducted between the dependent variable and all independent variables for a range of curve models, including linear, quadratic, compound, logarithmic and power. Second, these statistical results are checked with the expected impacts (Table 3) for screening out variables with opposite impacts.

Table 3. Variables applied in developing hedonic housing price model for reference area – Taipei City.

Category	Variable	Expected impact
Dependent variable	Housing price per m^2 (NT$1000/m^2)	
land characteristics:		
FAR assignment location characteristics (X_{FAR}):		
• Accessibility characteristics: to public facilities	Distance to closest parks/open space (m)	−
	Distance to closest school (m)	−
	Distance to closest mass rapid transit station (m)	−
	Distance to closest collector/arterial (m)	−
• Amenities-related location Characteristics: public facilities	Facing park (0/1)	+
	Width of front road (m)	∓
• Accessibility characteristics: to land use	Distance to closest commercial area (m)	−
	Beitou Dist., Daan Dist., Datong Dist., Nangang Dist., Neihu Dist., Shilin Dist., Songshan Dist., Wenshan Dist., Xinyi Dist., Zhongshan Dist., Zhongzheng Dist. (1/0)[a]	∓
Site characteristics (X_S): zoning	Maximum building coverage rate permitted	∓
	Maximum floor area ratio permitted	∓
	Residential II, III, III-1, III-2, and IV, Commercial I, II, III, IV (1/0)[b]	∓
Block/neighbourhood characteristics (X_N):	Total floor area in the block (m^2), total floor area in the block and surrounding block (m^2)	∓
Mixed land use characteristics (X_{MU}):		
• Quantity aspect		∓
– Building scale:	Total floor area of residents-needs non-residential land use in the building (m^2)[c]	∓
	Total floor area of residents-needs commercial use in the building (m^2)[d]	∓
– Block and neighbourhood[e] scales	Total floor area of residents-needs non-residential use in the block or neighbourhood (m^2)	∓
	Total floor area of residents-needs commercial use in the block or neighbourhood (m^2)	∓
• Type aspect:		∓
– Building scale:	Percentage floor area of residents-needs non-residential use in the building (%)	∓
	Residents-needs non-residential use in the building (1/0)	∓
– Block/neighbourhood scales	Percentage floor area of residents-needs non-residential use in the block or neighbourhood (%)	∓
	Residents-needs non-residential use in the block (1/0)	∓
	Percentage total land/floor area of residents-needs use in the block or neighbourhood (%)	∓
	Number of residents-needs land use types in the block or neighbourhood	∓
	Entropy of target and surrounding blocks	
	HHI of target and surrounding blocks	∓

(continued)

Table 3. (Continued)

Category	Variable	Expected impact
Improvements/housing characteristics:		
Residence characteristics (X_R):	Floor area of the residence (m^2)	+
	Residence located on the first floor (1/0)	+
Building characteristics (X_B):	Age of the building (year)	−
	Number of floors	+
	Total floor area of the building (m^2)	∓
	1–2 storey building (brick-built building), 3– 5 storey building (condominium without elevators)[f] (1/0)	∓

Notes:
[a]The baseline district is Wanhua District.
[b]The baseline zoning type is residential I. Zoning controls for three primary aspects of land use in Taipei, i.e. maximum building coverage rate, maximum floor area ratio and permitted land use types. All residential and commercial types allow mixed use of residential and commercial uses to a certain degree; in other words, most residential and commercial zoning types explicitly allow certain types of mixed use of residential and commercial uses. When maximum building coverage rate and floor area rate are controlled for, residential/commercial zoning types represent the degree of mixed use permitted.
[c]Residents-needs non-residential land use is composed of residents-needs commercial, clinics, offices, education facilities, religious venues, parking facilities and schools.
[d]Residents-needs commercial is composed of restaurants, retails, department stores and supermarkets.
[e]The neighbourhood is defined as the target block plus surrounding blocks in this research.
[f]The baseline is a building with six storeys or more, which are condominiums with elevators.

Results of hedonic housing price model for reference area – Taipei City. A housing price per floor area model for Taipei city is developed from 487 cases. Owing, however, to the lack of actual FAR data, the substep – calculating unit land area price for each housing sale case – is skipped, leading to biased results. In this model, with an explanatory power of 38.8%, most of the independent variables are significant at the 0.05 level, and at 0.10 for 'distance to closest collector or arterial'; 'facing parks' as a theoretically substantial variable is kept in the model for controlling purposes, despite being statistically insignificant (Table 4). In addition, all the independent variables are independent with VIF smaller than ten.

