



TESSELLATION PLANNING AND HONEYCOMB HOUSING

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Abstract

In *honeycomb housing*, produced by *tessellation planning*, small courtyard neighbourhoods of 5 – 16 houses are linked together into *cul-de-sac* communities of up to 42 houses, which in turn form part of a larger neighbourhood of up to 300 houses. This physical arrangement promotes communal interaction and safety from traffic and crime. The house types used are novel, with wide frontages and every attached house is a corner unit. The compact footprints encourage contour housing. Every house faces a public garden in the centre of the courtyard, accessible for the very young, old and disabled, where big canopy trees can be planted. Using mathematics, we can prove that substantially less road area is required, which improves both the green and the saleable land area. Densities can also be higher. The mathematical basis of *tessellation planning* allowed us to develop prototype software tools that produce pre-drawing feasibility studies, and following this, rapidly create the layout plan and land-use breakdown.

Keywords: Tessellation planning, Honeycomb housing, Defensible space

INTRODUCTION

Fly over the country and you will see rows and rows of houses. Is there another way to lay out buildings? We present here a new method of subdividing land for housing. We believe it produces better social, environmental and aesthetic outcomes, and in a way that also uses land more efficiently. We can prove mathematically that substantially less road area is required, which improves both the green area and housing density. The new method was conceived as a practical and economical substitute for the terrace house, but it can also be seen to be an alternative to all forms of row housing and the linear approach to planning.

Conventional row housing and the linear approach to planning

Dwellings can be arranged on individual plots of land as detached units or linked to each other. Whether detached or linked, they line up along streets to form row housing. In a row house, owners of individual plots of landed property maintain sole occupancy rights. Orthogonal grids have been used as the fundamental tool for subdividing land. Linear roads provide access to individually owned plots of land. Roads and gridlines may be distorted by design or necessity but they retain their linear nature.

Terrace housing

Terrace housing has long been considered the densest form of landed property development possible. Indeed, of all the types of housing in Malaysia, it is the terrace house that predominates. The typical lot varies from 16' x 50' to 24' x 100', but the most common lots now are 20' x 65' and 22' x 70'. The ubiquitous terrace house plan has been designed and re-designed many times but always within the same restrictive framework without much scope for innovation.

The housing layout has also become stereotyped. In the typical estate, the terrace houses are lined up along grid-lines with 40' service roads in front and much narrower back lanes and side lanes. Communal areas for schools, civic and religious buildings, as well as open areas for children's playgrounds and parks, are also provided. Despite the infrastructure provided, the design of many housing estates does not really meet the practical needs of the average resident. Apart from the aesthetic boredom of rows and rows of houses, among the drawbacks of the terrace house layout is the lack of public security and any genuine sense of community (Malaysian Encyclopedia Vol. 5 Architecture, 1998).

In trying to improve the monotony of housing in rows, planners have devised various strategies:

1. Strata-title development

In this approach, groups of houses share ownership of the communal facilities, allowing greater freedom in designing the access route and common facilities, and also allowing high densities. The Desa Park Homes (see Figure 1) development is an example of this type of approach. It is able to achieve densities as high as conventional terrace house layouts. However, strata- titles are considered not as valuable as land titles.

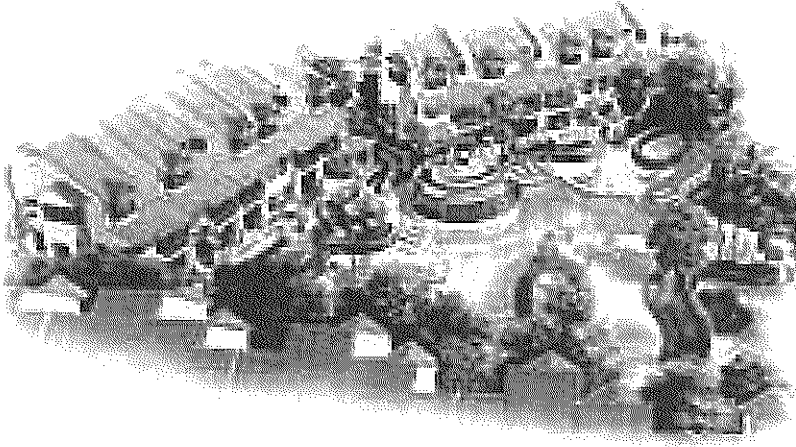


Figure 1: Strata-title Desa Park Homes

2. Organic layouts

Following the trend in more developed countries, local planners have devised 'organic' layouts, where winding roads and occasional *cul-de-sacs* break the boredom of the iron grid. However density is sacrificed. A Guthrie development at Bukit Jelutong is an example of this trend, but the houses there cost RM500,000 or more (see Figure 2).



Figure 2: Bukit Jelutong layout

3. Clustered layouts

Similarly, the cluster approach can produce interesting outcomes but, in most cases, loses out on efficiency. The circular clustering of houses at Brondby near Copenhagen in Denmark shows a wide expanse of green area between the clusters (see Figure 3).



Figure 3: Brondby, Denmark

4. Honeycomb housing

Using the *tessellation* method of planning, all the houses are built around small parks with large shade trees in hexagonal *cul-de-sacs*, which efficiently interlock to form townships similar to a bees' honeycomb (see Figure 4).

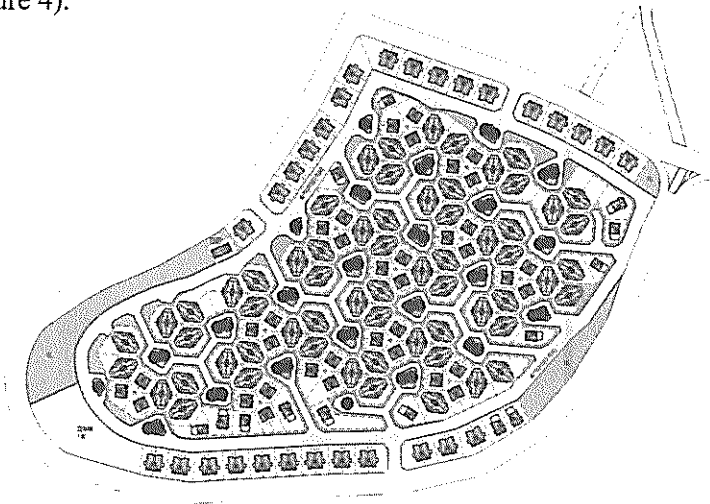


Figure 4: Honeycomb layout at Sungai Lunchoo Johor Bahru

TESSELLATION

In mathematics, to tessellate means to cover a plane with a pattern having no gaps or overlaps. For centuries artists and craftsmen have used tessellation as a tool to create visual effects on surfaces. Tiling is the most common form of tessellation and in its simplest form the tiles are regular polygons. The Muslim craftsmen in Spain in the 15th century created beautifully complex visual effects by tessellating a small simple basic tile pattern (see Figure 5). Intricate and complex designs can be built up from basic tile patterns in a simple way by this process (see Figure 6). In honeycomb housing, the creative power of tessellation is applied to town planning, where the colours are not merely decorative but represent functional space.

