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INTEGRATING SPACE SYNTAX THEORY IN SUSTAINABLE PLANTING DESIGN OF PARKS

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ABSTRACT:

The benefits of trees in urban parks for urban residents have been given wide attention. They are considered a major factor in defining spatial qualities of sustainable outdoor spaces. This paper investigates the influence of spatial configuration existed by proposed planting designs of trees on visual fields of an urban park using space syntax theory. The space syntax theory assumes that an urban area can be represented as a matrix of connected spaces, and that quantitative properties of this matrix in the form of syntactic measures can be measured using computer simulations. An experimental study using three different planting design proposals of an urban park was conducted, and data were analyzed using space syntax techniques. Results revealed a significant effect of planting arrangement on syntactic measures between three proposals. This study suggests that space syntax techniques, especially a level of pedestrian movement, may have significant value in schematic planting design stage that contributes to the establishment of sustainable outdoor spaces..

Conference Topic: New Approaches to Urbanisation.

Keywords:
Sustainable Urban Parks, Plantation design, Space Syntax.

1 INTRODUCTION

Recent literature has investigated the influence of landscape vegetation on the frequency and range of movement (Shriver, 1997), and on the choices of routes in specific places such as public gardens (Loiteron and Bishop, 2005). However, these studies focus more on pedestrian behaviour in small and closed spaces (Zacharias, 1997) and in unknown areas (Zacharias,

2006). It remains the necessity to generalize these observations in much larger, familiar environments in order to detect the processes of space perception that affects movement. To make a useful input to urban planning, research on movements in an intra-urban environment must integrate more qualitative data (Handy, 1996; Røe, 2000), such as landscapes, in order to understand how individuals decide their routine trips in an environment and how they are affected by pedestrian trips. The careful understanding of pedestrian movement and their social interaction in a landscape is considered fundamental factor in establishing sustainable outdoor environment (Antorp, 2006).

Robinson (2004) indicated that when spaces for people are designed, the size of plants relative to the dimensions of the human figure is critical. Basically, to distinguish areas on a plan by canopy height is considered an important design stage, because it is plant height that establishes much of the spatial framework and controls vision, movement and physical experience (Robinson, 2004 p.28). Preben Jakobsen, a Danish landscape architect, identified the most useful size categories for the designer as ground level, up to knee height, knee to waist height and below or above the eye level (Jakobsen, 1977). For design purposes, it is helpful to divide trees into small: mature height 5–10 metres; medium: 10–20 metres; and tall: 20 metres. This research focuses on small mature and medium trees from a visual and physical barrier. Medium trees can create spaces that contain smaller structure and therefore, have a greater effect on the spatial structure of urban landscape (Austin, 1982)

Trees are capable of defining space and increasing the degree of enclosure (Booth, 1985; Bell, 2004). The spatial arrangement of trees is expected to affect the visual field of a space. Salingaros (1999) reported that the use of urban space is linked to the information field generated by surrounding surfaces, and on how easily the information can be received by pedestrians. Successful urban spaces also offer tactile information from local structures meant for standing and sitting. The total information field in turn determines the optimal positioning of pedestrian paths and nodes.

Tree placement is a key element in urban landscape architectural design. Trees are one of the tools for space definition in outdoor open space. They provide shape and configuration to the spatial environments. Many aspects need to be considered when proposing sites for tree planting in urban areas (Wua et al., 2008). Important site conditions related to tree selection include climate factors, soil characteristics, environmental conditions, planting space, site

location, existing vegetation, aesthetics, land ownership and regulations, social influences, and maintenance requirements (Bassuk & Trowbridge 2004)

Gilman (1997) recommended various minimum widths of planting sites for trees with different full-grown sizes: 3–4 ft (0.90 – 1.20 m) for small trees, 4–6 ft (1.20 – 1.80 m) for medium trees, and greater than 6 ft (1.80 m) for large trees, with 1 ft (30 cm). Arnold (1980) encouraged the collective use of trees in groves, rows, and symmetrical units in urban design, and explains aesthetic principles used in grouping trees in a variety of settings. For design purposes, visual representation and simulation techniques are traditionally used help designers to visualize their concepts and to explore how the proposed planting layout might work, in reality. This paper investigates the use of visual simulation techniques to detect visual properties of spatial configuration initiated by planting design in a landscape environment.

