Urban Form and Density in Sustainable Development

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Introduction

Land development is an important component in sustainable development because it is where our food and raw materials come from and it is also the habitat for wildlife and fauna. Similar to other resources, it is a scarce commodity. Some of the destruction of this valuable natural resource is irreversible. The reduction of agricultural land will reduce our food supply capacity, and the destruction of environmental sensitive areas, such as wetlands, will affect the habitat and ecology of wildlife. The use of land unsuitable for development may bring harm to both the natural environment and human life. With increasing population and rapid economic development, there is a concomitant increase in land consumption. The encroachment of urban land use on agricultural land and environmental sensitive areas is a problem in many rapidly growing regions in Asia. The diminishing of agricultural land and environmental sensitive areas is affecting sustainable development of the region. There is a need to examine the amount of land consumption and their distribution in Asia to see how it is affecting sustainable development. Through better planned compact development and increase in density (Yeh, 2000; Yeh and Li, 2000),, a more sustainable land development can be achieved without limiting economic development.

Compact Urban Form

Urban form is a major factor influencing the sustainability of cities. There are evidences indicating a strong link between urban form and sustainable development, although it is not simple and straightforward. Significant relationships have been found between energy use in transport and physical characteristics of cities, such as density, size, and amount of open space (Banister *et al.*, 1997). Land development will bring about a series of costs that are related to the consumption of capital, resources and energy. Compact development will reduce development costs in providing infrastructure to new development sites as well as transportation costs. Compact urban form can be a major means in guiding urban development to sustainability, especially in reducing the negative effects of the present dispersed development in Western cities (Jenks *et al.*, 1996).

Cities in the developing countries are developing very rapidly. Most of the developments are in the form of urban sprawl at the fringe of the urban areas (Ginsburg, Koppel, and McGee, 1991). These urban sprawls have led to a lot of environmental and transport problems and the loss of valuable agricultural land. The promotion of compact development could help to protect the loss of prime agricultural land, reduce development cost and save energy and promote more sustainable urban development.

Take China as an example, the promotion of compact development has more important implications under current pressure of rapid urban expansion in China as a result of rapid economic development. Since the adoption of open door policy and economic reform in 1978, China has achieved marvelous progress in its economic development. However, rapid economic development has significant impacts on China's land resources, energy, environment and agricultural production. Rapid urbanization in China has led to many resource and environmental problems (Muldavin, 1997; Ash and Edmonds, 1998). One of the severe problems is the acceleration of agricultural land loss in the whole nation since 1978, especially in the late 1980s and early 1990s. China has an inherent land use problem because the per capita arable land is far below the world's average. Unfortunately, China's arable land base has continued to reduce as a result of recent rapid industrialization and urbanization that lead to further encroachment on this minimal farmland base (Ash and Edmonds, 1998). The shrinkage of arable land has resulted in the decrease of food production in some coastal regions. For example, paddy production in Dongguan in the Pearl River Delta in southern China has astonishingly dropped by 63% in 1979-94 (Yeh and Li, 1997).

The Pearl River Delta in Guangdong Province in southern China is the fastest growing region in China (Vogel, 1989; Yeung and Chu, 1994). Urbanization is very rapid as a result of its rapid economic development (Xu, 1990; Xu and Li, 1990). Many urban development, especially, in the small cities and towns, are in the form of urban sprawl. The Pearl River Delta was a main agricultural production area in the past. There are concerns on the encroachment of urban development on the valuable agricultural land and the deterioration of environment.

