

# **On the Use of Quasi-crystal and Fractal Concepts in the Design of Affordable Rural/Urban Landscapes**

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## **Abstract**

This paper describes the use of quasi-crystal and fractal concepts in the design of rural and urban landscapes for affordable housing. These are shown to provide a framework for the efficient design of communities in which affordable homes are organized using basic concepts from crystallography and fractal theory. In contrast to classical urban planning with single centers, distributed centers are integrated into the rural and urban landscapes using crystallographic and fractal concepts. These provide a framework for the dispersion of human traffic into well identified regions. The combination of quasicrystal and fractal theory is also used to provide a framework for the organic growth of communities around new distributed centers. These basic ideas are discussed within the context of a holistic framework for affordable housing.

Key Words: Quasicrystals, fractal crystallography, geometry, urban/rural landscapes, design, affordable housing.

## **Introduction**

The early civilization of the Egyptians, Greeks and Romans established a pattern of using basic concepts in mathematical geometry in the design of housing and infrastructure at different scales (Fathy, 1989). In more recent times, architects and engineers have also been inspired by shapes associated with atomic configurations such as buckeyballs and tetrahedral structures (Buckmaster, Fuller and Applewhite, 1975). Meanwhile, the problem of affordable housing and deteriorating urban and rural landscapes continues to grow as the world's population races past 6 billion (Adepoju, 1986). Increasingly, the trend of urban migration has continued to increase the pressure on growing towns, in ways that stretch the available infrastructure to limits that were never anticipated.

Crystallography provides some of the tools that can be used to design urban/rural landscapes (Nye, 1985; Burns and Glazar, 1990; Soboyejo, 2004). In classical crystallography, we normally identify a unit cell, from which a three-dimensional structure can be constructed by translations along three orthogonal axes. This may be adopted in the design of urban/rural schemes, where individual plots or houses may be considered as the building blocks for communities. However, such approaches are likely to result in excessive periodicity. It is, therefore, important to explore ways of introducing non-periodicity and aesthetics into the structure of urban/rural communities.

One of the ways in which this can be achieved is by the use of quasi-crystal theory (Penrose, 1974; Hildebrand and Tromba, 1986; Shechtman et al., 1984; Janot and Dubois, 1988; Steinhard and Jeong, 1996). Since their discovery in 1974 (Penrose, 1974), quasicrystals have been shown to form quasi-periodic patterns (Hildebrand and Tromba, 1986; Shechtman, et al., 1984; Janot and Dubois, 1988; Steinhard and Jeong, 1996).

Structural units with different orientations can also be introduced using the concept of fractals (Mandelbrot, 1986; Livio, 2002). The configurations of the atoms also depend strongly on the forces between atoms that give rise to the tiling picture of Penrose (1974), in which atoms arrange themselves into clusters with overlapping edges. Most recently, the perfect quasi-periodic tilings have been interpreted in terms of simple energetics that favor the formation of a single atomic cluster (Steinhard and Jeong, 1996). Eglash [1999] and Gerdes [1999] have also shown that fractal concepts have been applied to the design of African villages.

In this paper, we present some examples of curvilinear and non-curvilinear fractal-based and quasi-crystal-based approaches to the design of rural and urban communities in the developed and developing world. These will be explored within a holistic framework for the design of affordable urban/rural landscapes.

### **Design of Urban/Rural Landscapes**

This section presents selected examples of urban/rural landscapes that are inspired by concepts in crystallography and defects. These are shown to provide an efficient framework for the packing, or organization of people and infrastructure, into holistic communities. The examples illustrate the range of aesthetics that can be achieved via crystallography-inspired design concepts.

Let us start by considering a basic unit cell, which in this case may be a plot or an affordable home. For rural housing, this may be done within a curvilinear framework (Fig. 1). Note that the curvilinear framework provides generous living space which is possible due to the

relatively low cost of land in the rural areas. However, such space may be expensive in urban settings. Hence, a more efficient use of space is needed in urban areas.

The master plan may also be integrated into rural quarters (Figure 2), in which the homes are organized into two fractal units within a rural quarter. Note that there are 5 blocks within each fractal unit and a total of 10 blocks in the rural quarter containing 2 fractal units (Figure 2).

For larger communities, more fractal units may be introduced around distributed centers. This allows for the dispersion of traffic around the town, and avoids the traffic congestion that is expected from towns with single centers. Each fractal unit can, therefore, correspond to particular functions within a town. These may include regions for administration, business/commerce, industry, agriculture, parks, public works and living space.

An example of a town with five quarters is presented in Figure 3a. Note that this provides a framework for the organic growth of the town around distributed centers. Another example of a fractal-based approach to a town with 5 sections is presented in Fig. 3b. This includes spiral road networks for the introduction of infrastructure (roads, water supply, telecommunication cables and electricity) to the living space. A different aesthetic plan of a rural town with 5 quarters is presented in Figure 3c. Note that this allows for the fractal-based growth of the town around the established quarters, which are shaded in Fig. 3c. An alternative design of a rural sprawl is shown in Fig. 3d. This allows for the integration of farms or large agricultural plots on the periphery of the town. Similar approaches can be applied to the design of urban communities in which the infrastructural needs are networked into the living space. the holistic design of rural/urban communities.