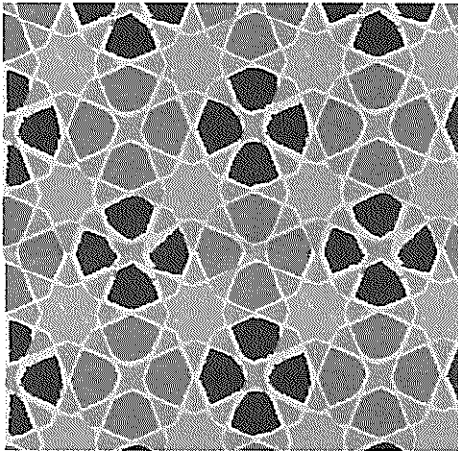


Figure 5

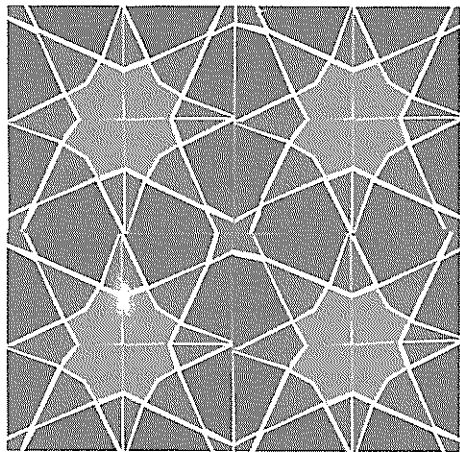


Figure 6

SEGMENTS OF THE TILE

A small triangular tile, the *mother-tile*, is the basic building block that creates the honeycomb layout. It contains three of the requisite elements of a township plan:

- road (yellow)
- House & garden (red)
- Public green area (green)

We call these colored segments *daughter-tiles*.

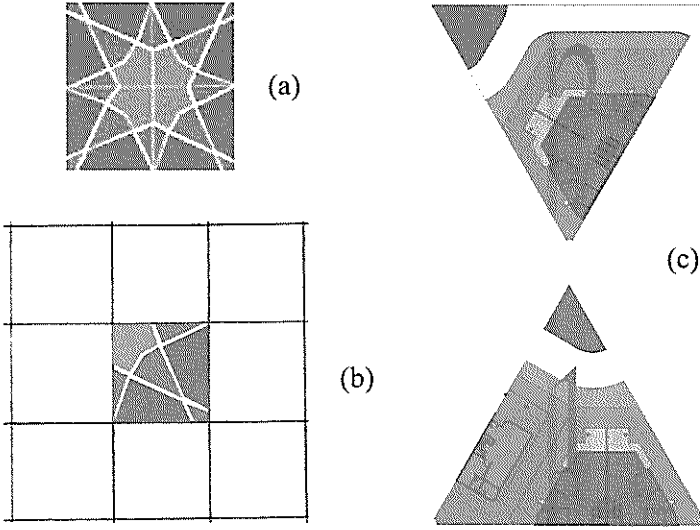


Figure 7: The *mother-tile*

The mother-tile, and close variations of it, tessellate according to simple rules to form what appears as a complex and intricate pattern. When tessellating, daughter-tiles meet and link up with similar ones in adjoining tiles. The same coloured daughter tiles form *conjoined tiles*. It is the complex shapes of these interlocking daughter-tiles that we perceive, rather than the simplicity of the triangular grid. Refer to Figure 8.

Conjoined house and garden tiles form the basis of new house types (see Figure 9). Linked Honeycomb Houses ideally join back to back and are accessed from different *cul-de-sacs*. This is the case with the duplex and triplex. But the houses can also link side to side at the same time, as in the cases of the quadruplex and sextuplex.

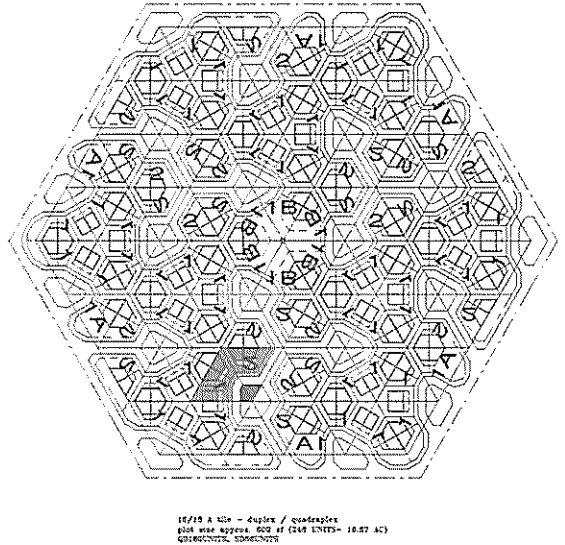
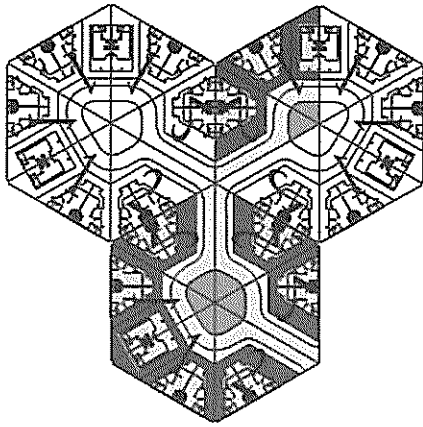
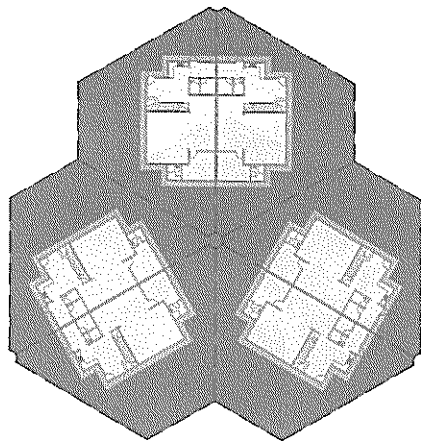


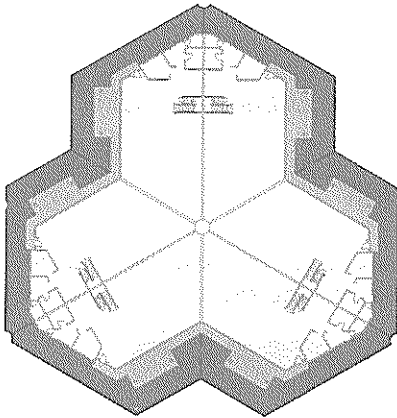
Figure 8



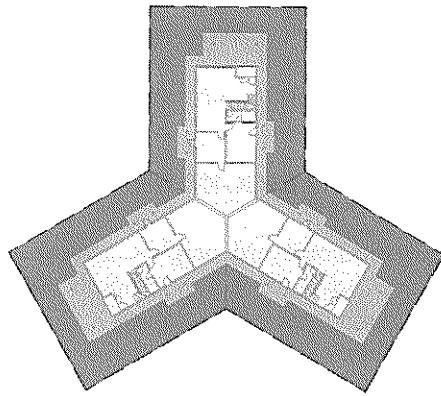
(a)



(b)



(c)



(d)

Figure 9

DESIGNING THE COURTYARD NEIGHBOURHOOD TILE

A *courtyard neighbourhood tile*, containing the planning elements necessary to form a small community, is created by tessellating the mother-tiles to form a hexagon. Communal space is created in the middle, surrounded by the houses. The road accesses each unit around the courtyard space and forms an extremely

efficient circulation system. Through this design we have created a spatial boundary, a central area that can become the communal focus, and a sense of entry into this place. The design is such that there is a clear, common perception of the neighbourhood. See Figure 10 and 11.