Land use changes and urban development analysis in Dongguan were carried out by the use of three temporal Landsat TM multi-spectral images of 30 m resolution dated 10 December 1988, 13 October 1990, and 22 November 1993. Principal component analysis of stacked multi-temporal images method was used in analyzing the images (Li and Yeh, 1998). The results of the analysis of the three images showed that the whole city was experiencing a fast expansion of urban areas at the cost of agricultural land. 1990-93 was a period of rapid deterioration in terms of accelerating urban expansion and agricultural land loss in the Pearl River Delta. This can be reflected in the satellite images. It was found that the area for urban land use rapidly expanded from 18,351 ha. in 1988 to 19,604 ha. in 1990 and to 39,636 ha. in 1993. Major urban expansion appeared in the early 1990s. The annual growth rate of urban area was only 3.4% in 1988-90, but it became 34% in 1990-93.

Compared with other cities in the Third World where land use changes were mainly located near the city proper, land use changes in Dongguan in 1988-93 did not mainly occurred in the city proper but more dispersed to other towns. The difference between rural and urban areas is becoming blurred. Looking down from the aeroplane, there is development everywhere. The dispersed development is mainly caused by rural industrialization, the rise of localism, land reform, the influence of Hong Kong, road development, and the lack of good land management and monitoring system (Yeh and Li, 1999). Taking the advantages of cheap labour, land, and more relaxed environmental and development control, the towns in Dongguan were developing as fast as the city proper and a more dispersed urban development pattern is resulted. Many of these developments were sporadically located, leap-frog, unplanned development. The loss of agricultural land to urban development mainly occurred in the city proper and towns along the railroad and super-highway from Hong Kong to Guangzhou. These are the areas that can be accessed to Hong Kong by rail or by road and are therefore more attractive for building housing and factories that are geared towards the Hong Kong market. The highly dispersed pattern of urban development experienced in the

Pearl River Delta is not uncommon in cities that are former rural counties in China, especially those in the fast growing provinces along the coast.

Urban expansion had resulted in the loss of 21,285.7 ha. of agricultural land that is made up of cropland and orchard, constituting 13.2% of its total agricultural land. Land consumption per capita has substantially increased from 128.4 m^2 to 295.8 m^2 during 1988-1993, both much higher than the national standard of 100 m^2. It is 226 m^2 for the city proper, Guancheng, and in some towns, such as Fenggang, can be as high as over 1,000 m^2. It is higher than Guangzhou, the provincial capital in the Pearl River Delta which is adjacent to Dongguan. In 1992, the built-up areas of the city proper had an area of 245 km^2 and a registered population of 3.05 million and floating population of 500,000 (Yao, 1992). The land consumption per capita is only 69 m^2 for the city proper of Guangzhou.

Comparison of Compact and Non-Compact Development

In order to evaluate the impacts of the highly dispersed urban development in the Pearl River Delta, the actual development of Dongguan from 1988-93 was compared with the result of a cellular automata (CA) model that aims to generate compact development with minimum agricultural land loss (Li and Yeh, 2000). Figure 1b is the modelling result for 1988-93 with the same amount of land consumption that actually occurred in Dongguan in the same time period. When compared with the actual development in 1988-93 in Figure 1a, land development from the model is more compact with much less loss of agricultural land. Table 1 shows the comparison between the actual development and modelled compact development. Only about one fifth of the actual land conversion occurs on the exact locations expected by the model. It means that a large proportion of 80.1% of the actual land conversion falls out of compact development.

Table 1 – Comparison of Actual and Modelled Compact Development with the Same Amount of Land Consumption in 1988-1993 (in hectares)

Modelled Compact Development	Actual Development		
	Converted	Not Converted	Total
Should Be Converted	4,098.7 *(19.3%)*	17,187.0 *(9.4%)*	21,285.7
Should Not Be Converted	17,187.0 *(80.7%)*	204,882.5 *(90.6%)*	222,069.5
Total	21,285.7 *(100.0%)*	222,069.5 *(100.0%)*	

