MULTILEVEL PEDESTRIAN MOVEMENT:
does visibility make any difference?

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Abstract

Hong Kong’s urban built environment is characterized by high-rise compact urban form with vertical distribution of land use accessed through multilevel spatial structure. In the large mixed use urban complexes developed around the high capacity mass transit system, the multilevel spatial structure (MSS) leads to various types of movement spaces like square, atrium, corridor, podium, footbridges, sub-ways. This variety of spatial expression connected by vertical transitional space induces varied pattern of movement that in turn has implications for the extreme high-density urban living. During the initial days of Hong Kong’s urban development this MSS was designed mainly to separate the pedestrian movement from the vehicular traffic. But in course of time it has evolved as an indispensable part of the compact built environment. Using visibility graph analysis this study investigates the visual dimension of a large multilevel complex in Hong Kong. The aim is to understand the relationship between the visual accessibility and pedestrian movement of such complex spatial system. Owing to the prominence of urban design parameters like the mass transit railway (MTR), level variation, and vertical transitional spaces which are characteristic to such compact development, the study develops an integrated model that includes the isovist properties and some other variables to take into account the effects of the key urban design parameters in a single statistical model. Preliminary finding of the study reveals, notwithstanding the strong influence of the urban design parameters, visibility of multilevel spaces seems to have significant effects on the observed patterns of movement. The study suggests that the visual accessibility of the multilevel public circulation spaces may prove to be an important spatial quality to the description of pedestrian movement in other highly complex but comparable built environment.

Introduction

Hong Kong’s current urban form supports the contemporary belief in the need to reduce the physical separation of activities. Its high-density mixed-use urban development supported by the high capacity mass transit railway (MTR) system favours the creation of pedestrian friendly spatial system. The large urban complexes developed around the MTR station generally house mixed land uses and act as the functional nodes in the global urban built environment. Public

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movement spaces in the compact urban built environment designed around the major attractors and generators movement are also compact. The vertically zoned spaces connected through vertical transitional spaces like lifts, escalators, and stairs result in dynamic patterns of horizontal and vertical pedestrian movement. Although certainly not unique to Hong Kong, the proliferation of multilevel and intensely developed pedestrian-circulation systems within urbanized area is probably second to none (Marshall, 2001).

The high-rise multilevel built environment of Hong Kong is more than an artefact that impacts upon the spatial behaviour of the people. The multilayered spaces that generally accommodate extreme high density pedestrian movement and co-presence are commonly designed with spacious atriums, double-triple height circulation spaces, wider corridors, footbridges and so on. These spatial elements help the space users orient themselves towards the overall environment.

The movement spaces extending through the multilevel spaces within a complex and through its surrounding areas result in an interconnected space system with continually varied visual experiences. The visual accessibility of the movement spaces as a whole appears to be crucial to influence the way in which people experience the spaces and how they use the whole complex (Turner, et. al., 2001). However, movement in such setting is strongly biased by the local urban design parameters and their interactions (Chang and Penn, 1998) particularly presence of the MTR stations; level variation; and location and type of vertical transitional spaces (Parvin, et. al., 2006b, 2006c, 2006d).

In many instances, due to the multiplicity of visual and physical accessibility and dominance of the local urban design parameters movement in high-density vertical built environment is relatively complex compare to the low density horizontal ones (Chang and Penn, 1998). Till date little is done about the ways in which strategic architectural decision that results in particular visual and spatial patterns may have social consequences (Hillier et al., 1993). Some recent studies show, in the compact built environment accessibility to well connected mixed land use contributes to the vitality of the urban life (Coorey, and Lau, 2005; Parvin, et. al., 2006a; 2006c).

In a recent study Parvin et al. (2006e) found the visual dimension of multilevel spaces has strong influence on the way people movement around in such complex built environment. The study investigates mainly the visibility properties, however, also puts forward research direction to unveil the significance of the local urban design parameters in shaping the patterns of movement. To this end, the study focuses on the issue - to what extent visibility of this multilevel space system has its effect on the movement behaviour of people with regard to the strong effect of the local urban design parameters. It is hypothesized that in high density multilevel urban complexes people’s decision to move from a point location is largely shaped by the visual experience of the surrounding spaces they get from that location.