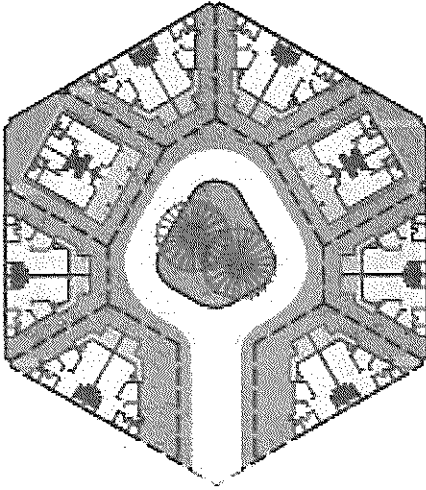


Figure 10: Courtyard Neighbourhood

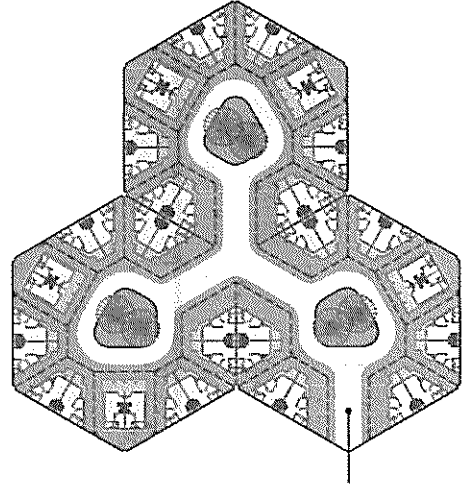


Figure 11: *Cul-de-sac* Neighbourhood

DESIGNING BIGGER NEIGHBOURHOODS

When the courtyard neighbourhood tile is tessellated, the roads are linked to create *cul-de-sac* neighbourhoods without loss of efficiency. Opportunities to link dwelling units into multi-unit blocks exist along the tile boundaries (see Figure 12). Joining many courtyard and *cul-de-sac* neighbourhood tiles on a real site is simple and efficient. It results in more livable spaces with an improved relationship between people and people, people and cars, and people and their environment.

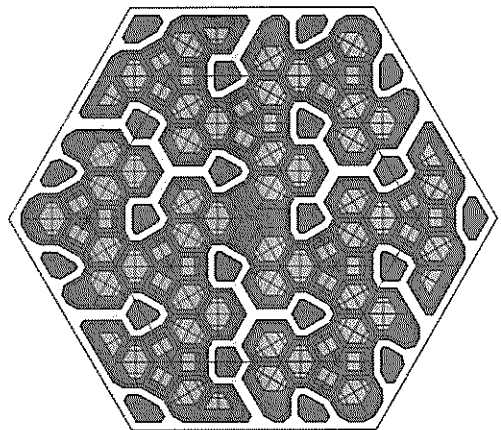


Figure 12: Precinct Neighbourhood Tile

THE SOCIAL ASPECT OF HONEYCOMB HOUSING

Using the tessellation method of planning, houses are built around a small park with large shady trees in a *cul-de-sac*: this communal garden, easily accessible to all, acts as a social focus for a small, friendly neighbourhood and is a defensible space designed to reduce crime naturally. The short winding roads reduce traffic speed so that urban areas become safe and pleasant for children and pedestrians, encouraging outdoor social interaction and the development of a community.

CARS VERSUS PEDESTRIANS

Planners have long realized the negative effect of fast-moving traffic on neighbourhoods (see Figure 13). Radburn in New Jersey, built over 70 years ago in the US, is the prototype for the separation of pedestrians from traffic. Delft in the Netherlands, built in the 1960s, is one of the first examples where the roads are designed with traffic-calming features to slow down vehicles (John Gehl, 1987).

In honeycomb housing the network of roads comprises looping *cul-de-sacs* and short connecting roads leading to distributor roads. This pattern slows down traffic naturally, rendering it safe for pedestrians. The short connecting road with no access to houses provides space for visitors' parking. See Figure 14.



Figure 13

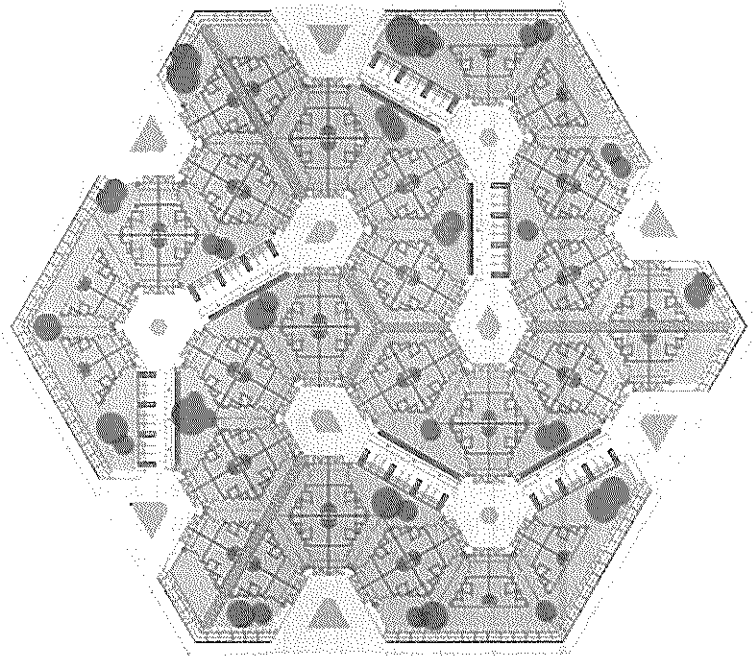


Figure 14

CREATING COMMUNITIES

The outdoor space between buildings is an important arena for social contact and spontaneous interaction, which are important in developing a sense of community. The creation of a safe, pleasant and shady area of suitable size, just outside the home, is a basic feature of honeycomb housing. The central courtyard becomes the social focus of the neighbourhood and is accessible to all to enjoy, the very young, the old and the disabled. Sociologists find that individuals relate better to small groups rather than large. In honeycomb housing the neighbourhood contains only 5 to 40 units defined clearly by the single access road and the communal courtyards. It is easy for people to get to know each other by sight, to get acquainted, to set up informal social groups and to initiate collective action. See Figure 15.



