Exploring Multi-layered Hyper Dense Urban Environments through Spatial Analysis

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Abstract
With ever increasing pressure on space and natural resources, the planning and design of hyper dense urban environments may become a reality for many city authorities. As a result, studies in hyper dense environments proves valuable for practitioner and academics a like. Space syntax is a spatial analysis that studies the relationship between spatial configuration and pedestrian behaviour in urban environment. The analysis has been described to only partially capture the distribution of movement in areas with heterogenous distribution of population density. Henceforth, the study of hyper dense urban environments raises a number of challenges for existing space syntax methodologies. This paper tests the degree to which public realm simulations are able to decode the distribution of pedestrian movements in hyper dense environments, namely in a district of central Hong Kong. Beyond this the paper explores additional urban design parameters for assessing multi layers environments towards more accurate representations. The paper finds that while two dimensional spatial modelling techniques provide an intuitive description of spatial structure in such environments, certain techniques accounting for other urban design parameters are needed to aid existing methodologies in deconstructing formal structure at a higher resolution and provide solid correlations with indicators such as pedestrian movement distributions. The results of the study was positive with the space syntax measures achieving a positive correlation (r-square=0.48). In the end, the factor of proximity to number of plots(morphological differences) and influences on elevation(elevation differences) were concluded to have strong combinatorial influences on pedestrian movement distribution in this area of the city. These additional parameters were tested as binary factors (0 and 1) in a multiple variate correlation that gave a strong correlation. (r-square =0.80) The evidence suggests further research is needed to address the degree to which these additional factors can have on the patterns of pedestrian movement distribution as well as testing the methodology in other parts of the city.

1.1 Introduction

Space syntax, started in University College of London, is a spatial analysis that studies the relationship between spatial configuration and pedestrian behaviour in urban environment. (Hillier and Hanson, 1984) The method has been well tested where it theorized spatial configuration being the generator of pedestrian movements. (Hillier, 1984) The theory suggests the angularity from all spaces to all other spaces influences the distribution of pedestrian movements. (Iida and Hillier, 2005) The method has been tested in a number of European cities with relatively high accuracy. However, the method have had less empirical evidence in cities with higher variance of density and absolute density. Space syntax has also been described to only partially capture the distribution of movement in areas with heterogenous distribution of population density.(Ståhle and Marcus, 2006)

Henceforth, the paper will tests the degree to which public realm simulations are able to describe the distribution of pedestrian movements in hyper dense environments, namely in a district of central Hong Kong. The results of the study was positive with the space syntax measures achieving a positive correlation(r-square=0.48). Various studies suggests, local urban design parameters can have influences in the distribution of movement.(Penn and Chang, 1998) As a result, combinations of additional urban design factors were hypothesize to have influence on the movement distribution. In the end, the factor of proximity to number of plots(morphological differences) and influences on elevation(elevation differences) were concluded to have strong combinatorial influences on pedestrian movement distribution in this area of the city. These additional parameters were tested as binary factors(0 and 1) in a multiple variate correlation that gave a strong correlation.(r-square =0.80) The relation suggests more rigourous methodology in these directions could be researched for further application.

1.2 Methodology

The method being employed is a traditional spatial analysis that relates pedestrian movement distribution and spatial measures computed from Space Syntax analysis. (Iida and hiller,2005) The study encompasses a detail pedestrian network of the study area, a pedestrian movement survey conducted during two time periods of the day and statistical correlation that links pedestrian distributions and space syntax spatial measures. To continue, additional urban design parameters were studied and combined with the spatial measure to further understand the spatial logic and structure of the area.

1.3 Location

Hong Kong is a special administrative region within the People's Republic of China. It is located in the south of Guangdong province bordered by the South China Sea to the south and Shenzhen Special Economic Zone to the north. The city region is separated into three distinct areas namely Hong Kong Island, Kowloon peninsula and New Territories. The area studied is Central district located on Hong Kong Island. Central district is one of the oldest district in the city since the occupation of Great Britain after the first opium war. It has also been its financial, political and judiciary heart for many years. The district is an urban collage that has evolved and constantly rebuilt over the course of the past 160 years that has interwoven intrinsically. The rationale to the selection of the district, is the district varied typologies of high density built form coupled with an extensive multiple level urban environment. The objective of the study is to test the relevance of the Space Syntax method but also as a tool to understand the spatial culture and characteristics of the district. The following diagram illustrates, variance of urban morphology and density in the area.

