Quantifying Urban Visibility Using 3D Space Syntax

C. Schroder, W. Mackaness, F.. Reitsma

The Institute of Geography, The University of Edinburgh, Drummond St, Edinburgh EH8 9XP
Telephone: (44) 131 6508163
Fax: (44) 131 6502524
william.mackaness@ed.ac.uk

1. Context

A city is a container of activities – a palimpsest of inter-related processes operating at various spatio-temporal scales. Examples of these social processes include pedestrian movement (Hillier et al, 1993; Jiang, 1999), crime (Hillier and Sahbaz, 2005; Nubani and Wineman, 2005), and social deprivation (Vaughan et al., 2005). In various ways these processes are affected by the architectural space and the built form. Furthermore these structures affect other key activities such as way-finding processes in complex built environments (Peponis et al., 1990), vehicle driver movements (Penn et al., 1998), and environmental processes such as traffic pollution (Penn and Croxford, 1997). It is not surprising then that much effort has been devoted to how we can model the various characteristics of the urban environment, in order to improve their design, and to understand the interdependencies and interactions between the built world and its occupiers. Hillier and Hanson, in the early 80s, developed the idea of space syntax to help simulate the likely effects of their designs on the surrounding area (Hillier and Hanson, 1984). Space syntax is defined as 'a family of techniques for representing and analysing spatial layout of all kinds' (Hillier 1999, 165), and its aim is to develop strategies of descriptions for configured, inhabited spaces in such a way that their underlying social logic can be recognised. The primary focus of the current literature examines urban spaces in reference to two dimensions (2D). Ratti (2005) suggests that using three dimensions would be the best means to describe a city enabling a more complete analysis of urban texture, importantly taking into account the height of buildings. Asami et al. (2002) stated that there is an urgent need for new space syntax methods that can capture and take into account the curvature of the surface of the space. The inclusion of the third dimension, either as the height of buildings or as the change in the topography of the surface, would allow researchers to more accurately depict the urban environment as an individual located in the setting sees it and to model other human and environmental processes and provide a vivid and more complete description of urban space. In this paper we describe the methodology and implementation of a 3D spatial syntax with a specific aim of creating a surface of visibility that summarises the varying degree of visibility among a set of buildings. We provide a literature review, explanation of the methodology, its implementation and evaluation for a small subset of buildings from the central business district of Wellington, New Zealand.

2. Space Syntax in Two Dimensions

The general idea underlying space syntax techniques is that space can be broken into components and analysed in the form of maps and graphs that describe the relative connectivity of those spaces. “In the studies of cities, one representation and one type of measure has proved more consistently fruitful than others: the representation of urban spaces as a matrix of the ‘longest and fewest’ lines – the axial map” (Hillier, 1999, p. 169). The axial map depicts the minimal set of axial lines required to completely connect areas within the space whilst also ensuring that the space is entirely surveiled (Turner et al. 2005). It therefore shows the least number of axial lines required to cover a layout and their connections. Figure 1 is an example 2D axial map for the French town of Gassin.

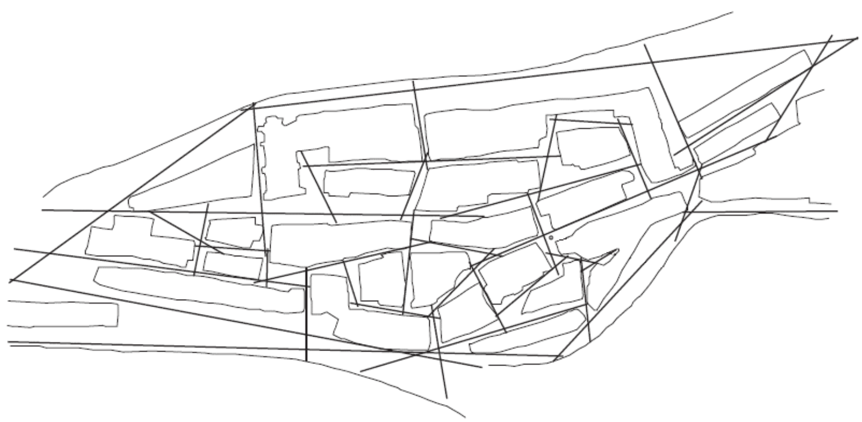


Figure 1. 2D Axial Map for the French town of Gassin (Hillier and Hanson, 1984, p. 91).

