Introduction

How many problems addressed in the 19th century have been solved, or at least alleviated? More than a century has passed since the modern town planning was born in Britain, notably by Ebenezer Howard, yet the environment continues deteriorating, its influence scale becoming global, the economic inbalance of the rich and the poor increasing, unemployment remaining, urban crime getting more violent. One may criticise the current economy: 'healthy' economy has not only caused high unemployment and corporate crime but also ecological disasters and social disintegration. "Conventional economists, whether neoclassical, Marxist, Keynesian, or post-Keynesian, generally lack an ecological perspectives" (Capra 1982: 431).

Among them, environmental change has become fatal to our existence as the increasing capacity of the human race to provoke adverse environmental change on a truly global scale after the Industrial Revolution, and environmental concerns appear to have entered a new era associated with human activity. Both the scale and scope of environmental degradation present fundamental challenges to the stability of the global environment, possibly posing a threat to the very survival of the human species as well as the other creatures. Some of these threats were identified as early as in 1972 at the United Nations Conference on the Human Environment (UNCHE) in Stockholm. Concerns over the global environment have grown, ranging from radiation pollution to acid rain, ozone layer depletion and global warming (Haughton and Hunter 1994).

Solutions have been sought on an issue-by-issue basis until the World Commission on Environment and Development (WCED) in 1987, where the so-called Brundtland Report was produced. This report introduced the concept of sustainable development with a chapter dedicated to the problems related to cities, their form and development patterns in particular, as a result of the complementary nature of urban and regional strategies.

Sustainable urban development is therefore a major theme for planners by the early 1990s (Hall 1998). Despite successful institutionalisation in the UK, planners still fail to include certain environmental considerations in everyday planning unless the central government does not specify it (e.g. Owens 1992). This is largely because it is “not at all clear how this mapped into actual everyday decision in everyday urban contexts” (Hall 1998, p.412). Indeed, most environmental problems arise from, or consumed, in urban areas (Haughton and Hunter 1994). In worst cases, badly planned areas and new towns by the then urban policies of economic restructuring, for example, have promoted suburbanisation in North America and, to less extent, any developed countries which is one of the reasons of the current vehicle emissions (Hall 1998).

Some critics such as radical ecologists see the system of the current society as the cause of these problems (Capra 1982). One of theoretical failures in town planning is the approach taken to describe the cities. For example, most of urban models are static whilst the real cities are, and should be, dynamic. A typical example is Howard's Garden City, although his original intention was more dynamic and flexible, which produced many garden cities around London, yet “the core of the British urban problem was still seen to lie in London” (Hall 1996: 133). Form follows function, as many, if not all, architects believe. And the function has been determined by the mechanical vision of the world. Roads, for example, have changed as people's needs change from movement to the place to meet other people and exchange information and goods. Many of the current largest cities, including New York and London, are originally port towns developed as transport nodes. Town planning, derived from architecture, then merged with social reforming, economic regeneration and now sustainable development, has seen its function in a vary narrow way. The planning policy changes as the nation's needs change. Howard (1898) saw it only as a solution to London's environment. Many of today's planners see it only as a tool to redevelop economically declined areas. Consequently, the form that followed the function defined by the planners has been dull, often removed the details as functions were removed.

A solution again came from physics. As early as in 1945, when town planning was to be legislated in Britain, Ilya Prigogine and his colleagues have shown that, in 'far from equilibrium situations' such as the cities, no optimisation principle and fluctuations can grow (Prigogine 1997). Since 1950s, the new science of form has followed this new science of function by Benoit Mandelbrot: fractal geometry came onto the academic stage, as well as design stage, with its ability to visualise the dynamic systems whose behaviour is either theoretically or empirically chaotic. In the study of urban morphology, despite the long relation of its location theory and central place theory and fractal geometry, there are still few attempts in relation to town planning. The analysis of optimisation in nonlinear mathematics, yet planners solution is very often linear, such as Le Corbusier's Paris plan for 3 million people.

Developments are, however, good examples of the processes of self-organisation, thus fractal geometry. A variety of land-uses are being continuously developed by the city's various internal and external demands. This spectacle that coloured map of land uses changes in the course of time reminds us of Conway's Life Game which boomed in 1970s.