The underlying assumption is that this visual experience is highly biased by the design of key urban design parameters like, MTR stations; level variation; and location and type of vertical transitional spaces. The study used the visibility graph analysis (VGA) method (Turner and Penn, 1999; Turner et al., 2001) to the description of the multilevel spatial configuration. It also conducted multiple regression and correlation analysis to understand the relationship between visibility and movement so as to test the research hypothesis.
Methodology

Visibility Graph Analysis

Visibility graph analyzes the extent to which any point in a spatial system is visible from any other. VGA derived from the concept of ‘isovists’ was first introduced in spatial analysis by Tandy (1967) for analysis of landscape. However, it was Benedikt (1979) who first treated isovists fully as a method for analysis of architectural space. Benedikt and Burnham (1985) showed how perception of space is affected by various isovist attributes. The appeal of the concept is that isovists are an intuitive attractive way of thinking about a spatial environment, because they provide a description of space from inside, from the point of view of individuals, as they perceive it, interact with it, and move through it (Turner, et. al., 2001). Isovists and isovist fields are of interest to spatial analysis in that they offer a way of addressing the relationship between the viewer and their immediate spatial environment (Turner and Penn, 1999).

Visibility graph based on isovists and their spatial relationships was first used by Braaksma and Cook (1980). Hillier and Hanson (1984) introduced visibility relationships of spaces into graph analysis of buildings and urban systems. They constructed the set of longest and fewest axial lines based on visibility and accessibility which traverse all the convex spaces (convex space is the minimal set of shortest and fattest non-overlapping convex polygons covering the space) within the system. Recently Turner and Penn (Turner and Penn, 1999; Turner et al., 2001) introduced visibility graph derived from isovists – the graph of mutually visible locations in a spatial layout, where the point locations or nodes form the vertices and visual connections between them form the edges of the graph. Through this visibility graph analysis we can obtain numerous measures of both local and global spatial properties that seem likely to relate to our perception of the built environment (Turner, et. al., 2001).

Till date various authors have used visibility graph analysis to study architectural space (Batty, et. al., 1998; Turner and Penn, 1999; Tuner, 2001; Turner, et. al., 2001; Desyllas and Duxbury, 2001). Turner (2001) and Doxa (2001) applies the method to investigate way finding while Batty, et. al. (1999); Turner and Penn (1999); Turner, et. al. (2001); Desyllas and Duxbury (2001) studied the relationship of VGA to pedestrian movement. Turner and Penn published findings on the extent to which occupancy of gallery rooms by visitors could be explained by VGA with a correlation coefficient of $r^2 = 0.634$. However, regarding the application of VGA in multilevel space system, empirical research is scarce. Desyllas (1999) applies VGA to the multilevel system of the Wales Millenium Centre to the study the visual fields of the interior circulation spaces. He applied the VGA tool to link all floors of the complex so as to transform the multilevel system into a graph of one spatial system. Turner, et. al. (2001) analyzed the two-level plans of Alvar Alto’s Villa Mairea House applying same technique. More recently, Parvin et. al. (2006a; 2006b; 2006c) conducted several studies in the high-density context of Hong Kong, where they used space syntax methods and found significant correlation between the configurational properties and density of movement.

Measures and Techniques

In order to study a large multilevel urban complex - Telford gardens/Telford Plazas in Hong Kong one global measure visual integration and one local measure visual clustering coefficient are used. Visual integration is akin to global integration and describes the relative visibility of a point location to all the other points within the space. The measure is essentially a normalized version of the mean...
depth of the visibility graph and it is important because it has been found to correlate with pedestrian movement ‘gate’ counts in several architectural studies (Batty, et. al., 1998; Turner and Penn, 1999; Tuner, 2001; Turner, et. al., 2001; Desyllas and Duxbury, 2001). Clustering coefficient of a given location measures the degree of convexity or conversely multi-directionality of the isovists generated from that location. It is derived from the ratio of actual direct connections of nodes within the isovist to the maximum possible connections of the same number of nodes if they were in a convex arrangement (Watts and Strogatz, 1998, Turner, et. al., 2001). Its value varies from 0 (in case of extremely ‘spiky’ multi-directional isovists) to 1 (for perfectly convex isovists). The clustering coefficient easily appears as an important spatial indicator of the potential perceptibility of co-presence and therefore the potential to form groups or to interact (Turner, et. al., 2001).