CENTRAL COURTYARD

Figure 15

DEFENSIBLE SPACE

The issue of public security in residential areas is a hot current topic. In a national survey conducted in July 2004 by Merdeka Centre and IKMAS, 42% of Malaysians surveyed said crime was their biggest worry. The concept of *Defensible Space* with a hierarchy of private space, semi-private space and public space, first proposed 30 years ago by Oscar Newman (1972), is now widely accepted (see Figure 16). Residents must be allowed to exercise influence over the environment just outside their homes: visitors should know when they are entering a semi-private domain. Environmental design

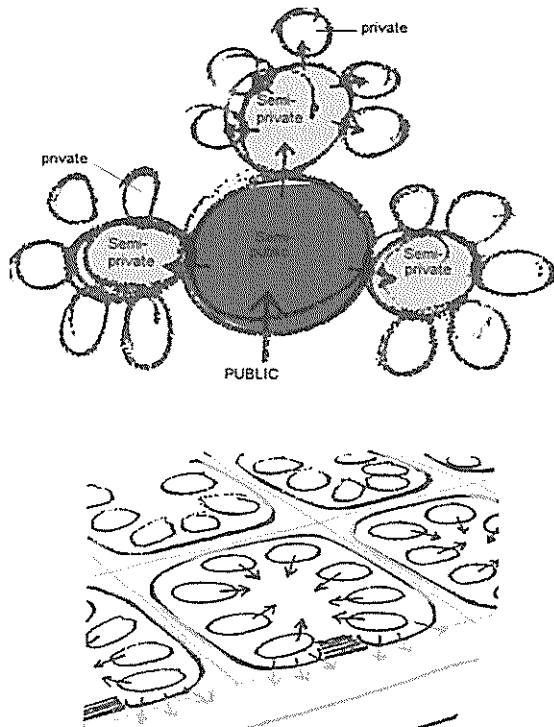


Figure 16

can assist in providing *natural surveillance* of the external spaces. The honeycomb layout can be seen as a technique to design townships where every house lies in a *cul-de-sac*, which naturally produces defensible spaces. Furthermore, it completely eliminates back-lanes from where 30% of break-ins in Malaysia originate, according to UTM researchers (A.B. Abas and I.N. Sugianto, 2004).

Play areas

Play is an important aspect of learning for the child; growing up can be seen as a process, where the child becomes more and more independent of the parent, exploring first the spaces around the mother and progressing to other rooms in the house and then the front yard. The opportunity for exploring new environments is best presented in small discreet steps so that children can explore them at their own pace (John & Elizabeth Newson, 1968).

The problem with the typical Malaysian situation is that the process of exploring new territory independent of the parent stops at the front gate, beyond which parents do not consider it safe. When the child is finally old enough to go out unaccompanied by an adult it is too big a transition and the child is disadvantaged compared with one that is able to explore bit by bit the neighbourhood around the home.

This suggests that the spaces outside the home should be made conducive to the growing-up process. They should be safe for smaller children, with ample play and civic amenities. Play areas with football fields some minutes away from the home do not serve the needs of pre-schoolers or young primary school children.

The environmental aspect of honeycomb housing

Tessellation planning makes undulating land suitable for high-density landed property development with less cut and fill. Big trees in the *cul-de-sacs* provide cooling shade; they also serve as a source of food and a habitat for small birds and animals.

Sloping sites

Building long rows of terrace houses cheaply requires hills to be cut and streams to be filled. Honeycomb link units have compact footprints that allow more level changes to be placed between the blocks. In this respect their shape is very much like big detached houses, and it is evident from existing townships that the typical developer flattens large expanses of land for his terrace houses,

but lets the bungalows go up and down to better suit the original contours (see Figure 17).

Bringing nature into townships

The road shoulder with its underground cables and pipes is not suitable for trees: but big shady species can thrive in the small communal gardens of honeycomb housing. The clearing of trees to create concrete jungles is the main contribution to the heat-island effect. Roofing houses with thick insulation and shading the external hard landscape and roads by maximizing the tree canopy area are strategies used in honeycomb housing. Evaporation from leaves will further cool the external environment. The landscaping of the parks will create microhabitats. Linking the small islands of green via the footpath landscaping and the private gardens will encourage biological diversity.

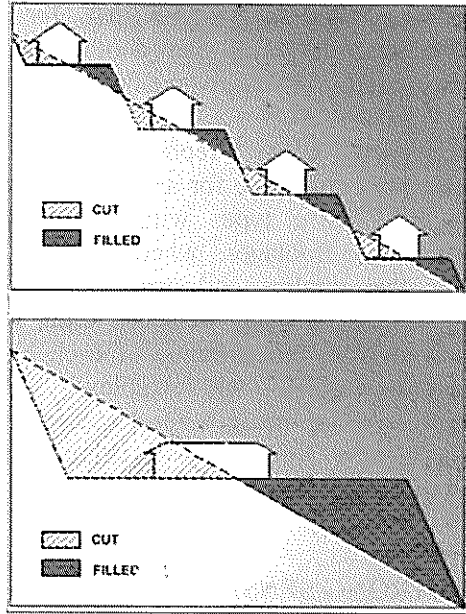


Figure 17

WILDLIFE TECHNOLOGY

Wildlife technology is a new concept being developed by UPM (Universiti Putra Malaysia). Suitable species of introduced butterflies, birds and small mammals will gradually adopt a honeycomb township as their natural home (John & Elizabeth Newson, 1968).

Residents of honeycomb townships can once again live like their rural ancestors, in harmony with nature, by contrast with people in the present urban concrete jungles.

AESTHETIC ASPECT

Tessellation Planning, without incurring any cost penalty, allows new townships to break free from the mental grid-lock that produces rigid rows of housing. To most architects, designing yet another terrace house is a boring chore (see Figure 18).

Honeycomb housing represents a new and refreshing challenge for architects. It leads to new house types with wider, more articulated frontages, where linked units like the duplex and triplex give the impression of being detached units when viewed from the entrance of each house. The quadruplex and sextuplex give the impression of being semi-detached units. These new forms give architects more room for creativity. See Figure 20.

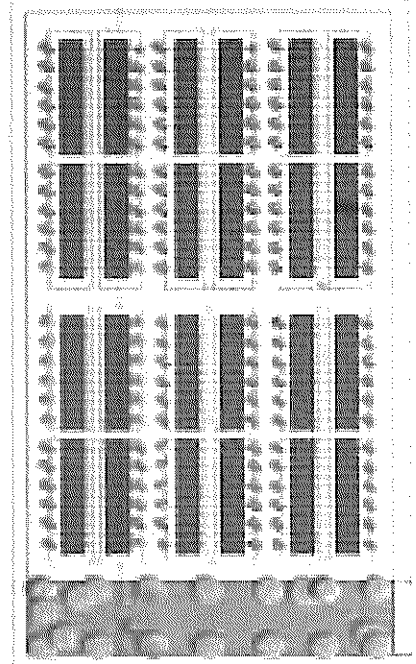


Figure 18

A STRONG SENSE OF LOCATION

The home is often a family's biggest investment: its resale value is affected most by its location. A home in a private and exclusive location, within a nice friendly neighbourhood, set in a lush, mature landscape with birds singing in the trees, will fetch higher resale values.