Figure 1
Map of Central District in Hong Kong

2.0 Spatial survey

In order to understand the complex pedestrian network, a high resolution spatial model was employed instead of the low resolution axial model. The methodology maps out a more detail description of pedestrian urban environment including multi-level urban environment.

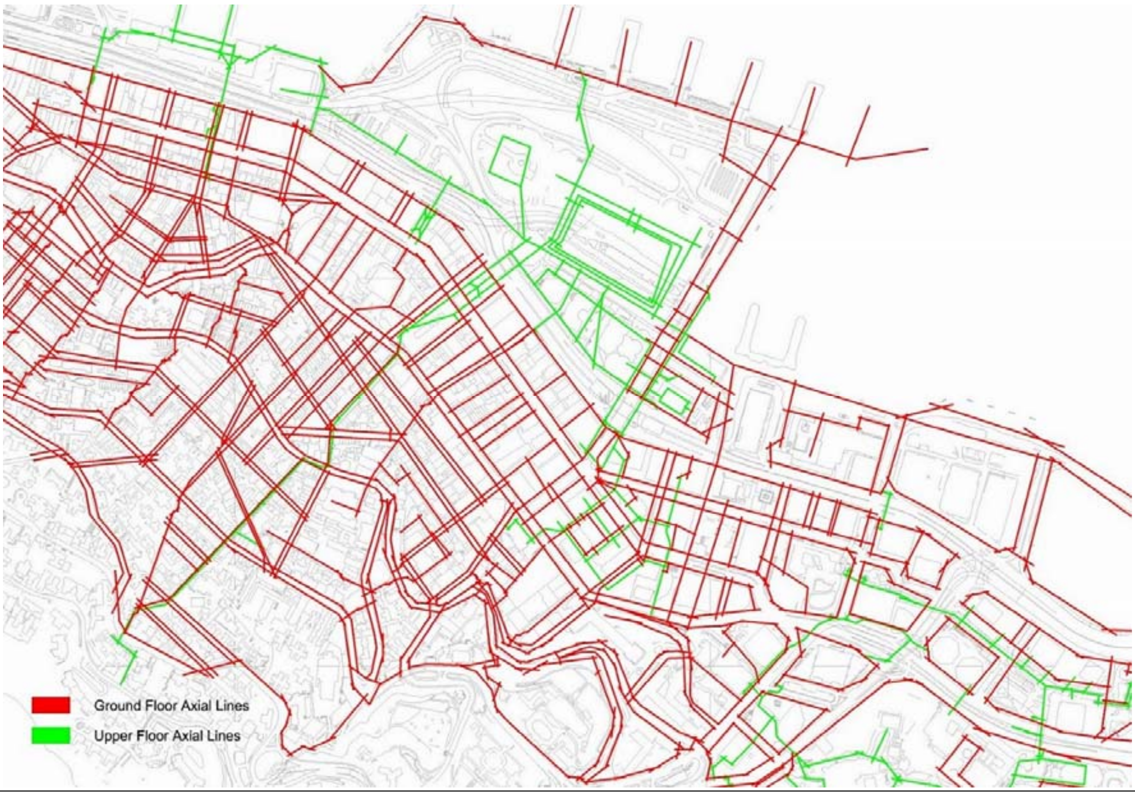


Figure 2

High resolution axial mapping of Central district in Hong Kong

An assumption was made where locations with stair ways or access to second floors was given an extra change of direction to reflect the topological step or angular cost required to reach the next space. The traditional Space Syntax analysis was employed in Depthmap 8.0(Turner, 2000-2009) , the software developed at University College London. The software computed both the spatial between-ness(through-movement) and spatial closeness (to-movement) over a number of network distances (R400m, R800m, R1200m, R1600m, RN-metre) which can be weighted by the length of segments.