In order to investigate the multilevel built environment the study conducted VGA linking all the levels so as to analyze the multilevel complex as one continuous system. The study use DepthMap a computer program to perform the visibility analysis. The movement data (collected from 45 observation point by applying the ‘gate’ method of observation) is taken from a previous study done by Parvin, et. al. (2006c) in the same study area where the logged movement density has been correlated with the axial integration derived from axial mapping of space syntax method. To account for the effects of urban design parameters the study develops an integrated movement model that includes both visibility properties and other variables in a single statistical model. In order to test the hypothesis multiple regression and correlation (statistical package JMP is used) analysis is conducted.

The Study Area

Telford Gardens/Telford Plazas is a large multilevel complex, with predominantly higher density; multilevel spatial system; primacy of pedestrian movement; and mainly residential development with mixture of various types of land uses. Figure 1 shows the survey map of the study area and its immediate surroundings of Telford Gardens/Telford Plazas. The area marked by dotted line is the area of observation. With a site area of 40 acres Telford Gardens/Telford Plazas complex is located in Kowloon Bay.

![Figure 1: Survey map of the study area](image)

The land uses are arranged at eight different levels and accessed with grade separated multilevel pedestrian circulation system. The residential blocks start from the podium level of Plaza I surrounding the squares (Figure 2) while office tower starts from the podium of...
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Plaza II. The complex includes two regional shopping centres, one cinema and other recreational/GIC facilities with a major transportation node of bus terminus, minibus/taxi stand and Kowloon Bay MTR station, that make it a regional attraction. MTR station is the focal point of the whole development and acts as the major generator of movement. The office towers are clustered in the southern part of the study area occupying less than one-fourth of the total site while residential/commercial/GIC and spacious open spaces occupy the rest of the study area (Figure 3). The commercial land uses are arranged in the podium in two adjacent Plazas (Plaza I has two levels and Plaza II has four levels) connected to the MTR station at the lower ground level.

Visibility Graph Analysis of the Study Area

A visibility graph of the pedestrian movement spaces of the study area is constructed by using the Depthmap software. The visibility graph is constructed for the all locations (nodes) specified on an evenly spaced grid of 0.3m, covering publicly visible and accessible areas. A planar isovist – visibility or accessibility field – is generated from each grid.

Figure 2:
Square surrounded by mixed land uses

Figure 3:
Aerial view showing location of major attractors and generators of movement

Office Towers
GIC
Squares
Residential Towers
Telford Plaza II
Telford Plaza I
MTR Station
point to produce a network of all direct connections between nodes and from that, a visibility graph, analyzed to obtain patterns of configurational and visual properties (Turner, et. al., 2001). The complex has eight levels of publicly accessible land use. Before analyzing the graph, all the levels are linked to convert the multilevel spaces into one continuous system. In order to account for the relation and continuation between interior, exterior and surrounding urban areas, the links are used as the integrating element representing the vertical transitional spaces.

Figure 4 shows the visual integration of the movement spaces. The colouring shows from red for the most integrated (and shallowest from all other nodes on average) through to blue for the least integrated (deepest on average). The visual integration shows the pedestrian spaces between the Plaza and square; space along the Boulevard; and circulation spaces connecting the Plazas are picked up as the main focus of integration in the area. While space in the MTR station, corner space of the square adjacent to the residential blocks and upper 3 levels of Plaza II appear to be visually segregated. However, compare to the interior, outdoor circulation spaces appear to have better visibility, and vertical transitional spaces are also found to have better visibility. As a whole the system shows a shallow visually integrated core lies on the major outdoor circulation spine of the complex that connects different land use at eight levels and the surrounding spaces.

The pattern of clustering coefficient shows (Figure 5) that the MTR station, and major circulation corridors of the commercial complexes are highly clustered (red for higher value through to blue for lower value) whereas the squares and the atrium spaces in the commercial
complexes offer multi-directional fields of view, suggesting a space system with potential for possible co-presence and interaction. However, the vertical transitional spaces show higher clustering coefficient that suggest less conspicuous location of the vertical circulation.