2 BACKGROUND:

2.1 Simulation of visual fields in environmental design

In environmental design work there has been a motivation of incorporating visibility techniques with advances in agent-based simulation and virtual reality (VR) technology. For example, Penn et. al (1997) have employed “agents” that navigate through VR environments to retrieve isovists which are, according to Benedikt (1979), represent measures of visible space throughout configurations and the associated visual fields through space that they produce. On the other hand, Batty and Jiang (1999) have developed a parallel “agent system” to construct isovists. Extending work on isovists, Conroy (2001) has investigated the formal visual properties of paths that people take within controlled experiments in VR environments.

Turner (2003) argued that while these innovative techniques add a three-dimensional quality, they do not break down into recent uses of visibility analysis, which can be divided essentially into two categories: either classification or assessment of the perceptual qualities of the environment. This paper extends this argument that visibility analysis of proposed planting designs might be able to detect the specific effects of spatial properties of space caused by various planting arrangements in landscape designs.

2.2 Space syntax theory

Space syntax is best described as a research program that studies the correlation between human societies and space from the perspective of a general theory of the structure of populated space in all its different forms: buildings, settlements, cities, and landscapes (Hillier, 1996; Hillier & Hanson, 1998; Bafna, 2003). Space Syntax is also defined as a graph-based theory used by architects and urban designers to examine how the spatial layout of buildings and cities influences the economic, social, and environmental outcomes of human movement and social interaction (Dawson, 2002). Space syntax was developed at University College, London by Bill Hillier, June Hanson, John Peponis, John Hudson, and Richard Burdet (see Hillier et al, 1983). Space syntax techniques offer precise quantitative descriptions of the way in which a setting's built spaces are organized (Hillier et al., 1983). According to Hillier and Hanson (1984), the social meaning of the environment arises from spatial composition.

Space syntax is built on two recognized ideas, which attempt to reflect both the objectivity of space and our intuitive engagement with it (Hillier & Vaughan, 2007). The first idea is that we should think of space not as the background to human activity, as we think of it as the background to objects, but as an essential aspect of everything human beings do in the sense of moving through space. Movement is essentially a linear, interface requires a "convex" space in which all points can see all others and from any point in space, we see a variably shaped, often sharp, visual field we call an "isovist" (Benedikt, 1979). The second idea is that human space is not just about the characteristics of individual spaces, but about the interrelations between the many spaces that make up the spatial layout of a building or a city. This is called "configuration of space". The purpose of this study is to investigate the effect of spatial configuration of trees that would contribute in development of design proposals of urban parks using space syntax theory, which could be used to generate a strategic design framework based on detailed analysis of spatial configuration.

2.3 Space Syntax Methods

Social structure is essentially spatial and inversely that the configuration of populated space has an essentially social logic. This principle is very important in landscape design, which seeks to create an outdoor environment for people to accommodate their social interaction.

Integration

The fundamental concepts of Space Syntax include "integration" and "connectivity". The "integration" of space is a function of the mean number of lines and changes of direction that are required to go from that space to all other spaces in the spatial system. Integration is accordingly about "syntactic" not "metric" accessibility and the expression 'depth' rather than 'distance' is employed to illustrate how far a space lies from any other. All lines in a spatial layout have certain depth values from every other line. The integration value of a line is a mathematical way of expressing the depth of a line from all other lines in the system. These values will differ significantly from one line to the next, but it is one of the most significant properties of architectural, urban, and landscape spatial configurations (Hillier & Hanson, 1984, 1998; Hillier, 1996). According to Ortega-Andeane et al. (2005), a space is "integrated" when the other spaces have a relative shallowness in relation to it. It is said that a space is "segregated" when the other spaces have a relative depth in relation to it.

Connectivity

Connectivity is another fundamental concept in space syntax theory. It refers to the degree for a node and can be defined as the number of other nodes directly connected to it. Connectivity, path length and clustering coefficient are three key measures for topological analysis of a given space. They constitute essential measures for exploring small world and scale free properties. Some research point out that integration is closely related to human spatial behavior. It was reported that a consistent relationship exists between the spatial integration measures of an urban space and observed human movement flows in it (Hillier B,, 1993). Kim and Penn (2005) reported a consistent relationship, in urban areas, between spatial cognition and syntactic integration. Specifically, a pedestrian movement rate in an outdoor space can be predicted with other syntactic results from space syntax analysis. Several researches have been conducted to show the comparisons between measured pedestrian movement rates and spatial integration (Hillier, 1996; Dawson, 2003; Raford, 2003; Read, 2001). The results endorse such relationships. This evidence suggests that space syntax methods of representation and measurement of spatial configuration of outdoor spaces could be of use in studies of planting design since it is expected to influence pedestrian movement patterns in urban parks.