2.1 Pedestrian survey

Id	Pm_hourly	Am_hourly	Mov_avg
13A	1,440	1,248	1,344
13B	168	144	156
14A	2,496	1,512	2,004
14B	2,664	2,112	2,388
15A	2,544	1,776	2,160
15B	4,320	1,536	2,928
16	1,608	864	1,236
17A	1,032	504	768
17B	1,104	408	756
18A	816	504	660
18B	792	600	696
19	960	408	684
20A	1,920	1,608	1,764
20B	912	720	816
21A	2,928	2,352	2,640
21B	1,920	1,008	1,464
22	2,160	1,488	1,824
23A	1,032	528	780
23B	312	96	204
24A	1,776	1,920	1,848
24B	1,296	1,152	1,224
25A	2,664	816	936
25B	1,056	288	672
26A	336	144	240
26B	1,032	336	684
27A	2,400	1,488	1,944
27B	312	240	276
27B	312	240	276
28A	1,008	504	756
28B	1,464	1,248	1,356
29B	1,032	432	732
30A	1,104	840	972
30B	840	240	540
31A	1,224	1,200	1,212
31B	2,400	3,408	2,904
32A	3,360	1,728	2,544
32B	3,048	2,664	2,856

Table 1

Pedestrian observations table (37 pedestrian gates)

After this, a pedestrian movement survey was carried forward in 37 gate locations over two time periods (AM/PM) by two individuals. There was one gate exclusion beside the old central police station which is currently a site under redevelopment planning. The result from the pedestrian observation survey is compiled with the figures translated to average all day hourly movement rates in all the survey locations.

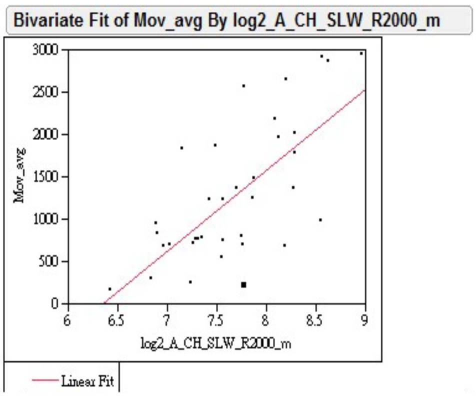
3.1 Early pedestrian correlation

The initial spatial analysis includes a bi-variate correlation to observe the relationship between spatial configuration and pedestrian behaviour. The following diagram shows the local(R2000) through movement potential of the study area and average pedestrian movement.

Figure 3

The spatial betweenness of all space up to the network distance of 2000metres weighted by segment length(LogChR2000SLW) combined with all day average hourly movement

The initial analysis gave a positive correlation (R-square at 48%) between the pedestrian movement and the spatial measure of Log Choice R2000SLW.



Linear Fit

Mov_avg = -6075.136 + 956.54291*log2_A_CH_SLW_R2000_m

Summary of Fit

RSquare	0.478839
RSquare Adj	0.463046
Root Mean Square Error	597.1961
Mean of Response	1273.714
Observations (or Sum Wgts)	35

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	10813471	10813471	30.3201
Error	33	11769226	356643.21	Prob > F
C. Total	34	22582697		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-6075.136	1338.42	-4.54	<.0001*
log2_A_CH_SLW_R2000_m	956.54291	173.7156	5.51	<.0001*

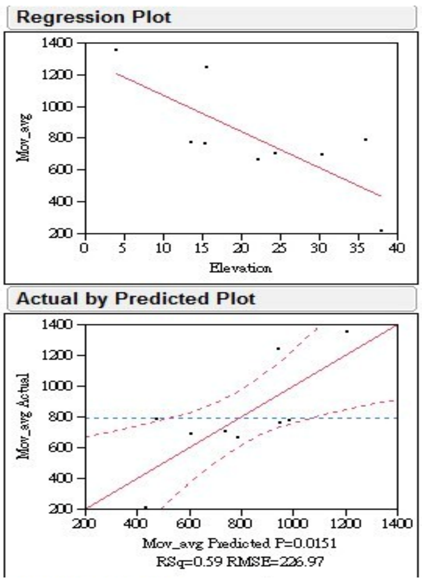
Table 2

Scatter plot diagram between Log Choice R2000SLW with all gates of average Pedestrian movement. (R-square 48%)

This measure calculates the betweenness up to the network distance of 2000metres weighted by the length of each segments. This positive response illustrate a relationship between spatial configuration and pedestrian movement. This response also shows the validity of employing a high resolution spatial model within a complex urban environments. As well, the response illustrates the existence of additional urban design factors that influences pedestrian movement distribution in the area. The analysis provides evidence to study these additional factors.