**Relation between Visual Integration and Movement: Initial Findings**

In order to reveal the pattern of movement field observations are carried out. The observation route includes a fair sample of spaces within the axial spaces representing both indoor and outdoor public circulation spaces; and major and minor pedestrian streets. The movement data is obtained using the ‘gate’ method of observation, in which a stationary observer counts all people with respect to crossing a notional gate across the survey segment. The data is gathered at five different periods of a day (8:00-9:00am; 12:00-1:00pm; 2:00-3:00pm; 5:00-6:00pm; and 7:00-8:00pm) for a total of 25 minutes (five minutes observations of five time periods through one week day) for 45 observation points. The data is expressed in terms of people per hour in the axial map of the case study area (Figure 6).

The movement data reveals the MTR station (on the ground level) acts as the main generator of movement. Major circulation takes place along the Boulevard on the upper ground level that connects the peripheral Wai Yip street with the MTR Station through the commercial plaza (Telford Plaza I); the MTR station on ground level; and the transitional space connecting Plaza II, Boulevard and Plaza I. At upper ground level the highest movement density (9774 person per hour) along the boulevard includes mostly resident people and some visitors coming from the footbridge that connects the surrounding

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**Figure 5:**

Visibility graph analysis of Telford Gardens/Telford Plazas showing visual clustering coefficient
areas across the Wai Yip street to the complex. While at ground level the higher density (5040 person per hour) in the MTR station and in the transitional spaces (around 8944 person per hour) those connect Plaza I with the MTR station includes both visitors and residents of the Telford Gardens and Plazas.

As a whole, the field observation reveals the major pedestrian flow is originated from the MTR station and ends up in the MTR station. Starting from the MTR, pedestrians move on to different levels to meet their purposes. The distribution of movement density at different level is found to be biased by two spatial elements – the location and type of vertical transitional space in relation to the MTR station; and level change. In case of transitional spaces escalators are found to be mostly use than stairs or lifts. While different density at different level is influenced by the direct connectivity to the MTR station. Apart from these, the footbridge connecting the complex to its surrounding areas also influences the movement pattern.

![Composite Axial Map showing daily mean movement rate per hour](image1)

![Location and size of movement gate derived from the movement density shown in the composite axial map](image2)
Observing the patterns of movement in relation to the patterns of visual integration, the general movement pattern seems relate to the visual integration pattern. To carry on quantitative analysis of this correspondence, the visual integration value of the observation gates are calculated. The area of the gate is selected to facilitate the comparison of visibility graph values with the observation data in the corresponding physical location represented by dots on the axial map (Figure 6). Figure 7 shows the location of gates on different floor plans of the complex. The VGA attributes of each gate are the average of the VGA attributes of the points that comprise the gate. Getting the values for the gates the visual integrations of these gates are then plotted against the logarithm of the movement density. The correlation analysis reveals a moderate correlation with a value of $r^2 = 0.43$ (Figure 8). The figure suggests considerable effect of visibility on the movement density.

RSquare = 0.425007, $Y = 4.0572066 + 1.0078662 \times X$

Figure 8: Scattergram plot showing the movement against visual integration

Figure 9: Residual by predicted Plotmap
An axial analysis of the study area conducted by Parvin, et. al. (2006c) where the axial integration was correlated with the movement density revealed a fair correlation coefficient of $r^2 = 0.19$. The study found, despite having higher very good accessibility ($r^2=0.81$) the axial analysis revealed a weak local-global interface due to lack of connectivity to the well integrated spaces. Compare to this finding the VGA reveals better ability of visual dimension to the description of movement patterns. More importantly, it shows a considerably increased level of fine scale detail, especially in the changes in integration value along the length of the streets, the increased integration at street intersections and in variations across the body of open squares (Turner, and Penn, 1999).