3 MODELLING OUTDOOR SPACES

In the past, many methods of spatial analysis have been developed for a better understanding and modelling of real-world experience. The space syntax theory assumes that any urban area can be represented as a matrix of connected spaces, and that quantitative properties of this matrix can be measured using computer simulations. Space syntax models the spatial configurations of outdoor urban spaces by using a "connectivity graph" representation. Such a configuration of space identifies patterns that can be used to study urban layouts and human behaviours (Jaing et.al, 2002).

Visibility and visual perception are of a great significance on how people behave, appreciate and experience the environment and could be determinant factors in designing landscape spaces. Space syntax studies of pedestrian behaviour in building and open urban environments have shown that there is a consistent correspondence between the configuration of space and the patterns of usage found within it. Researchers in the space syntax community claimed, through several empirical studies (Hillier et al., 1993; Penn et al. 1998; Dysyllias & Duxbury, 2001), that human movement both pedestrian and vehicle can be predicted by local integration measure.

3.1 Visibility Graph

In order better to describe the spatial characteristics of environments, Turner et al (2001) have developed visibility graph analysis (VGA), a technique that permits the integrative analysis of several positions inside an environment by calculating the inter visibility of positions regularly distributed over the whole environment. This technique suggests additional second-order measurand, such as "clustering coefficient" and "integration" (global topology-oriented characteristics values). A further advantage of VGA is that its analysis process can be completely automated (Benedikt, 1979). There is empirical evidence that isovists capture environmental properties of space relevant for spatial behavior and experience (Turner & Penn, 1999). Desyllas and Duxbury (2001) reported that in an open and less-defined outdoor space, a significant correlation between VGA visibility and pedestrian movement than between other space syntax analysis techniques including axial map representation of space.

3.2 Pedestrian movement and agent-based model

"Agent-based" model is among the most important space syntax techniques used in simulating the pedestrian movement in an environment. Turner and Penn (2002) compared the number of visitors moving through an indoor architectural space with the number of "agents" progressing through an agent-based model of the same environment. They reported that the agents use natural movement rules through selecting a position at random from the current field of view, and therefore, moving towards it for a number of steps before redefining the destination. Turner (2003) applied similar model to an urban environment. He recommended that in the outdoor environment it is required to apply careful selection of arrival zones and duration in the system that correlate closely with pedestrian movement patterns. The significance of Turner's (2003) analytic method is that agent-based model suggests to focus on the human accessible topology as invoked through the process of inhabitation, and accordingly, simplifying the tools an architect or environmental designer requires to assess the social adequacy of a specific project. The current paper attempts to extend this assumption to the context of landscape design through assessing the impact of proposed planting layout on space inhabitation and its feedback on design proposals.

Aim of Study

This study investigates the effect of planting design of urban parks based on the assumptions of the space syntax model, especially a level of pedestrian movement, which may have extensive value in schematic planting design stage. In this context, the space syntax technique of VGA will be adopted. It offers the possibility to estimate the theoretical accessibility or "natural movement" by measuring integration. The measures of VGA are expected to assist in studying the effect of spatial configuration of the proposed trees planting in landscape space on visual fields and expected pedestrian movement. This technique is supposed to help in predicting visibility and accessibility of planting design schemes of an urban park.

4 METHODS

4.1 Study area

El-Qanater Gardens is a large rural environment 20 km north east of Greater Cairo and is considered a popular destination for middle class families for one-day picnics and outdoor recreation. Fig. (1) shows the satellite image of the study area and its immediate surrounding of El-Qanater Gardens. The area highlighted by hatched pattern is the specific area of study. The objective of development is to study the pedestrian movement within the landscape through proposing three different planting schemes. A detailed analysis of space use pattern and quantitative analysis of each planting design proposal for El-Qanater area is conducted using the VGA technique.

4.2 Measures and Techniques:

The technique of spatial analysis applied in this study is based on the analysis of the visibility polygons drawn from each of a grid of tiles covering all accessible areas (Turner et al, 2001). In order to investigate a large landscape area – Qanater Garden in Cairo - one global measure "visual integration", and one local measure "visual clustering coefficient" are used. Visual integration is similar to global integration that explains the relationship of each space to the space network as a whole. It describes the relative visibility of a point location to all the other points within the space. This measure is important because it has been correlated to "pedestrian movement gate counts" in previous studies (Batty, et al., 1998; Turner et al., 2001; Desyllas & Duxbury, 2001).