In the thesis, I will explore how this new idea begins to answer, or at least help us to, the current planning issue of sustainable transport: reducing the need to travel in Britain's national policy. In addition to this, I have set a series of ambitious objectives: to link the practice-theory gap by supplying a method to view both models and real cities; and to construct a dynamic design theory based on it. By doing so, I shall seek to give some practical guide to everyday planning rather than pursuing academic interests as many researchers have done for the last few decades. The tool I use is fractal, the geometry of describing the nature, chaos and complex systems. Indeed, there is a growing number of studies to see artificial systems as fractal, some related to urban morphology and geography. However, there is few discussion which has tried what it implies in the context of planning, what Hall (1998) calls “divorce of theory and practice” (p.418). In this thesis, therefore, I will seek to link the current studies of fractal cities with planning in reality. Some criticise that planners have transplanted many theories from physical science, often unnecessarily or wrongly, and this thesis may challenge this. The concept of fractal may not be one of them, or may be. Yet the potential of fractal geometry is enormous particularly when fractal dimension is defined to mention a physical value of the city in a way density does.

Fractal cities: a new paradigm towards 21st century?

The city is often said a cancer, an overgrown organ which takes all the food, so much food it can no longer perform its proper function (Haughton and Hunter 1994). It is also said a parasite in a similar sense. However, there is a distinctive difference between cancers and parasites. Whilst cancers occur within the body and lead it to death, parasites are external and sometimes build a symbiotic relation with their host. We have, in this sense, an interesting study on parasites. William Daniel Hillis (in Levy 1992) interprets parasites in a comprehensive and unique way in his computerised Artificial Life. In host-parasite relation:

> If a host population evolved strategic traits to foil the parasite, the parasite would in turn evolve a strategy to compensate. William Hamilton, among others, had suggested that the presence of parasites might have been integral in accelerating the pace of evolution to a rate capable of yielding its present diversity and complexity... If one thought of [hosts] as chessplayers, [the parasites] were chess impresarios, who produces a series of opponents. The fist ushered in fumbling novices, provided that experienced players when the beginners were consistently vanquished, and eventually flew in cunning grand matters.
>
> Under continual attack from these challengers, the host were forced to devise evolutionary strategies that would maintain and even improve the quality of their sorting... (p.201).

The comparison of the systems with and without parasites is easy: the host with parasites found a better solution they could not have hoped to attain. Hillis (in Levy 1992) concluded, "the interesting thing in natural selection is not the evolution of a single species, but things like the coevolution of hosts and parasites" (p.203). We know that dinosaurs have, after prosperity, come to extinction for whatever reason. If cities and human beings are parasites, nature and us may be seeking the most efficient way collaboratively.

The naturally grown cities have some kind of symbiotic relations with nature and human beings and other creatures, thus sustainable not because it is natural but because it is the result of a continuous series of trials and errors. The thesis seeks a new paradigm by adopting and developing the concept of fractal cities to visualise the a possible form of sustainable cities. Fractal is a new scientific interest of anything with natural shape. Indeed, “many important patterns of Nature are either irregular or fragmented to such an extreme degree that ... classical geometry is hardly of any help in describing their forms” (Mandelbrot 1983: p.1) and more and more application on artificial objects have been sought rapidly. So far, I shall point five characteristics of fractal F in mind:

> i) F has a fine structure, i.e. detail on arbitrarily small scales;
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> ii) F is too irregular to be described in traditional geometrical language, both locally and globally;
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> iii) Often F has some form of self-similarity, perhaps approximate or statistical;
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> iv) Usually, the fractal dimension of F (defined in some way) is greater than its topological dimension;
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> v) In most cases of interest F is defined in a very simple way, perhaps recursively (Falconer 1990).

The first two characteristics are tightly related. Fine structure of an object is full of details that cannot be described in Euclidean geometry. Although its primary function can exist without any detail, it is usually thought as primitive. The only exception in human history is perhaps modernism. Fractal brings back once lost details of urbanité in city planning. The third characteristic is related to one of design philosophies: consistency, or robustness and appropriateness in Bentley et al's (1985) term. When an architect designs a church, for example, all the details are related to the concept, as Michael Angelo's Last Supper has existed in the doumo in Milano for four hundred years. As Camillo Sitte (1965) has pointed out, his other masterpiece, David, has lost its context completely since it was replaced in a museum. The remarkability of fractal is, however, largely in the concept of fractal dimension that combines art and science, idea and reality and simplicity and complexity.