However, the initial finding with a moderate correlation suggests the influence of the local urban design parameters on the way visibility impacts upon the movement patterns. As found from the empirical observation and movement data, movement in the multilevel complex is highly biased by the spatial parameters like the MTR station, level variation and location of vertical transitional spaces, it is assumed that the effect of visibility on movement is also influenced by these parameters. As the VGA does not take into account the prominence of these parameters, the visual integration patterns appears to be in less conformation to the real movement patterns found from the field observation. However, from this initial findings it is hypothesized that, in high-density the multilevel spatial structure the effect of visibility space use is influenced by the multiple interacting urban design parameters. Furthermore, the moderate correlation between visual integration and observed movement patterns suggests that, to the description of multilevel movement visibility analysis needs to be calibrated taking the multiple interacting effects of these urban design variables into account.

**Multilevel Movement: Towards an Integrated Approach**

To include the interacting effect of the urban design parameters in the visibility analysis of movement patterns three urban design variables are derived for each of the parameters by adjusting the visual integration values of the observation gates.

**Derivation of Variables for the Urban Design Parameters**

*MTR station (G):* The variables $G$ is derived for each of the observation gates lies on the major routes that directly connect the MTR stations to the complex and the surrounding areas. The value is derived by dividing the associated visual integration value with a value of 0.7. The value is set at 0.7 after testing a range of values from 0 to 1, as it produces the maximum possible correlation after adjustment.

*Level variation (L):* From direct field observation in the case study areas it is found that floor level with direct connection to MTR entry/exist has higher level of pedestrian movement compare to the level that is connected to the MTR indirectly or through changes of vertical or horizontal direction. In light of the variation of observed movement density in the observation gates at different levels these changes of movement rate are expressed numerically with a range of value from -1 to 4 depending on ease of accessibility from the MTR station. The variable $L$ is then derived by deducting the value from the corresponding visual integration value of each gate at different level.

*Vertical transition (T):* In the multilevel complex the pedestrian movement is not only affected by the location of the vertical transitional spaces but also their configuration, which are defined objectively by three elements: type of vista; transition type (escalator, lift, stair); and connection with the main circulation spine. Each of the selected space is weighted with either 1 for positive effect or 0 for
negative effect according to the degree of obviousness of the elements. The variable T is then derived by deducting the value from the corresponding visual integration value of the gate situated in the transitional space.

**The Integrated Model**

An integrated movement model is developed that includes the visual integration and other variables in a single statistical model. The Multiple Regression technique is used in this study to find out the nature and strength of relationship between the independent and dependent variables. This technique is called estimation by least square (Sall, et al. 2001). In the model density of movement is taken as the response (or dependent variable) (Y) and visual integration (V), and three other urban design variables (G, L, and T) are taken as the regressors (independent variables) (X).

The integrated movement model is:

\[ M = b_0 + b_1V + b_2G + b_3L + b_4T + e \]

Where, M is density of movement, V is visual integration (average), G is the adjusted visual integration value for the spaces directly connected to the MTR station, L is the adjusted visual integration value for level variation in relation to the MTR station, and T is the adjusted visual integration value for transitional spaces in relation to the MTR station and level variation.

**Results and Findings**

The model produces a significant RSquare (0.55) that suggests that visual integration becomes a significant regressor while the effects of urban design parameters are included in the analysis. The result (summary of fit, Table 1) shows that the model accounted for 55% of the variation around the mean (RSquare). The analysis of variance (ANOVA) shows the overall regression of Y on the independent variables is significant. The F ratio of the whole model (11.7177) (Table 2) is highly significant (p<0.0001), indicating that the model does fit better than simply the mean. It shows that at the 0.05 level of significance F is considerably higher than 2.8. Also the residual by predicted plot (Figure 9) does not show any pattern; therefore the regression model is a good one to infer the density of movement by visual integration, and the variables account for MTR station, level variation and vertical transitional spaces.

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Apart from this, an analysis of significance (effect test) shows (Figure 10) among the individual variables visual integration’s (V) contribution to the model is significant compare to that of the urban design variables. Other than visual integration MTR is found to have greater influence on the density of movement. To understand the interaction among the variables the study derives a set of combined variables. The combined variables are – [(V/G)-L], [(V/G)-T], and [(V/G)-L-T].

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**Table 1:**
Summary of fit

**Table 2:**
Analysis of Variance
The analysis of significance of the combined variables shows \( [V/G] - L - T \) that consists of visual integration (V), value for MTR (G), value for level variation (L), and value for the transitional space has the highest contribution among all the variables (Figure 11).