In order to investigate the landscape, the study conducted VGA using Depthmap 9.0, a computer programme to perform the visibility analysis (Turner, 2001; Turner, 2004; Mahmoud & Brown, 2009). To investigate the effect of planting pattern, a comparative method was developed includes visibility properties of the three planting design proposals in a single statistical model. In order to test the hypothesis, multiple regression and correlation analysis is conducted using SPSS software.

Three planting design proposals were developed. All three proposals used same number of trees, the tree spacing followed Gilman's (1997) recommendations. The first proposal applied rectangular array (Arnold, 1980). The second proposal used curved, free

form configuration. The third proposal applied rectangular array yet adding a central space along the main walkway to test the impact of Bell's proposition that suggests that "node" can increase balance and visual inertia of landscape space. (Bell, 2004).

Fig. (1) Aerial photograph of the study area, hatched area shows the experimental area

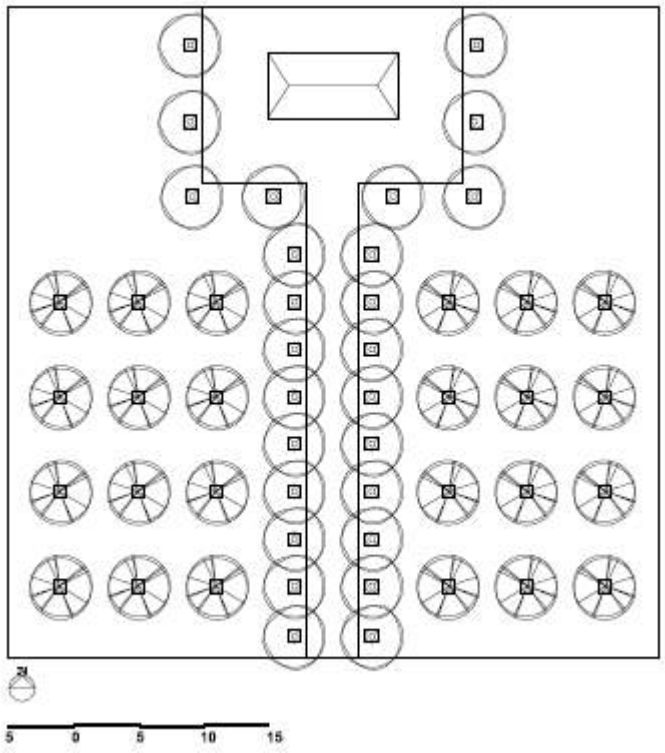


Fig. (2-a) Planting Design Proposal No. 1

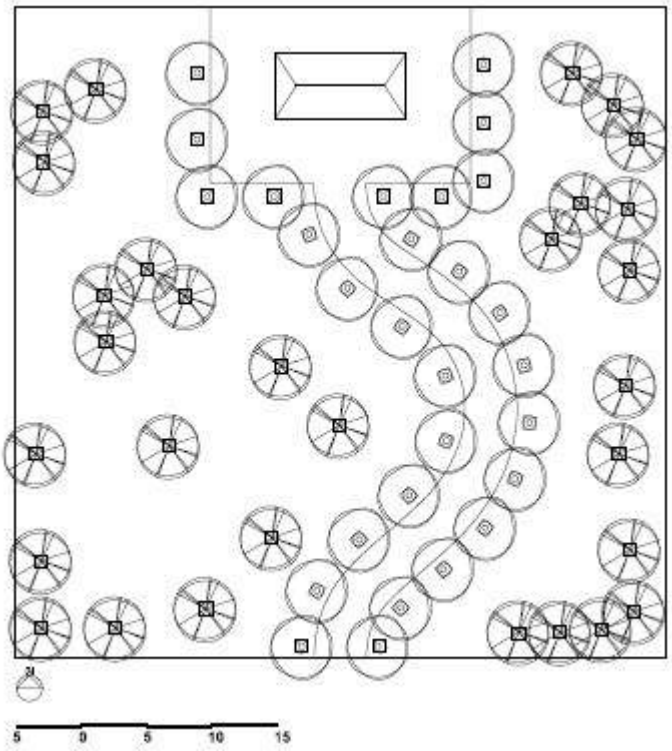


Fig. (2-b) Planting Design Proposal No. 2

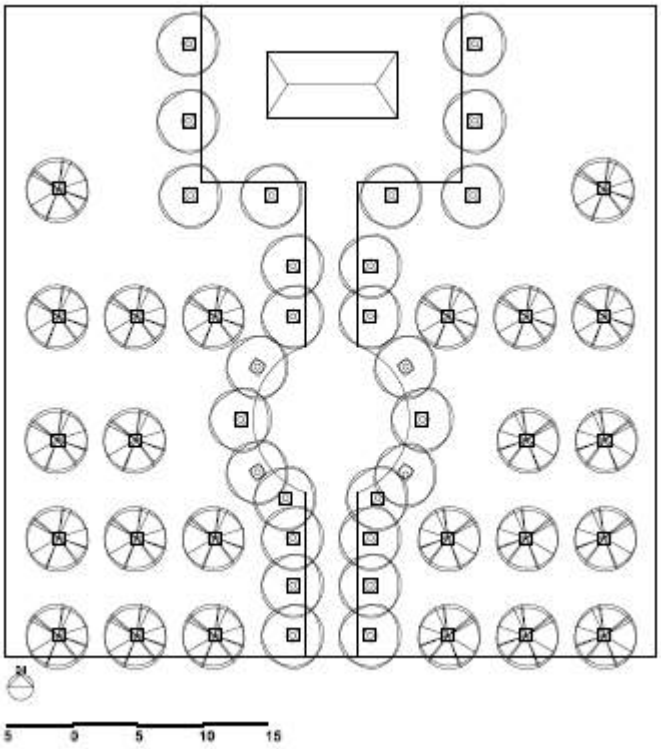


Fig. (2-c) Planting Design Proposal No. 3

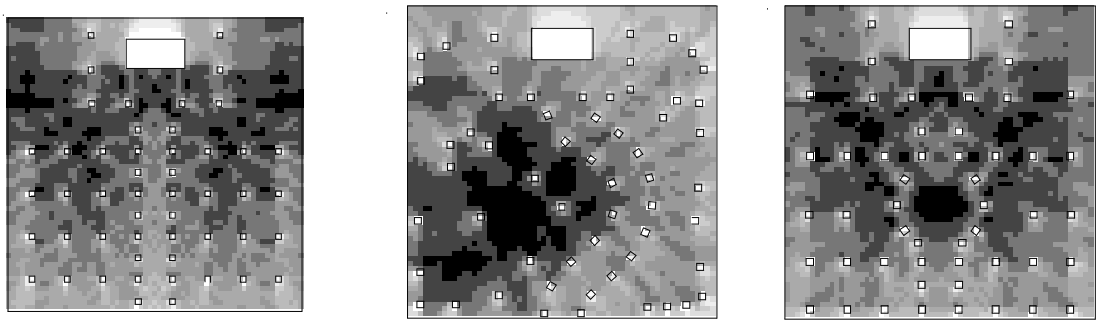