3.2 Additional Factors Elevational difference

One factor studied is elevation differences between the gates. Despite, the high resolution spatial model being able to take into consideration some vertical changes in direction from escalators to stairs, there is an overall vertical height inclination towards the southwest of the district that the spatial model did not considered. Henceforth, one hypothesis is that the higher the total elevation differences of the pedestrian gate is away from the main connector of the city, the lesser the pedestrian movement. The gates within close proximity to pedestrian esclators are excluded due to the decrease of elevation effect. As well, these gates have been take into consideration through the high resolution spatial modelling. The elevation affected gates are defined as all gates that are more than 10 metres network distances away from all pedestrian escalators or elevator that has an elevation of over 5 metre above the level of the main spatial connectors of the city(Queens Road Central). The scatter plot gave an Rsquare of 60% for these eight gates.



Summary of Fit

RSquare	0.593864
RSquare Adj	0.535845
Root Mean Square Error	226.9706
Mean of Response	792
Observations (or Sum Wgts)	9

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	527294.49	527294	10.2356
Error	7	360609.51	51516	Prob > F
C. Total	8	887904.00		0.0151*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1300.2575	175.9599	7.39	0.0002*
Elevation	-22.90251	7.158565	-3.20	0.0151*

Table 3

Scatter plot diagram between Elevation with elevation influenced gates of average pedestrian movement. (R-square 59%)

Despite the small sample in the bi-variate correlation, the positive response suggest that elevation differences is a factor that influences the distribution of pedestrian movement in the area. In addition, gates in proximity to pedestrian escalator have higher movement levels suggest the cost of movement associated with elevation differences diminishes through the escalator. As a result, the affected gates was attributed a dummy factor of 1 within the multiple variable correlation as factors that are affected by elevation differences. Since the objective of the study is to identify these additional factors, binary variables was used in computing the multi-variate correlation. Method with stronger rigourity shall be explored in future studies to understand the degree the factor influences the distribution of pedestrian movement in the area.

3.3 Additional Factors Differences in Urban Morphology

The second factor studied is differences in urban morphology between the location of the gates. The plan of the district suggests two different types of hyper dense urban morphology in the area that is reflecting the different periods of reclamation and development in the city. One notable morphological differences between the areas can be distinguished by the sizes of plots. Newer areas has larger plots whilst older areas has smaller plots. Henceforth, proximity to plots density would be specifically studied. The hypothesis states that the gates nearer to lower plot counts would have a different spatial culture to the gates nearer to higher plot counts. To test, a 50 metre buffer was attributed to each of the gates where gates that has less than 5 plots within the buffer zone is considered a large plot urban area and the gates with more than 5 plots within the buffer zone was considered a small plot urban area.

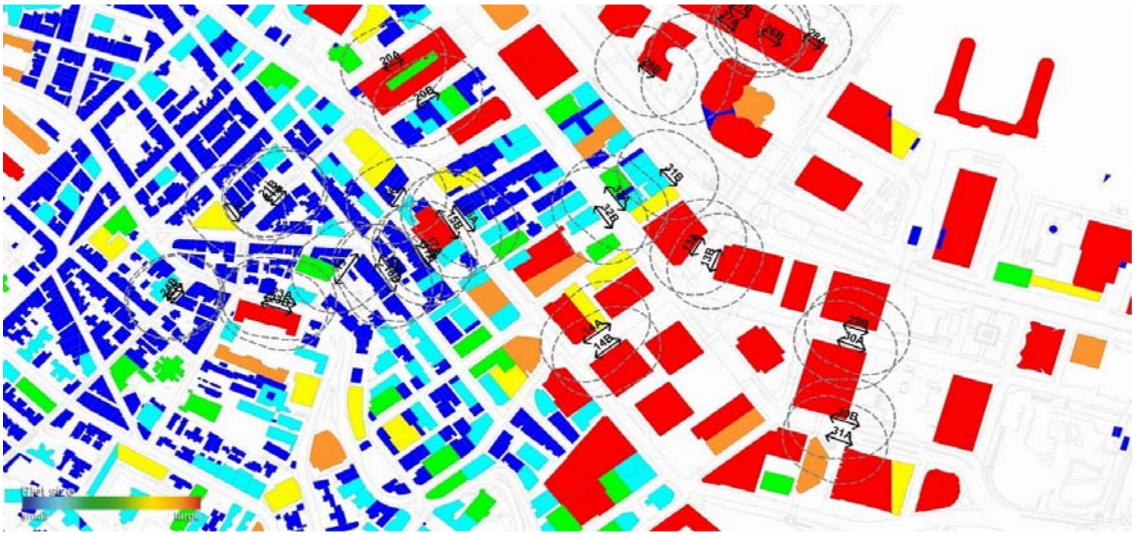
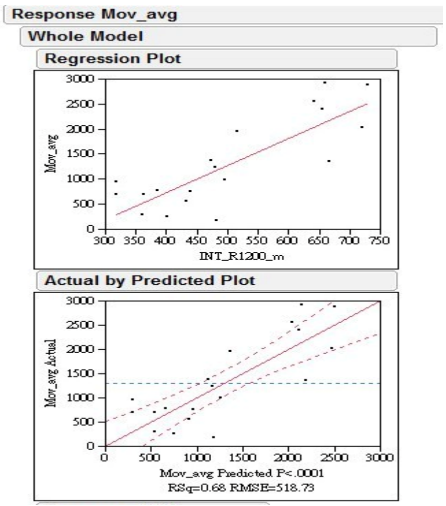