Unit land area hedonic price model of Taipei city. Based on the Taipei hedonic housing price model, a Taipei hedonic land price model is developed for an 'average' unimproved block with variations in FAR assignment location characteristics. This land price model will be applied to the Wenshan plan area, and is broken down into three parts: division of intercept into contributions from land and improvements characteristics, incorporation of FAR assignment location variables, and setting-up of the 'average' unimproved block for the model. First, the intercept is input as half of the constant, primarily because it is more reasonable than the zero and perfect contribution hypotheses, and because proportional contribution is theoretically groundless and difficult to calculate (equation (13)). Then, the FAR assignment location characteristics enter the land price model with the coefficients from the housing model. Finally, an 'average'

Table 4. Taipei hedonic housing price model.

Category/variable	*B* (Sig.)	β	VIF	Mean/mode	SD
Dependent variable: Housing price per m^2 (NT$1000/$m^2$)					
Land characteristics:					
• FAR assignment location characteristics (X_{FAR}):					
Square distance to closest park/open space (m^2)	$-1.95*10^{-5}$(0.00)	−0.13	1.12	262^2	$1.17*10^5$
Square distance to closest mass rapid transit station (m^2)	$-4.70*10^{-7}$(0.00)	−0.12	1.22	1542^2	$4.189*10^6$
Distance to closest collector/arterial (m)	−0.09 (0.07)	−0.03	1.08	26.7	6.5
Facing parks (0/1)	3.80 (0.35)	0.03	0.09	0	N/A
Width of front road (m)	0.30 (0.00)	0.13	1.02	8.7	7.5
Distance to closest commercial area (m)	−0.01 (0.00)	−0.11	1.60	238.4	192.9
Daan Dist.	11.88 (0.00)	0.13	1.15	0	N/A
Datong Dist.	−6.63 (0.00)	−0.09	1.14	0	N/A
Shilin Dist.	9.16 (0.00)	0.22	1.26	0	N/A
Songshan Dist.	9.58 (0.02)	0.09	1.06	0	N/A
Wenshan Dist.	−10.42 (0.00)	−0.16	1.17	0	N/A
• Site characteristics (X_S): zoning					
Maximum building coverage rate permitted (%)	0.07 (0.01)	0.28	9.38	47%	6%
Maximum floor area ratio permitted (%)	−0.004 (0.02)	−0.26	9.36	265%	111%
• Mixed land use characteristics (X_{MU}):	,				
Percentage floor area of residents-needs non-residential use in the building	−3.82 (0.04)	−0.04	1.56	0.18	0.18
Residents-needs non-residential land use in the building (1/0)	−12.30 (0.00)	−0.12	3.08	1	N/A
Entropy of target and surrounding blocks	2.80 (0.03)	0.23	8.68	0.88	1.40
Square entropy of target and surrounding blocks	−0.39 (0.06)	−0.19	7.97	2.74	8.24
Improvements/housing characteristics:					
• Residence characteristics (X_R):					
Residence located on the first floor (1/0)	27.98 (0.00)	0.41	1.08	0	N/A
• Building characteristics (X_B):					
Age of the building (year)	−0.83 (0.00)	−0.33	1.45	18.55	6.96
1–2 storey building (brick-made building)	17.95 (0.00)	0.18	1.20	0	N/A
Constant	57.59 (0.00)				
Summary statistics:					
Number of cases	487				
Adjusted R^2	0.388				
F (Sig.)	17.243 (0.00)				
Durbin-Watson	1.825				

unimproved block is defined as an unimproved block located in an average neighbourhood in the city, except for the variations in FAR assignment location characteristics. Consequently, all land characteristics at geographic scales larger than block are incorporated, resulting in two entropy-related variables at the levels of target and surrounding blocks. This is done by inputting the means of these two variables into equation (13-1), indicating a NT$464 reduction in housing price (equation (13-2)).

$$V_{\mathrm{LU},i} = 29.295 + (a_{\mathrm{N}}X_{\mathrm{N,ave}} + a_{\mathrm{MU}}X_{\mathrm{MU,ave}}) + a_{\mathrm{FAR}}X_{\mathrm{FAR},I} \quad (13-1)$$

$$= 29.295 - 0.464 + [-1.95 * 10^{-5} * (\text{distance to park})^2 - 4.7 * 10^{-7} * (\text{distance to rapid transit station})^2 - 0.09 * (\text{distance to arterial}) + 3.8 * (\text{facing park}) + 0.3 * (\text{road width}) - 0.01 * (\text{distance to commercial}) - 10.5 * (\text{Wenshan})] \ldots \quad (13-2)$$