4.3 Visibility Graph Analysis of the Study Area

To identify the space syntax measures, a visibility graph of the pedestrian movement spaces of the study area is conducted using Depthmap 9.0 software. The visibility graph is constructed for all locations (nodes) specified on an evenly spaced grid of 1.50m, covering publicly visible and accessible areas. A planar isovist – visibility or accessibility field – is generated from each grid point to produce a network of all direct connections between nodes and from that, a visibility graph, analyzed to acquire patterns of configuration and visual properties (Turner, et al. 2001). The landscape has one level of publicly accessible space. The grey-scale shows from dark grey for the most integrated (and shallowest from all other nodes on average) through to white colour for the least integrated (deepest on average). The visual integration shows the pedestrian spaces within the proposed park design; and circulation spaces connecting the park spaces are picked up as the main focus of integration in the area.

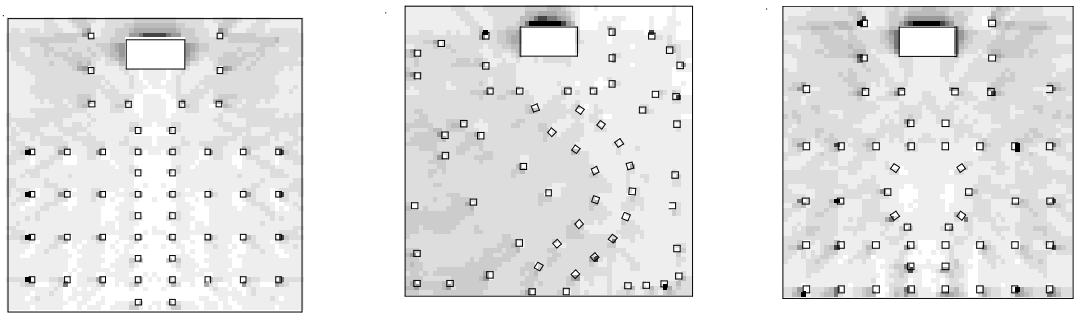
Intelligibility analysis using the correlation between connectivity and integration provides a clue of how the whole spatial configuration is clear to its users (Syntax, 2004). Since literature indicated that visual integration was found significantly correlated to movement (Parvin, et al. 2007; Desyllas & Duxbury, 2001).