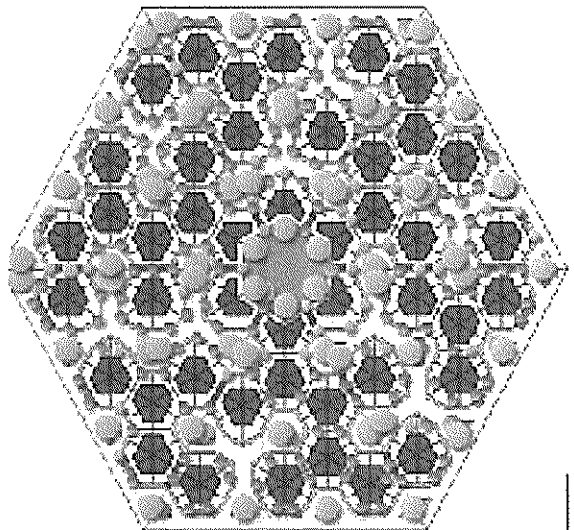
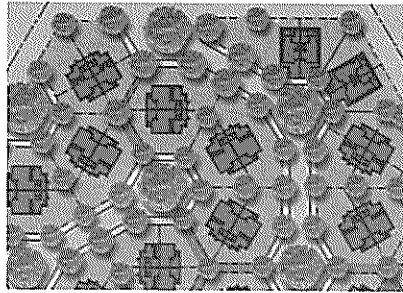
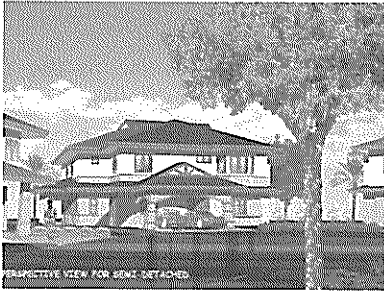
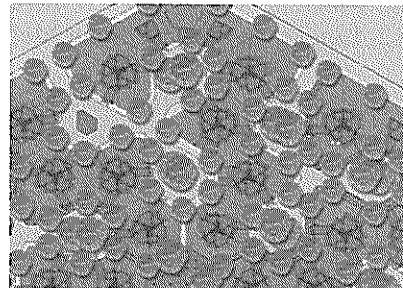


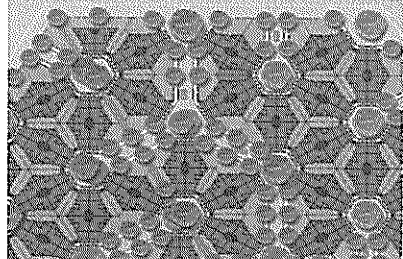
Figure 19



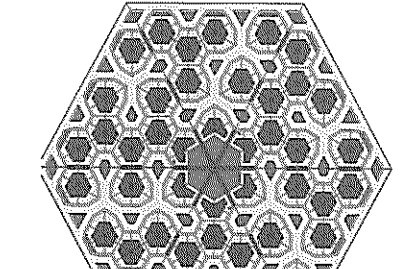
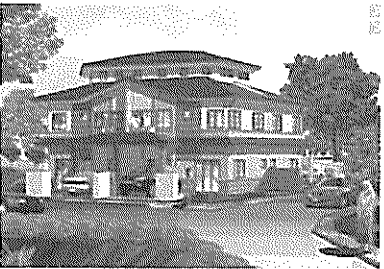
(a) Duplex



(b) Triplex



(c) Quadruplex



(d) Sextuplex

Figure 20

Hierarchy of roads

It is very easy to get totally lost when looking for a house in the typical Malaysian township. Make one wrong turn and it is easy to compound this error with other mistakes, which takes you further and further away from where you actually want to go.

Using the tessellation method, we can adopt a technique to make it easy for people to navigate the streets and not to have to worry about getting lost. In the example shown, there is one main entrance road, Jalan Tulip Utama, in this 100 acre site which is 66' wide. Then there are smaller 50' distribution roads, Jalan Dahlia 2, Lingkar Orkid 3, Sabit Melati 4, and so on. See Figure 21.

The houses are accessed from *cul-de-sacs*, which are addressed in a hierarchical fashion, each referring to the distribution road they come from, Desa Dahlia 1/2, Desa Orkid 1/3, Desa Orkid 2/3, Desa Orkid 3/3, and so on. See Figure 22.

The fact that the smaller roads do not connect to other small roads means that if we make a wrong turn into one of them, we go out the way we came in. Miss a turning on the circular road, and we just have to keep going until we get back to the junction again. Errors are not compounded. The system is self-correcting.