Step 2-3: Predicting collective location demand for each block and FAR distribution. With the FAR assignment location characteristics measured in step 2-1 the unit land area value of each block is predicted with equation (13-2), and FAR can be calculated with equations (14) and (11).

$$\mathrm{FA}_i = \mathrm{FA} * \frac{\mathrm{V_{LU,i}} * \mathrm{A_i}}{\sum \mathrm{V_{LU,i}} * \mathrm{A_i}} = 2,363,843 * \frac{\mathrm{V_{LU,i}} * \mathrm{A_i}}{\sum \mathrm{V_{LU,i}} * \mathrm{A_i}} \ldots \quad (14)$$

The New FAR Plan (Figure 3b) shows that blocks with high FARs assigned to them are generally clustered around three local commercial areas, around parks and along the riverside open spaces. Compared with the nearly equally distributed FAR of the original land use plan (Figure 3a), their FAR caps could be raised. In contrast, the blocks with lower assigned FARs could be reduced to reflect the market location needs, when other policies are not considered (Figure 3c).

TOD simulation analysis. The purpose of this section is to apply the above FAR distribution method to the Wenshan plan area to examine how the assigned FARs change owing to the introduction of three mass rapid transit stations scheduled to be built in the near future (Figure 3d). The mean distance to the closest metro station will be reduced from some 1.5 to 0.5 km if the three stations are built, and the mean land value will be increased by about NT$900 (about US$33) per m^2. Based on the above land value model a FAR plan is derived (Figure 3b) which, however, is nearly identical to the above New FAR Plan even though 'distance to metro transit station' is one of the most significant FAR assignment location characteristics, as represented by the standardised coefficient in Table 2. Furthermore, though the land value within the 5-min walking distance from the station is increased as expected, the increase percentage is lower than that outside the station area (Table 3) owing to the quadratic relationship of 'distance to transit station' in the land value model. Consequently, the mean FAR assigned within the station area is reduced, as opposed to the increase outside the station area, differently from the anticipated high demand in the TOD station area in Taipei city in 2001, only four years into the Taipei rapid transit system.

Conclusions and policy implications

This paper provides a residential floor area distribution alternative considering both location advantages largely determined by land use plans from the supply-side perspective, and market demand for the location. The characteristics of location advantages incorporate accessibility levels in public facilities and commercial areas, where residents' activities take place, as well as amenities preferred in residential areas. This location-demand residential FAR distribution method, offering more residential space for locations with better overall accessibility, serves more residents' activity needs in a shorter distance, and helps materialise the goals of sustainable land use-transportation planning in terms of less travel energy consumption and tailpipe pollution. Even though the area-wide minimum level of service of public facilities is managed in the floor area generation process through the setup of planned population size and the scattering of public facilities, the concentration of high FAR locally may cause two 'congestion' issues – high residential density and traffic congestion at smaller spatial scales, such as blocks – which are beyond the scope of this research and may depend on such measures as urban planning or design, and transportation planning to tackle.

This FAR distribution protocol may be applied to new town, newly planned districts of a well-developed city, large-scale urban renewal areas, and the identification of blocks to which to transfer development rights. It may also make a floor area ratio plan more responsive to such changes as the implementation of a mass rapid transit system. Nonetheless, this method only emphasises the efficient utilisation of locations without considering other factors, including urban design and physical limitations such as slope, all of which contribute to a more complete floor area ratio planning process. Finally, this method requires further improvement regarding the resolution of the constant of the housing price model and the determination of the parameter (i.e. α) in assigning floor area in equation (10-1).

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Notes

1. The reason why design-derived amenities are not incorporated is twofold: they are not easy to quantify, and they are subject to change at a relatively low threshold level.
2. Other than the manual survey to acquire data on actual FAR, advanced technologies such as LiDAR data (Yu et al., 2010) provide a potential easy access to it.
3. The outliers have been removed as in step 2-2.
4. New Taiwan dollar.
5. Commercial land use for residents (i.e. residents' needs – commercial land use) is composed of restaurants, retail, department stores and supermarkets. Non-residential land use useful for residents (i.e. residents' needs – non-residential land use) is composed of commercial land use for residents, clinics, offices, education facilities, religious venues, parking facilities and schools.
6.

$$\text{Entropy} = \underline{\left\{-\sum_k [(p_i)(\ln p_i)]\right\}/(\ln K)}$$

Where p_i is the percentage of land use i; K is the number of land use types.

$$\text{HHI}(k) = \sum_1^k (p_i)^2$$

Entropy and HHI adopt residential and non-residential land uses useful for residents, totalling eight land use types.

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