However, one of the potential problems within the periodic fractal based approach is the limited range of geometries that can be achieved. Hence, it is of interest to consider other ways of achieving aesthetics in rural/urban landscapes. This can be done by combining fractal-based and quasi-crystal approaches to produce a range of non-periodic patterns. Selected examples of possible patterns are presented in Figures 4a-4c. These include: non-periodic (Fig. 4a), chiral (Fig. 4b) and spiral (Fig. 4c) patterns of homes or plots within a fractal unit. It is clear that these are just a few of the aesthetic forms that are possible.

### **Holistic Approach to the Design of Sustainable Urban/Rural Landscapes**

It is interesting to note that the fractal-based method of distributed centers has been applied to the design of villages in Africa (Eglash, 1999; Gerdes, 1999). This is illustrated in Fig. 5, using a fractal image of other Ba-ila settlement in Southern Zambia that is taken from Eglash, (1999). The fractal simulation shows individual units around distributed centers, and the

potential for further expansion of the village within this framework. Note that the gradients in the status of individuals within this community is reflected by the increase in size from front to back. Also, the architecture has a ring shape that has been modeled by Eglash (1999). The real challenge in the example of Fig. 5 is how to network the electricity power supply to rural communities that are often far from the grid.

Based on the above arguments, it is clear that a different approach is needed for the organic development of sustainable new towns. Such towns should be developed through a partnership between government, business/industry and social entrepreneurs. Within this framework, the government acquires the land and does the layout for the town, with inputs from all the stakeholders. The layout must include all the components required for sustainable living, i.e. plots for farming and living, micro-finance districts, business and industrial zones, entertainment districts, parks, schools, transportation networks and infrastructural networks, and hybrid sources of energy. For each of these basic requirements, alternative approaches are needed to develop sustainable plans for long-term financing. Hence, the government should not assume all of the risk and responsibility for the cost.

For example, the cost of the residential and business/industrial buildings and entertainment regions could be financed largely by private funds, once the layout is complete. Hybrid energy sources (solar, wind, hydro, tidal and fossil fuel) could also be partly financed by private funds, since these may become enterprises that can recover the original investments within the normal investment framework. In contrast, the initial cost of the infrastructure, transportation networks, hospitals, parks and schools will need government financing, which may be recovered through long-term taxation over a period of ~20-50 years.

Since the growth of the new town is likely to be organic, an evolving template should be developed in which the different components of the urban/rural community can be organized around distributed centers. In this way, the appropriate scaling may be achieved in each of the components, without losing the quasi-periodic structure and the functionality of the space. This can be achieved by the application of the quasi-crystal and fractal-based design concepts presented earlier. Within this framework, the urban/rural community may start with a relatively small number of fractal units, with distributed centers that are integrated into an urban/rural area. The functionality and growth of each space is designed specifically by town planners using a fractal-based template. Municipal authorities would be expected to work in partnership with the urban planners and architects to ensure that the designs introduce all the basic elements required for sustainable communities. The connectivity between the different regions can also be engineered to minimize traffic congestion. This may be achieved by the use of spiral networks that bring roads, water, and energy to key areas in the urban/rural communities (Fig. 5c).

Within the communities, the living space could refer to the plot shape or the actual affordable home. This represents the basic unit cell in these regions. Shared infrastructure may also be shared at overlapping edges, as in quasicrystals. Furthermore, the plots should contain space that will allow for the future expansion of the living space, as the space requirements grow from an initial home design. This is clearly a concept that might be difficult to introduce into urban areas, where the cost of land is relatively high. However, in such cases, it might be possible to introduce a second floor of living space to accommodate future space requirements.

Before closing, it is important to discuss the role of financing, which has not been considered in detail in this paper. This is discussed in a separate paper by Okwo and Soboyejo (2006). In this paper, we consider most of the key components that are required for the holistic design of an affordable infrastructure, water from rainwater harvesting, alternative energy, recreational and living space. The key is to explore creative financing schemes that can be used to make these components affordable. Hence, multiple credit/financing schemes are needed for multiple levels of investors to finance business and industrial districts that are the engines of urban life. In the case of rural areas, cooperative schemes should be created to provide farmers with seeds, ideas and agricultural field support. The cooperatives should also provide the farmers with financing, and facilities for the storage, preservation and distribution of agricultural produce. Above all, such cooperatives should add value to the agricultural produce by engaging in simple food preservation and manufacturing that utilizes agricultural inputs. It is only through such value addition to agricultural produce that we can create sufficient wealth to overcome rural poverty, and poor living conditions in the rural areas of the developing world.

### **Summary and Concluding Remarks**

This paper presents a new approach to the design of urban and rural landscapes. This includes the use of quasicrystal and fractal-based concepts in the design of communities that integrate all of the components required for sustainable development. Unlike existing urban/rural plans with single centers, distributed centers are used to disperse traffic around regions that provide all the functional living and working space within an integrated holistic framework. Percolating spiral networks are also used to provide connectivity of infrastructural components such as roads, water and energy supply. The paper concludes with a few comments on the possible role of financing in the development of sustainable urban/rural communities.

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Figure 1      Combination of straight and curved sections for improved aesthetics in rural and urban housing scheme.

Figure 2 Example of two fractal unit within a rural quarter. Note that there are 5 blocks within each fractal unit and a total of 10 blocks in the quarter

(a)

(b)

(c)

(d)

Figure 3 - Organic growth of rural landscape around distributed centers: (a) five quarters in rural administrative subdivision; (b) alternative configuration for five administrative subdivisions – 200,000 people; (c) rural new metropolis with five new towns – 200,000 people, and (d) rural new megapolis with 10,000,000 people

(a)

(b)

(c)

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