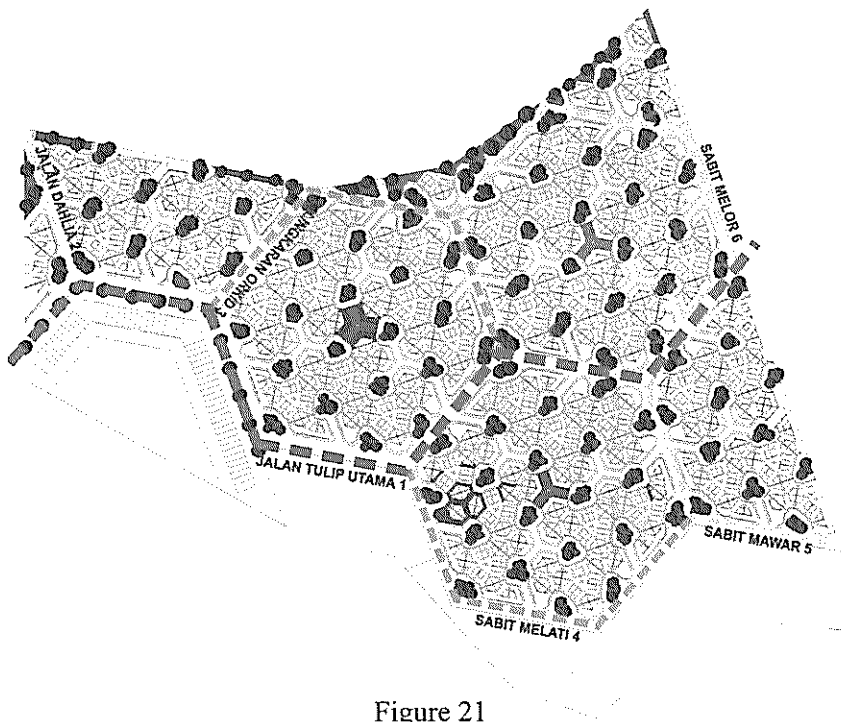


Figure 21

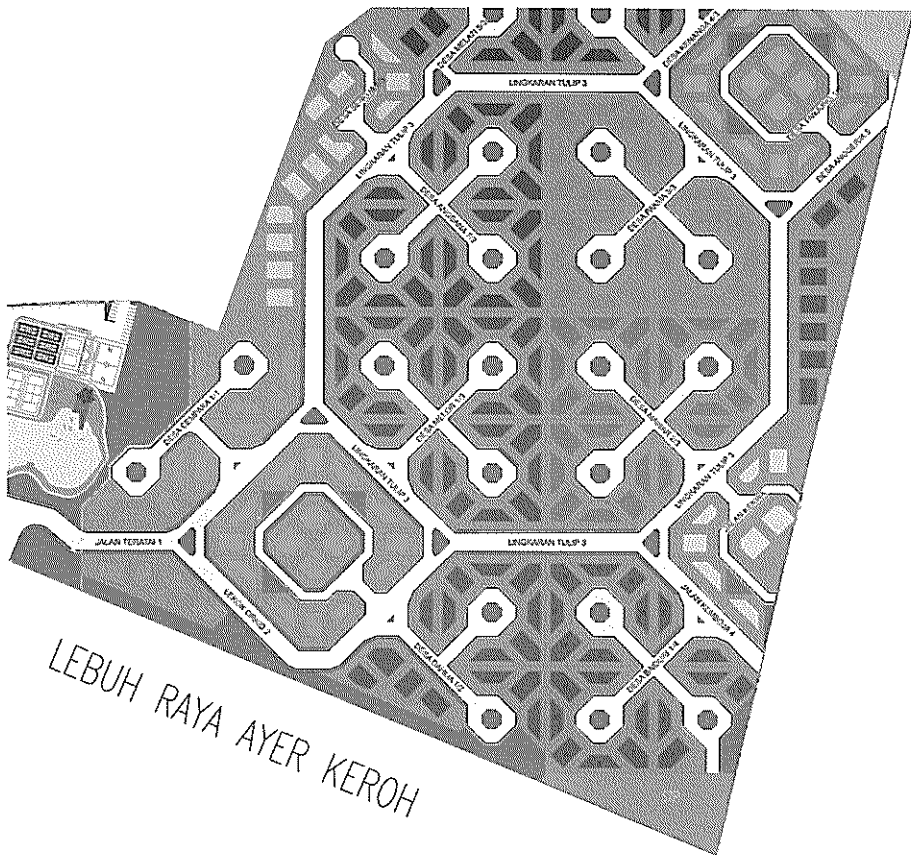


Figure 22

The economic aspect of honeycomb housing

A terrace can be seen as a row of houses surrounded by roads. In contrast, honeycomb houses surround the road. It is easy to understand intuitively that roads accessing internally are more efficient than roads accessing houses from the external boundary. This accounts for the efficiency of *cul-de-sacs*. See Figure 23.

Given a fixed area and number of houses to access, the shorter the *cul-de-sac*, the less the area taken up by the road. A square *cul-de-sac* neighbourhood has less road area than a long rectangular one (see Figure 24). A circular one by itself would be the most efficient (see Figure 25). However, as we have seen with the example from Brondby, Denmark, the circle does not tessellate (Figure 26). However, hexagonal neighbourhoods interlock without gap or overlap.

The second consideration is the length of the distribution roads that encircle a precinct. The perimeter of a hexagonal precinct is 7% shorter than the perimeter of a square one of the same area.

The third factor is the shape of the individual lot and its effect on the buildable footprint after taking account of setback requirements. In the example shown, the truncated triangle shape of 6000 square feet yields a higher plinth area compared to a typical 60' x 100' site (Figure 27).

All of the above factors combine in honeycomb housing to produce greatly increased efficiency of land use.

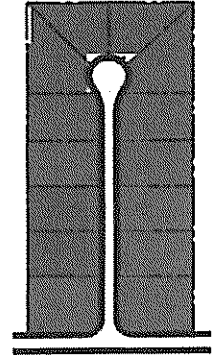


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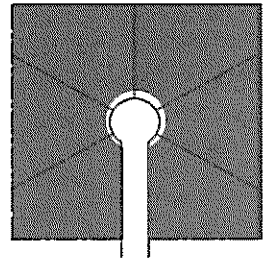


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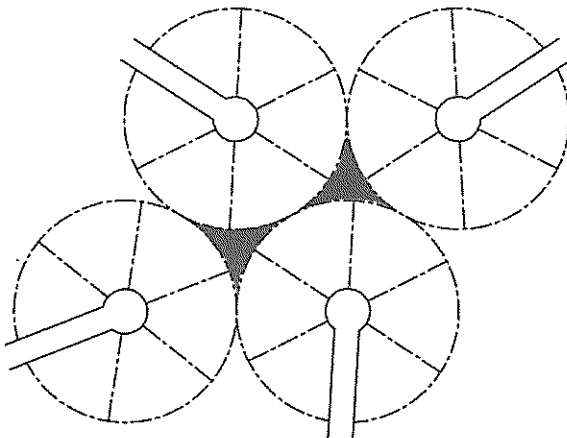


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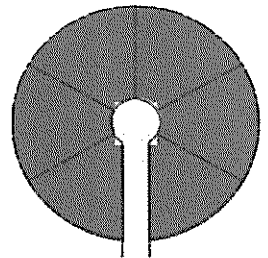


Figure 25

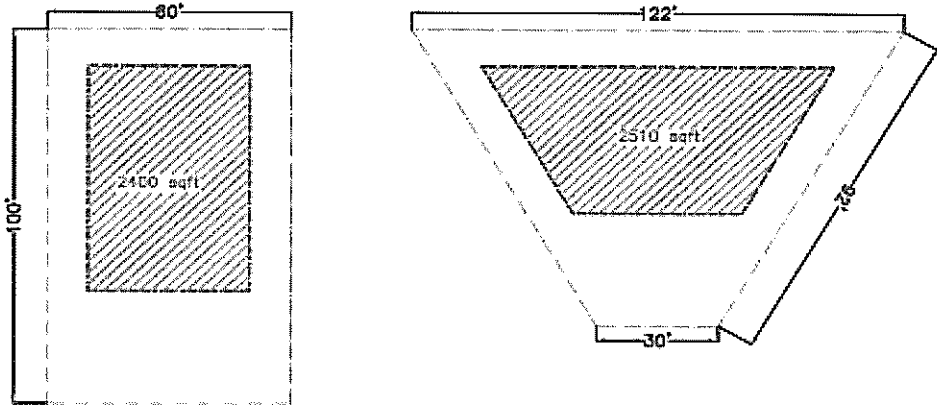


Figure 27: The honeycomb housing system offers bigger buildable areas than the row housing.

ANALYSIS

Reducing roads and improving land-use efficiency

A honeycomb neighbourhood comprising 5 units of quadriplexes and duplexes is compared with a terrace house arrangement of an equivalent 5 units. We then compared a honeycomb neighbourhood comprising 16 units of quadriplexes and duplexes against a terrace house arrangement of an equivalent 5 units (see Figure 28). It is demonstrated in the table below that the honeycomb layout is more land-use efficient (Table 1).

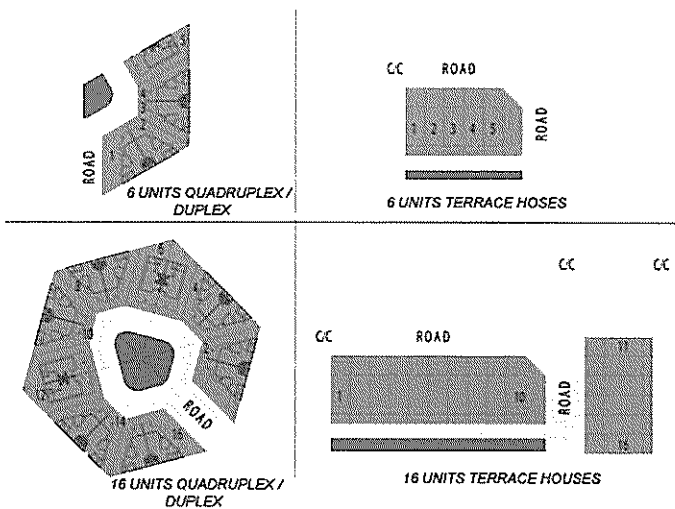


Figure 28

Table 1: Honeycomb Terrace

5 UNIT				
	HONEYCOMB HOUSE		TERRACE HOUSE	
	(SM)	(%)	(SM)	(%)
ROAD	334	26	611	41
GREEN	93	7	103	7
HOUSE	861	67	761	52
TOTAL	1288	100	1475	100
16 UNIT				
	HONEYCOMB HOUSE		TERRACE HOUSE	
	(SM)	(%)	(SM)	(%)
ROAD	879	23	1323	35
GREEN	264	7	269	7
HOUSE	2721	70	2190	58
TOTAL	3864	100	3782	100

A similar exercise comparing 2 and 8 detached houses laid out in rows and against the same numbers of equivalent honeycomb houses comes to the same conclusion (Figure 29). Comparisons of private and public green areas and of potential tree canopy areas also yield interesting results (Table 2).