Figure 4
Plots size distribution of the district illustrating the differences in urban morphology from large plots dominated area in the east and northeast and small plots dominated area in the west and southwest.

These two categories of urban morphology was than analysed seperately with the space syntax measures. The gates in proximity to larger plots is more closely related to the spatial measure of spatial closeness(integration) up to the network distance of 1200m.(R-square 69%)



Summary of Fit

RSquare	0.680948
RSquare Adj	0.66218
Root Mean Square Error	518.7338
Mean of Response	1290.316
Observations (or Sum Wgts)	19

Analysis of Variance

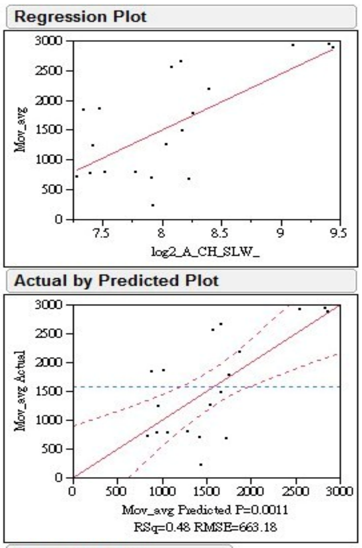
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	9763169	9763169	36.2829
Error	17	4574441	269085	Prob > F
C. Total	18	14337610		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-1415.421	464.6917	-3.05	0.0073*
INT_R1200_m	5.3878936	0.894475	6.02	<.0001*

Table 4 *Scatter plot diagram between Integration R1200 with gates of large plots dominated average pedestrian movement (R-square 69%)*

The gates in proximity to smaller plots is more closely related to the spatial measure of spatial betweenness(choice) over all spaces within the network.(R-square 48%)



Summary of Fit

RSquare	0.477632
RSquare Adj	0.446904
Root Mean Square Error	663.1843
Mean of Response	1575.789
Observations (or Sum Wgts)	19

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	6836498	6836498	15.5441
Error	17	7476829	439813	Prob > F
C. Total	18	14313327		0.0011*

Parameter Estimates

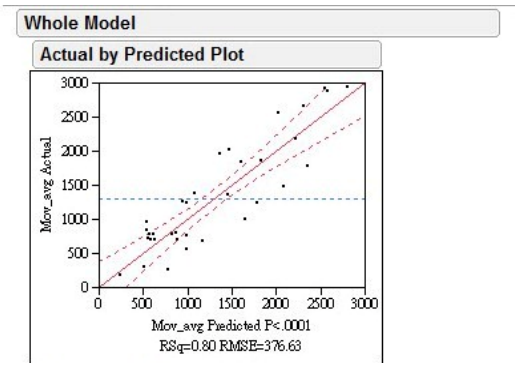
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-5996.538	1926.66	-3.11	0.0063*
log2_A_CH_SLW_	937.9765	237.9082	3.94	0.0011*

Table 5

Scatter plot diagram between Log Choice RN with gates of small plots dominated average pedestrian movement (R-square 48%)

These positive responses suggest there are two different spatial culture co-existing in the district that is affected by different influences(to-movement and through-movement) and that the proximity to density of plots have influences on the distribution of movement. The gates that is close to large plot urban area is attributed a dummy factor of 1 and the gates that is close to small plots urban area is attributed a dummy factor of 0 within the multi-variate correlation. Since the objective of the study is to identify these additional factors, binary factor was used in computing the multi-variate correlation. Method with stronger rigourity shall be explored in future studies to understand the degree these factors influence the distribution of pedestrian movement in the area.. One such method is place syntax analysis developed at KTH (Royal institute of Technology) in Stockholm, Sweden which calculates the number of places (plots) that is accessible to a place through an axial line. (Ståhle, 2006) Place syntax, which connects spatial configuration and spatial distribution of densities, would allow for research in areas with heterogenous distribution of density as illustrated in the district of central.