Structure of Thesis

The first two chapters discuss the necessity of a new paradigm to achieve truly sustainable cities. Chapter 2 reviews the current policies and practices of sustainable cities in North America, Europe and the UK because there is a gap between policies and practices (chapter 2) and academic studies (chapter 3). The development and design control should be responsible for the sustainability of cities because there is a potential for urban planning to improve our living as well as to deteriorate it, but planners have lost confidence because they have missed the way towards the ideal city if it exists. As Alexander (1997) has pointed out, all that practitioners need is now clear judgement of alternative measures. This issue is perhaps a common feeling among planners as the article attracted two comments and, probably more local discussions.

The new measure should be implemented. Planners no longer have the power once Georges-Eugéne Haussmann had when he restructured Paris. Although in some countries, planners still have strong development control in transport and land-uses, not so in many countries. In such countries, planners are now to determine the development proposals issue. In the UK, for example, planners' most likely tool is development control based on the development plan to determine each individual planning application. Therefore, the measure should be rather bottom-up approach than conventional top-down theories, such as Howard's Garden City, which have promoted New Towns and Urban Development Corporation.

Chapter 3 reviews the current academic studies of urban form and energy efficiency mostly, although not always, in terms of transport. Many of the theories are borrowed from physics such as gravity model and entropy, which have been taken completely out of its context and misinterpreted. In applying them, planners have removed many factors that give urbanity to the city, in order to make a 'model' of city. Yet, Fritjof Capra (1982) rightly addressed:

> ... Scientists construct a sequence of limited and approximate theories, or 'models', each accurate than the previous one but none of them representing a complete and final account of natural phenomena. ...
>
> The question, then, will be: how good an approximation is the Newtonian model as a basis for various sciences, and where are the limits of the Cartesian world view in those fields? ... (p. 93)

When making an airplane, for example, this approximation does not cause a significant damage, even though we still have many accidents. The recent accidents of atomic power plants have reminded many people of this question. In the city where one factor may cause multiple effects that subsequently trickle down to minor, or in some cases up to major, effects as a result of accumulation, the appropriateness of approximation is often ambiguously discussed, or sometimes, completely ignored by planners.

Another issues found in the review is that most of them have ignored the context. Most notably, planners' favourite of international survey is criticised. Indeed, the cities in different countries are in different historical, ecological, social, political and economic context and none of the studies has considered to that extent that approximation does not fail to represent the reality. Banister et al. (1994), for example, compared five cities in England with varied sizes and varied transport policies. The analysis, as could have been predicted, failed to identify which of them affected the travel demand in those cities, and to what extent. Newman and Kenworthy's (1989) international comparison of 30 cities vary up to 10,000 per cent in its sample city size.

Because these lack in academic sense, in the following chapter, I will have to undergo the background analysis of urban form and traffic demand. That is, the effects of self-sufficiency, size, population and density on travel demand in the context of medium English towns. The result is in some cases quite different. Also in this chapter, I will compare the effects of these urban factors on travel demand.

Chapter 5 will seek to construct a possible design theory of the sustainable city with less travel by adopting the new science of efficient natural forms. First, I will define fine structure and fractal city. Design of fine grain is the topic as well as that of urban hierarchy. Engwicht (1993) has observed:

> The tragedy of many modern, Western cities is that they have become mono-cultural. By mono-cultural, I do not mean that they do not contain many cultures and a wide range of activities, but that these have been segregated and fenced off from each other much as a farmer may fence off different crops. (p. 27)

This , in terms of design, means accessibility and, in terms of urban design, permeability. And in this sense, fractal gives us a effective guideline because it is the most natural and efficient form of transportation in the reality. It is reasonable, therefore, I will postulate the hypothesis of fractal and locational optimisation. The mathematical analysis of optimisation, indeed, gives us a form that look like fractal.

And finally, fractal dimension is introduced as a method to prove the hypothesis as well as a planning tool to measure the city's fineness. The concept of fractal dimension is a crucial element of the thesis. With the dimension, it is now possible to compare the fineness of street patterns, and mixed-ness of land-uses of the existing cities and urban models, as if comparing size, population or density. And the measurement procedure is, thanks to the power of the Geographical Information System (GIS), quite practical compared to the other studies reviewed in Chapter 3 as it takes only 10 minutes for a city. This fact is called a fine grain of the city and that of land uses and street patterns are widely recognised.

In chapter 6, I will introduce the theory of fractal dimension and develop an estimation method to apply to sample English towns to prove this hypothesis, using MapInfo, a desktop GIS application. Discussion follows the analysis, which focuses on the difference of reality and models and the relation of fractal dimension and travel demand.