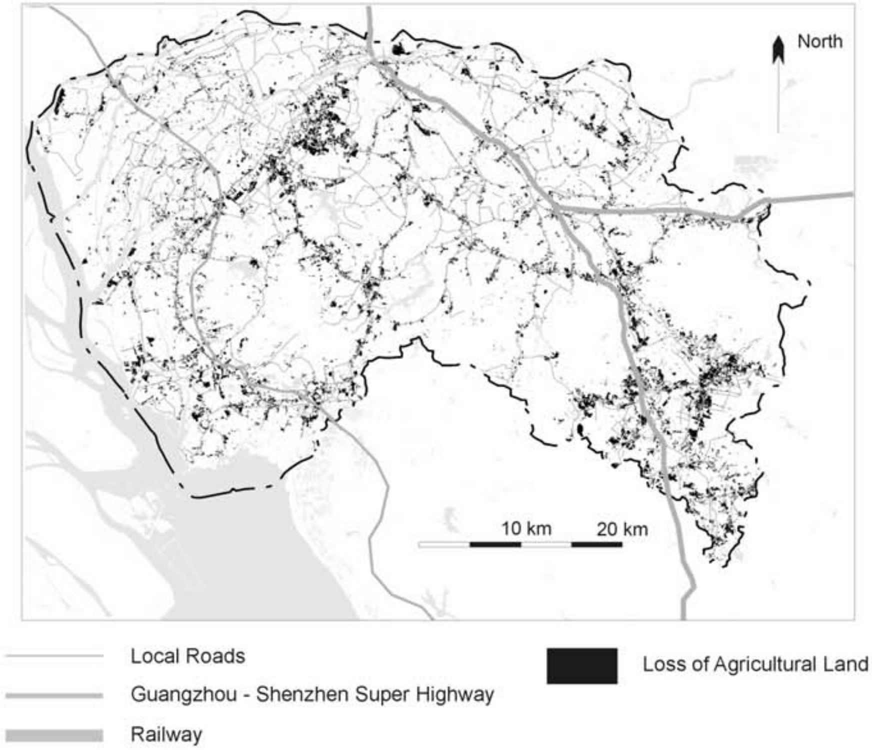
The evaluation of the actual development and the modelled development is carried out by measuring the compactness and agricultural suitability loss. Compactness index is used to identify whether development is concentrated or dispersed. The compactness index *CI* can be calculated by the equation:

$$CI = \sqrt{A}/P \quad (1)$$

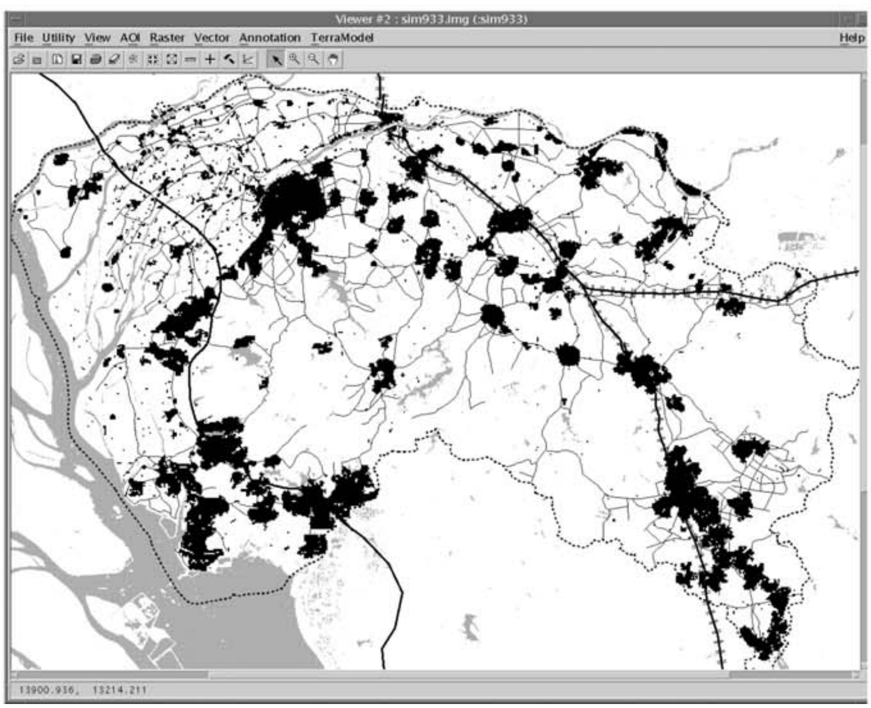
where *A* is the total area and *P* is the perimeter of development sites.