3.4 Multivariate correlation Spatial factors - Elevational difference - Urban Morphology



Summary of Fit

RSquare	0.801184
RSquare Adj	0.781303
Root Mean Square Error	376.6344
Mean of Response	1305.176
Observations (or Sum Wgts)	34

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	17149149	5716383	40.2978
Error	30	4255604	141853	Prob > F
C. Total	33	21404753		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-3123.607	986.8243	-3.17	0.0035*
log2_A_CH_SLW_R2000_m	661.71293	121.9369	5.43	<.0001*
Elevation_indicator	-1133.586	188.5473	-6.01	<.0001*
morphology_indicator	-891.9497	164.0164	-5.44	<.0001*

Table 6

Scatter plot diagram between Log Choice R2000SLW+elevation differences+morphology differences with all gates of average pedestrian movement. (R-square 80%)

Note: One gate has been excluded from all the correlation analysis beside the central police station. The site is currently disuse and will be redevelop in the near future.

To test the validity of these additional factors, a multi-variate correlation between pedestrian movement distribution and the three contributing factors of spatial measures, elevation differences and urban morphology differences were tested. The final result of this multi-variate correlation was very positive. (R-square of 80%) The influences of the three factors which is described in the T-value suggests relatively equal influences between these three factors.(T-value is within the range of -3.00 to +3.00) This suggests that all three variables; namely spatial configuration, elevational difference and differences in urban morphology all contributes to movement distribution with relatively equal and combinatorial influence.

4.0 Conclusion

The paper finds that while two dimensional spatial modelling techniques provide a positive description of spatial structure in such environments, certain techniques accounting for other urban design parameters are needed to aid existing methodologies in deconstructing formal structure at a higher resolution and provide solid correlations with indicators such as pedestrian movement distributions. The factor of proximity to number of plots(morphological differences) and influences on elevation(elevation differences) were concluded to have strong combinatorial influences on pedestrian movement distribution in this area of the city. These additional parameters were tested as binary factors(0 and 1) in a multiple variate correlation that gave a strong correlation.(r-square =0.80) The evidence suggests further research is needed to address the degree to which these additional factors can have on the patterns of pedestrian distribution as well as testing the methodology in other parts of the city.

References

Conzen, M. R. G., 1981, The urban landscape: historical development and management, (ed.) (1981), London: Academic Press.

Hillier, B., Penn, A., Hanson, J., Grajewski, T., Xu ,T. 1993 Natural movement: or configuration and attraction in urban pedestrian movement in Environmental and Planning B: Planning and Design, 1993, volume 20, pages 29-66

Hillier, B. Hanson, J., 1984, The social logic of space, London, Cambridge University Press.

Hillier,B. 1996, Space is the machine, London, Cambridge University Press.

Hiller, B. and S.Iida, 2005 "Network and Psychological Effects in Urban Movement, " in Cohn, A.G. ad D.M.Mark(eds.), Proceedings of Spatial Information Theory: International Conference. (Ellicottsville, : COSIT, 2005)

Hillier, B. 2008 "The new science of space and the art of space: Towards a space-led paradigm for researching and Designing the city in Haas, T. New Urbanism and Beyond Designing Cities for the future(Rizzoli International publication, 2008) 30 - 39

Jiang, B., Claremunt, C.2002 Integration of space syntax into GIS: new perspectives for urban morphology, Transactions in GIS 6(2002) 295 - 309

Parvin, A., Ye, A., Beisi, J., 2008,Effect of visibility on multilevel movement: a study of the high-density compact built environment in Hong Kong URBAN DESIGN International (2008) 13, 169–181. doi:10.1057/udi.2008.22

Marcus, L. 2008, Spatial captial and How to measure it: An outline of an analytical theory of urban form in Haas, T. New Urbanism and Beyond Designing Cities for the future(Rizzoli International publication, 2008) 135 - 139

Stahle, A., Marcus, L. and Karlstrom, A. 2006, "Place Syntax - Accessibility wiht Axial lines," Environment and Planning B: Planning and Design submitted 2006.

Turner, A.(2000-2009) Depthmap 8.0: programmed by Alastair Turner and developed at the VR centre for the Built environment Barlett School of Graduate studies University College London, Gower Street, London, WC1E6B