Gate count analysis

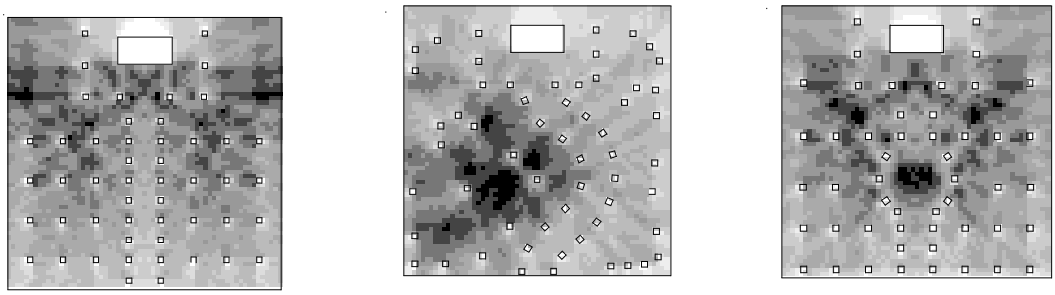
In this context, the calculations are applied on proposed environment. Theoretical gate count must be used to estimate the proposed movement pattern. Depthmap "agent" Tools was used to calculate the expected "gate count" which predicts pedestrian movement within the three proposals based on spatial configuration of trees. This tool was developed by Turner (2003) and found useful in predicting theoretical movement (Hillier & Iida, 2005; Bada & Guney, 2009).



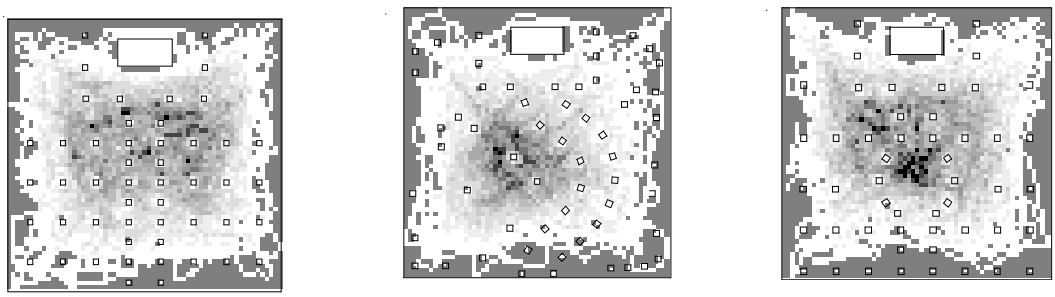
Connectivity



Clustering coefficient



Visual Integration (HH)



Gate Counts

Fig. (3) Graphical representations of VGA of three planting design proposals

To detect the between-proposals difference in space syntax measures, numerical data were exported from Depthamp in a tabulated format and inserted in SPSS software. Data of each of the design proposals were grouped into a single SPSS file. Statistical analysis of variance (ANOVA) was calculated to reveal the effect of spatial configuration on space syntax measures.

5. RESULTS

5.1 Intelligibility Analysis:

Based on the results from visibility graph analysis VGA and data at the case study area, the relationships between planting design and characteristics of spatial space and pedestrian movement are analyzed. A graphical comparison of the proposed planting design based on the results of space syntax analysis is shown in Fig. (3). VGA indicates that the highest value of global integration occurs in the second proposal which shows curved pathways (Table 1), while both first and third proposals showed nearly equal values of global integration. In the first proposal, measure of visual integration varied from 13.23 at the entrance and reached its peak of 19.57 at the space in front of the kiosk. In the second proposal, there was an emergent warmer colour in the visual integration map resulted in the left portion of the park with the highest value of visual integration (22.55) compared with the low measure at the entrance space (14.77).

The measure of clustering coefficient was mostly consistent with the pathway in the first proposal. In the second proposal, the measure of clustering coefficient decreased along the pathway starting from 0.545 at the entrance space to 0.494 at the space in front of the kiosk. In contrast, the third proposal showed a consistent increase in clustering coefficient from 0.465 at the entrance to 0.527 at the kiosk.

The measure of mean depth in the VGA is strongly correlated with visual integration in the first proposal (R^2 = 0.9710), the second proposal (R^2 = 0.9511) and the third proposal (R^2 = 0.9637). The measurement of mean depth is also strongly correlated with connectivity in the three proposals (R^2 = 0.9998, 0.9989 & 0.9997). However, there was varying strength of correlation between mean depth and clustering coefficient. The correlation was stronger in

the third proposal (R^2 = 0.2592), then the first proposal (R^2 = 0.2283). On the other hand, the correlation was weak in the second proposal (R^2 = 0.0019).