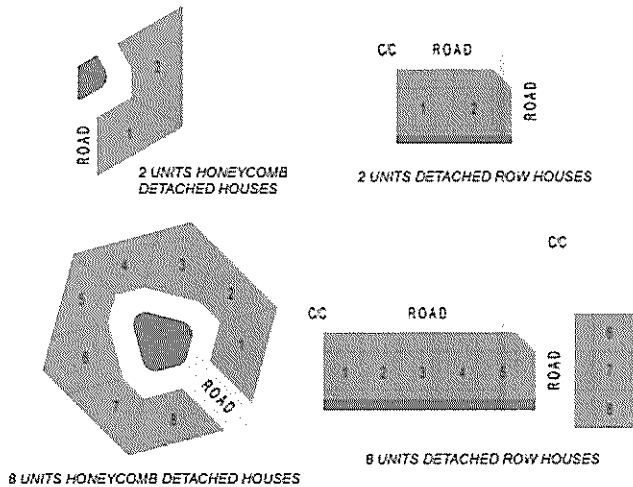


Figure 29

Table 2: Honeycomb Bungalow

2 UNIT				
	HONEYCOMB HOUSE		BUNGALOW	
	(SM)	(%)	(SM)	(%)
ROAD	334	26	426	33
GREEN	93	7	90	7
HOUSE	861	67	761	60
TOTAL	1288	100	1275	100
8 UNIT				
	HONEYCOMB HOUSE		BUNGALOW	
	(SM)	(%)	(SM)	(%)
ROAD	879	23	818	25
GREEN	264	7	235	7
HOUSE	2721	70	2190	68
TOTAL	3864	100	3243	100

Honeycomb housing produces greatly increased land use efficiencies. These advantages are summarized in the mathematical table comparing an 18' frontage terrace housing against sextuplex honeycomb housing (Table 3).

Table 3: Mathematical Comparison

% of site	Terrace Housing	Honeycomb Housing
Road Area	46%	37%
Saleable Land	43%	52%
Private Gardens	6%	12%
Public Green	10%	10%
Potential area Shaded by Trees	15%	46%
Houses Per Acre	13.2	16.5

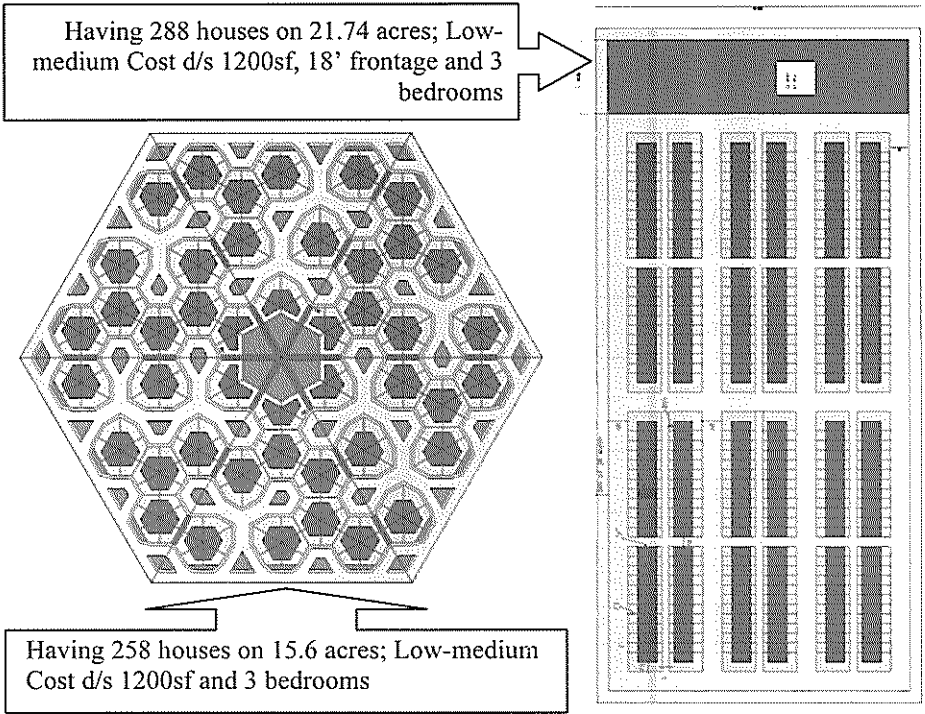


Figure 30

Figure 31

Apartments

Tessellation planning can also be applied to the layout of apartments. The apartment blocks are arrayed around an open courtyard which contains the driveway, car parks and a central garden. In the new designs of 5 storey Honeycomb apartments, access corridors are eliminated. Units cluster around a well ventilated and naturally lighted central lobby on each floor which serves as a semi-private meeting area for residents and a safe playpen for their children. Each floor is accessed by stairs, an also a lift to cater for young families, the old and the handicapped (see Figure 32, 33 & 34).

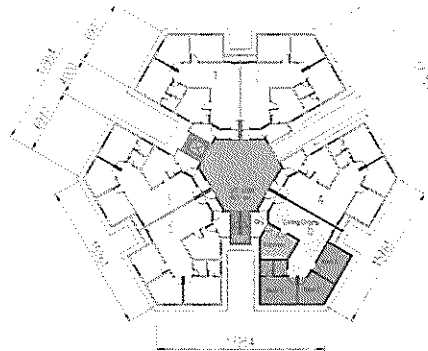


Figure 32

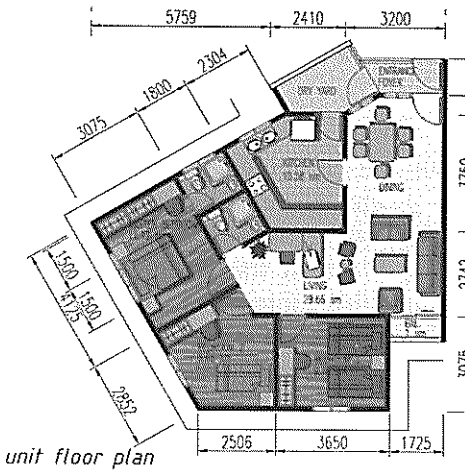


Figure 33

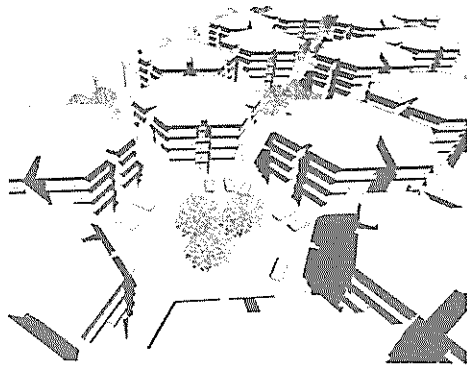


Figure 34

Proof of concept

Presenting our ideas to various people in the housing industry, we find that most warm to them. However, doubts are often expressed as to whether others in the industry or consumers can accept this radically new concept. Furthermore, many are also skeptical about our claims as to the improvement in land-use efficiency: they expect such 'complicated' layouts to be more expensive. Certainly, we agree that our claims on the cost savings are counter intuitive but we can prove them.