Figure 1 - Comparison Between Actual (a) and Modelled Compact (b) Land Development with the Same Amount of Total Land Consumption in 1988-1993

(a)



(b)



The index of suitability loss can measure the impact of land development on land that is suitable for agriculture. It represents the amount of agricultural land of the best quality consumed by urban development. It is calculated by:

$$TSL = \sum_{\{ij\}\in\Omega} \sum_{k} S_{k\{ij\}} \qquad (2)$$

where TSL is the total suitability loss, $S_{k\{ij\}}$ is the agricultural suitability score for agricultural type k in location ij, and Ω is the set of all cells of land loss. The agricultural suitability score ranges from 1 to 7 for the two main types of agriculture – crop and orchard, 7 being most suitable and 1 being most unsuitable.

The index of total suitability loss can be standardized by finding the average suitability loss to remove the effects of the sizes of regions. This will enable comparison with other areas that have different sizes. Same as the agricultural suitability score, the average suitability loss ranges from 1 to 7. A higher value indicates that urban development has encroached on more fertile agricultural land. The average suitability loss index ($AvSL$) is calculated by:

$$AvSL = \sum_{\{ij\}\in\Omega} \sum_{k} S_{k\{ij\}} / nn_k \qquad (3)$$

where n is the total number of cells of land loss and n_k is number of agricultural types.

Table 2 shows that the modelled compact development has much better performance than the actual development in terms of compactness and agricultural land loss. Compact development is able to provide a much compact urban form which is 5.5 times more compact than that of the actual development. Sustainable compact development also has lesser amount of agricultural suitability loss with a lower value of total suitability loss (*TSL*) and average suitability loss (Av*SL)*.

Table 2 - Comparison of the Compactness and Suitability Loss Between Actual Development and Sustainable Compact Development

	Compactness Index (*CI*)	Suitability Loss *(TSL)*	Standardized Suitability Loss *(AvSL)*
Actual Development	1.78	5,537	6.2
Modelled Compact Development	9.79	3,878	4.8

There can be substantial savings in development and infrastructure costs with the sustainable compact development model. Infrastructure includes the supply of water, electricity, gas, telecommunication, and the construction of roads. A rough estimation of various kinds of infrastructure costs is presented in Table 3. It is assumed that the basic infrastructure has already been built along the main transport networks. The infrastructure development costs of each developed land parcel are the costs for connecting the land parcel to the main provider along the main transport network. The development costs (DC) of each land parcel can be calculated by the following equation:

$$DC = \sum_{\{i\}\in\Omega} \sum_{k} C_k D_{i(N)} A_i \quad (4)$$

where C_k is the unit price for each type of infrastructure k, $D_{i(N)}$ is the distance between the developed land parcel i and its closest network N, A_i is the area of the developed land parcel, and Ω is the set of all development parcels.

Table 3 – Comparison of Infrastructure Costs Between Actual Development and Modelled Compact Development (in million US$)

Items	Unit Price (US$/km)	Actual Development (in million US$)	Modelled Compact Development (in million US$)
Electricity	770,000	528.31	339.31
Water	130,000	89.20	57.29
Gas	520,000	356.78	229.15
Telecommunication	520,000	356.78	229.15
Roads	2,580,000	1,770.18	1,136.92
TOTAL		3,101.25	1,991.82

Buffer analysis in GIS was conducted for calculating the development costs. It can be seen that the development costs of sustainable compact development is only about 64.3% of that of the actual development! Very substantial savings can be achieved by sustainable compact development. This has not taken in account the annual savings in the transport cost and the resultant savings in energy. As dispersed patterns will increase the average length of each trip, the total consumption of fuels will be more. For example, the gasoline consumption is 120,700 kl per year for the existing dispersed pattern according to statistical data. However, the estimated gasoline consumption would be reduced to only 18,700 kl per year for the compact pattern as the average distance was significantly reduced. This represents a substantial saving of 85% of gasoline consumption.