Results of intelligibility analysis (i.e., correlation between connectivity and visual integration) revealed that Correlation coefficient R^2 between the visual connectivity and visual integration of point is significant R^2= 0.9737 on the first proposal and equivalent to0.9719 in the third proposal. However, it was found least (R^2 = 0.9559,) in the second proposal. The third proposal which integrates grid planting with central curved space provided stronger correlation between visual stability (clustering coefficient) and connectivity (R^2 = 0.2535) compared with the first proposal which includes a rectangular (R^2 = 0.1146) while the second proposal showed inadequate correlation (R^2 = 0.0009).

5.2 Social Structure of Space

Literature indicated that visual integration was found significantly correlated to movement.(Parvin et al., 2007; Desyllas & Duxbury, 2001) When the 'agent' facility in Depthmap software was used to show the traces of 500 sighted agents with 170 degrees of vision thatselect a point within their field of vision randomly, move towards it three pixels (2.4 m) and repeat the process (Turner, 2003; Bada & Guney, 2009). In proposal One density of traces follows the central pathway structure to a remarkable degree, while in proposal Two it shifted to the western side of the park away from the main pathway, hence allowing further exploration of the park landscape, this is reflecting the local scaling of spaces rather than overall configuration. In the third proposal, density of traces was highest in the central space along the pathway, in summary emphasizing the focal point at the central space and reflecting the local scaling of the overall configuration.

5.3 The impact of Spatial configuration on visual fields

The effect of spatial configuration on visual fields (represented by space syntax measures) was analyzed by Analysis of Variance (NOVA) test using SPSS software (Table 1). Results revealed that spatial configuration significantly affected all visual fields ($p < 0.001$)

This finding suggests that different alignment of trees in the proposed designs, resulted in different spatial configurations, and they are expected to influence the visual fields that are experienced by users when they encounter the spaces, in reality.

Table (1) Analysis of Variance, influence of spatial configuration on syntactic measures and comparisons of mean scores.

Factor	**Levels**	**Mean**			**F-Value**			
		Connectivity	**Visual Integration H-H**	**Visual Clustering Coefficien**	**Connectivity**	**Visual Integration H-H**	**Visual Clustering Coefficien**	**Gate Count**
Spatial Configuration	Rectangular Array	1525.08	15.8304	0.5161	6.934**	43.500**	60.110**	3.278**
	Curved composition	1515.57	16.2719	0.5262				
	Central Node	1498.34	15.9128	0.5168				