Consumer and industry surveys

Reactions to honeycomb housing have been tested through scientific surveys. UPM undertook a targeted consumer survey at a Home Ownership exhibition in the Mid Valley Shopping Mall in June 2004. Researcher staff gave out questionnaires after a 15 minute pictorial explanation at our booth. From 116 respondents, 76% said they would like a house in a honeycomb township. Similar results were obtained even from housing developers. From 69 members of the Housing Developers Association who responded to a questionnaire given out after a 60 minute presentation, 78% agreed to the statement that 'Honeycomb townships are desirable'; 61% agreed they could be commercially implemented, with 35% unsure but only 4% disagreeing. Another survey of 59 respondents attending an August 2004 seminar on 'Lightweight Steel for Residential Construction' also yielded positive results: 91% thought honeycomb townships were desirable and 80% agreed they could be commercially implemented.

Clearly, honeycomb housing, based on the tessellation method of planning, is capturing the imagination of both consumers and the housing industry.

General mathematical model

Distances and areas of a tessellation layout and an equivalent terrace layout were expressed in terms of variables x , y , etc. Using formulae from the Pythagoras theorem and the solution to quadratic equations, a mathematical model of the two alternatives was built up. We then tracked how land-use efficiency and density vary as a range of buildable footprint areas of the two alternatives are input. We were able to prove in all cases that tessellation layouts reduce the total area of roads, thereby resulting in more saleable land, and lowering infrastructural cost. We also showed that housing densities can be improved.

Infrastructure

By going through the same process with the length and the quantity of roads and drains we also found big reductions. There was a small increase in the cost of sewerage but overall, there was a substantial reduction in Infrastructure costs.

IT aspect and prototype software

The industry-standard method of designing housing layout is largely an intuitive process. The design and drawing of a housing layout is required before a feasibility study can be done and the first solution is very unlikely to be satisfactory. The search for an optimal solution involves a lot of hard work with multiple iterations between layout drawings and feasibility studies and is often not done fully. By contrast, the tessellation method of planning involves geometrical manipulation that can be captured by mathematical formulae and a set of algorithms that can be programmed.

Proposed systematic computer-aided process

Thus, a key feature of the tessellation method of planning is the fact that it makes possible an application software that can rapidly produce a feasibility model capable of handling what-if questions to reach an optimal layout proposal; a further capability is the almost automatic production of a drawing of that layout.

There is no similar software in the market that provides these capabilities based on the conventional method of design. The application software described may become a compelling alternative to the current slow and laborious intuitive method.

Using the mathematical model and employing a set of algorithms, and partly funded by Malaysian Venture Capital Bhd, we have developed:

- A prototype of software that can rapidly produce a feasibility model able to handle what-if questions to reach an optimal layout proposal without drawing a layout plan first. Density and percentage sellable land are calculated using the mathematical model (Figure 35 and 36).
- AUTOCAD add-on tools that simplify and speed-up the drawing of tessellation layouts

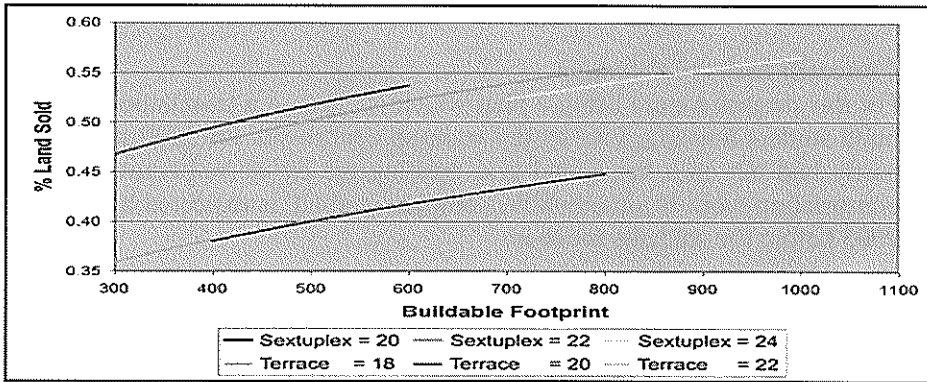


Figure 35

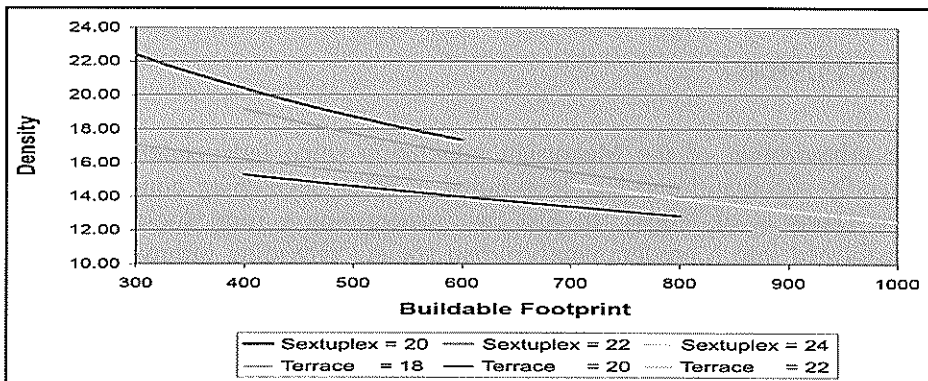


Figure 36

THE PROJECTS

From case studies and using the feasibility planner, we are able to show developers that they can improve their sales revenue from the increase in sellable land and units, and reduce their costs by cutting down the amount of roads and drains to be constructed. We are already working as consultants on real sites to realize the first tessellation developments.

a) *Puncak Alam*

We are working on the layout of a 400 acre mixed development site north of Shah Alam. The proposal includes low and low-medium cost apartments, medium to high medium cost attached housing, industrial and commercial properties and the full range of amenities that make up a township.

b) *Universiti Industri Selangor*

For this project we are using a plan which is close to a tessellation layout to build student housing. Five storey walk-up apartments for 5000 students are partly laid out on a hexagonal grid creating the *cul-de-sac* courtyards. The construction work is already 80% complete and CF is expected by February 2005 before the students move in.

Research and Development

We have been advised by senior patent attorneys, following worldwide searches, that tessellation planning appears to be entirely novel and can be considered an invention. We have taken steps to apply for patents in Malaysia and Australia.

CONCLUSION

The urbanization of the Malaysian population since Independence has been generally successful and has been noted in other developing countries (Mohd Peter Davis et al, 2004). In just two generations a rural society has been transformed into a predominantly urban society providing improved incomes, health, nutrition, housing and education in a population that has grown from 8 million to 25 million. However, in this rush to modernize there have been some negative side effects. But these are mistakes that were made; they are not inevitable consequences of urbanization. Once honestly accepted, the mistakes can be avoided in future townships in Malaysia and importantly in other developing countries as they embark on rapid urbanization.

We believe that there are commercially feasible technological solutions that can improve the homes and townships we live in. We should like to spread our new ideas on honeycomb housing to as many people as possible so that these ideas can be put into practice as part of a wider concept which we call *township technology*. We will be offering to license our proprietary knowledge on tessellation planning to town-planners and architects almost free of charge.

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