**Correlation Analysis**

Analysis of correlation between the movement density and the combined variable \( [V/G] - L - T \) shows (Figure 12) dramatic increase in the correlation coefficient \( r^2 = 0.69 \) compare to the correlation \( r^2 = 0.43 \) between movement density and visual integration. However, the findings both from regression and correlation analysis suggest that the pattern of movement is better predicted by the VGA while the effects of the key urban design parameters are taken into account which confirms the research hypothesis.

**Discussion and Conclusions**

The study has investigated the significance of visual dimension of multilevel spaces in shaping the movement patterns with regard to the multiple interacting effects of key local urban design parameters. The study outcome is twofold - firstly, the case study reported here shows that the visibility graph analysis offers one possibility to research into multilevel urban built environment whose spatial form would otherwise escape conventional representation. Secondly, the study brings light into the interplay between the isovist properties and the major urban design parameters to the description of movement patterns in high-density built environment like Hong Kong. However, the findings and their implications can be summarised in the following brief inferences.

- Well integrated visual field including the MTR stations and major horizontal and vertical circulation spaces at different levels contributes to improved efficiency of multilevel circulation system.
• Higher visual integration of public circulation spaces especially the strategic locations like MTR station, lifts or escalators, transitional spaces between different land uses, footbridges, atrium; and opens spaces/squares leads to better integrated spatial structure within the complex.

• The visual integration core including the spaces directly connecting the MTR stations to the complex and to the surrounding spaces can accommodate the higher density of movement so as to result in a shallow and well connected circulation spine.

• The pattern of clustering coefficient with multi-directional fields of view improves possibility of higher movement and co-presence of space users. In an extreme high-density context like Hong Kong achieving this visual quality in public spaces may have long term positive social-behavioural implications on the city dwellers.

• Multidirectional visual field in multilevel single spaces like atrium, or free flowing double-triple or multiple height open spaces helps the users having better spatial perception and orientation in the complex built environment.

In light of these study outcomes strategic design guidelines can be drawn towards an efficient layout of multilevel pedestrian spaces, however, important research issues with regard to the compact built environment of Hong Kong are still there to address. A series of recent papers (Hillier, et. al., 1996; Hillier et al, 1993; Hillier, 2004; Hillier, and Iida, 2005) have outlined a generic process by which spatial configurations, through their effect on movement, first shape, and then are shaped by, land-use patterns and densities. As found in this study, notwithstanding the powerful and independent effect of visual dimension on use of space, in the context of similar high-density multilevel development like Hong Kong, the urban design parameters like MTR, grade separation, location and type of vertical transitional spaces, have significant effects on the patterns of movement. Nonetheless, prominence of these urban and design parameters are dependant on the urban design attributes such as the density variables like building density, population density, building height profile; degree of mix of land use; surrounding areas spatial pattern and so on which might have considerable influence on the interacting effects on the overall patterns of movement. Further research is needed to unveil the influence of these density attributes on the degree and extent to which visibility of multilevel space system can have its effect on the patterns of pedestrian movement.

References
Batty, M., Cornoy, R., et. al., 1998, The Virtual Tate, CASA, London.


i. It is a global measure that explains the relationship of each space to the space network as a whole represented by axial map.

ii. For gate method of observation refer to Parvin, et. al., 2006.

iii. For detail of space syntax methods and techniques refer to Hillier and Hanson, 1984.


v. In terms of residential density, building density, and population density the study areas are High Density residential Zone (R1), with maximum domestic plot ratio of 8 and population density of around 2500 person per hectare.

vi. The area of the gate shown in Figure 7 is a fairly selected region of points around the gate where the observation date is recorded (Turner, 2003).

vii. Correlation between depth and integration.

viii. The estimated model is:  

\[ y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + e \]

Where, \( y \) is the response (density of movement); \( x_1, x_2, x_3, x_4 \) are the regressors \( (x_1 = V, x_2 = G, x_3 = L, \text{ and } x_4 = T) \); \( b_0, b_1, b_2, b_3 \), and \( b_4 \) are the parameter estimates and \( e \) is the residual.