** $p < 0.001$

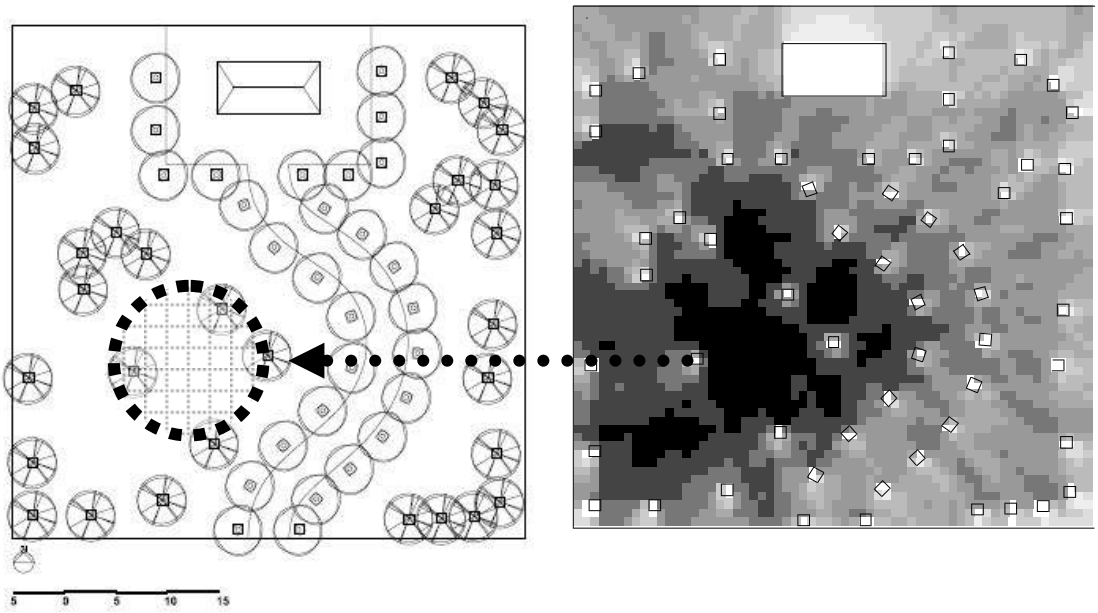


Fig. (5-a) Location of the most connected area of the design proposal

Fig. (5-b) Connectivity Analysis of 2nd proposal

6 DISCUSSION

The aim of this study was to determine how planting design can influence visual fields of three planting design proposals of an urban park using space syntax technique. The proposals were developed in three different manners. The first proposal followed symmetric, rectangular array of the trees and straight pathways; the second proposal followed the curved pathway and random pattern grid; while the third proposal applied a combination of a symmetric rectangular array and a circular space at the center of a straight pathway. All proposals used identical number and same species of trees. Although preliminary, the results show that visual fields created by the spatial configuration of trees were correlated to.

The first proposal did not show significant changes in Visual Integration analysis through Depthmap. It appears that this proposal with the straight lines and symmetric layout did not generate a variety of visual fields. In the second proposal, Visual Integration analysis shows an emergent warm colour which appears a spot resembling a main node to the western side of the pathway through the designed park. Spatial network seems to have a structure as well as a stronger integration with the global space at this portion of landscape space. This result could lead the designer to insert an attractive visual component, e.g. colorful flower composition or a piece of sculpture not higher than the eye level to take advantage of this strong value visual integration.

In the third proposal, Visual Integration analysis shows an emergent warm colour which looks a bit like a main node along the pathway through the designed park. Spatial network seems to have a structure as well as stronger integration at this space. This finding could guide the designer to add a visual element, e.g. water fountain not higher than the eye level to make use and emphasize this visual integration.

Results of intelligibility analysis. The R^2 between the visual connectivity and visual integration of point is significant R^2= 0.9737 on the first proposal and equal to0.6719 in the third proposal and was found least (R^2 = 0.9559) in the second proposal. The third proposal

which integrates grid planting with central curved space provided stronger correlation between visual stability (clustering coefficient) and connectivity ($R^2 = 0.2535$) compared with the first proposal which includes the rectangular array of plantation ($R^2 = 0.1146$) while the second proposal showed inadequate correlation ($R^2 = 0.0009$). This result revealed an area within the second proposal that showed a high degree of connectivity within the space. This outcome may guide the designer to make use of this advantage and add some design elements within this area to enhance the aesthetics of the design. Results are also suggesting that the third proposal managed to create a space system with potential for possible co-presence and interaction at the central space, while the two other proposals did not show sufficient clustering potential.

Results of 'agent' facility showed that density of traces follows the central pathway structure to a remarkable degree, while in proposal Two it shifted to the western side of the park away from the main pathway, hence allowing further exploration of the park landscape, this is reflecting the local scaling of spaces rather than overall configuration. In the third proposal, density of traces was highest in the central space along the pathway, in conclusion emphasizing the focal point at the central space and reflecting the local scaling of the overall configuration.

It appears that the curved and central node alternatives will satisfy several visual aspects, including connectivity, increased integration with global context. They also are expected to encourage social activities in larger portions of the park. On the other hand, the grid alternative will develop a rather static space where the central walkway is isolated and do not permit further exploration of the rest of the park.

According to the results, even though trees are one of the most important factors influencing preference of landscape, their spatial configurations are influencing the visual fields. This contribution will necessarily affect the pedestrian movement, hence the social structure of the landscape leading to a more sustainable design of outdoor environments. Landscape architects should not limit park planting designs to symmetric layouts since curved and free from arrangements may allow enhanced visual and social experiences of the space. Such considerations correspond to the findings of Bell (2004) that curved freeform shapes contributes to more dynamic and less boring landscape experience.

CONCLUSIONS

In conclusion, tree planting design had a significant effect on visual fields in urban parks. Though the experimental study sought to understand different issues, the results led to the general conclusion that curved free-form arrangement of trees, and to a less extent central spatial node of trees generated relatively more integrated and connected spaces within the park design. The space syntax techniques used in this study could be used to suggest further development to enhance design proposals. Careful study of visual fields embedded in the design proposal could help predicting pedestrian movement and therefore, social structure of proposed designs. This could be of great value for landscape designers in understanding how their designs will work to establish a more sustainable design of outdoor environments. In this context, space syntax approach can be used in further research to investigate other spatial parameters including tree heights, colours, texture and form.

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