Conclusions

The protection of valuable agricultural land is important in China where cities are growing rapidly since economic reform in 1978. The Pearl River Delta has pioneered the urbanization process with tremendous change of landscape in recent years which has caused significant loss of valuable agricultural land. Excessive agricultural land has been consumed in the early 1990s as a result of the property boom in southern China that was fueled by the property boom in Hong Kong (Yeh and Li, 1999). There were excessive land conversion and urban sprawl. Rapid land development and agricultural land losses are taking place in Dongguan. 23.7% of the total area of Dongguan had undergone changes in 1988-93 (Yeh and Li, 1997). This is much higher than the 3.2% land use change in Hong Kong in a similar period in 1987-95 (Yeh and Chan, 1996).

Rapid urban expansion is inevitable in the Pearl River Delta during the fast-growing period, but the patterns of urban sprawl should be under control to conserve land resources. Urban sprawl which does not take into considerations of urban forms and valuable agricultural land has produced severe impacts on agricultural production and sustainable urban development. Some towns have unusual high degree of urban sprawl and excessive per capita land consumption because of improper urban planning and management. In many rural towns, over-estimation of population growth has led to excessive use of land resources, resulting in much larger per capita land consumption than the nation's standards. There is an urgent need to control such development patterns so that further development in the region can be sustained.

There has been worldwide concern on sustainable development especially after the 1992's Rio's UN Conference on Environment and Development. Many countries have prepared Agenda 21 for the formulation and implementation of strategies for sustainable development. As food supply is a main component of sustainable development, it is important to make sure that unnecessary urban development on valuable agricultural land can be prevented as far as possible. It has been shown that substantial reduction of the loss of good agricultural land can be achieved with the same amount of land consumption through compact development. Furthermore, compact development can also save development, transport and energy costs substantially, further achieving the objectives of sustainable development. It can save as high as 35.7% of land development and infrastructure costs and 34.0% of gasoline consumption. Compact development can protect the valuable agricultural land from development and reduce development, transport and energy costs.

Apart from compact development, it is also necessary to examine whether the amount of land consumption is really necessary. A better development control process and planning system with a sustainable development objective may need to be formulated and implemented in cities experiencing urban sprawl. Higher development intensity may also be needed to minimize land consumption (Yeh and Li, 2002). With the same amount of population and economic activities, the amount of land needed will be reduced if there is an increase in the density of development.

Although there are negative impacts of high density development, however, they can be reduced through better planning, design, and management, making the living and working environment less crowded at a fixed density (Yeh, 2000). High density may not necessarily associate with crowding which is the perception of human beings on the environment. Crowding can be affected by the physical design and layout of the internal and external environments of the building in which the person lives and works, and the culture, habit, and socio economic background of the person. Citizens also have to be educated to know how to behave in public areas in high density regions. Planners, architects, urban managers, communities and citizens all have to work together to make high density living livable. Hong Kong has the highest density in the world. However, the experience in Hong Kong shows that high density if better planned and managed can also produce an interesting and pleasant environment. In Hong Kong, in the last ten years, there have been a lot of advancements in the planning and management of the external and internal environment of buildings, urban design, and traffic management that make high density to be less crowded and more livable and acceptable. Compact development with increase in density can limit urban sprawl, minimize loss of natural habitat and agricultural land, minimize infrastructure costs, minimize transport costs and energy consumption, and achieve a more sustainable land development.

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