3. Space Syntax in Three Dimensions

The methodology focuses on the extension of the axial map into simple 3D block space (taking into account the height of buildings, but assuming a flat underlying elevation). The development of the 3D axial lines has been based on algorithms identified by both Peponis et al. (1998) and Turner et al. (2005) for the creation of ‘all line axial maps’ in 2D space. Within three dimensional space, the all line axial map algorithm has been extended to take into account the height of the buildings. The algorithm presented here was developed and tested within ESRI’s ArcGIS software using Visual Basic for Applications (VBA) and ArcObjects. The algorithm takes as input the outline of the buildings (the building’s footprint) together with a height value. Additionally, an arbitrary ‘external’ convex boundary is defined which acts to constrain the creation of the 3D axial lines (so they are developed only within that boundary). The algorithm firstly develops two sets of vertices representing the corners of the buildings (Figure 2).

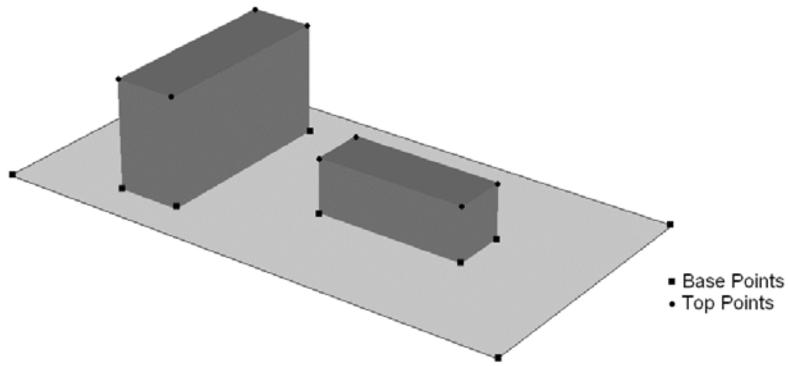


Figure 2. An example of both the base and top point collections.

The first collection (base) represents the base of the buildings with every corner point assigned a z value of zero. The base collection also contains the corner points for the boundary box which are also assigned a z value of zero (assuming the world to be a flat Euclidean surface). The second collection (top) of points represents the top of the buildings - each point is assigned a z value relating to the height of that building. The next step is to develop a line collection that connects each point in the base collection to every point in the building top collection. Each line is tested to see if it crosses any of the building footprints. If it does, then the line is removed from the collection. The algorithm then extends the lines until they intersect either a building or the boundary box (Figure 3).

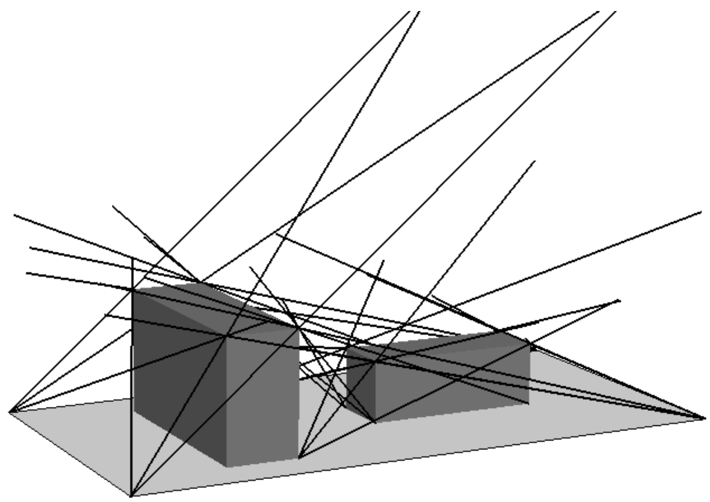


Figure 3. The complete set of lines constituting the 3D all line axial map

From this set of lines a visibility surface is created. This surface is constructed based on the slope of the 3D axial lines. The slope of each line is, therefore, calculated. A 3D axial line with a gentle slope would mean that an individual would have a ‘plaza like’ view of the space whilst an axial line with a much steeper slope which reflect a ‘canyon like’ view of the space. The algorithm also generates the set of intersection points among the 3D axial lines (Figure 4). The average slope value of the two intersecting lines is assigned to that intersection point (for any pair of intersecting lines) (Figure 5).

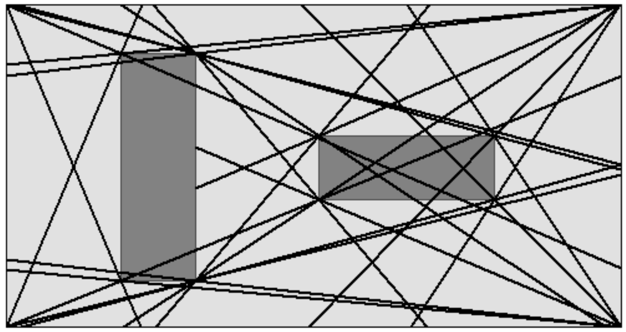


Figure 4. Finding points of intersection (The 3D all axial line map from Figure 3 represented in 2D).

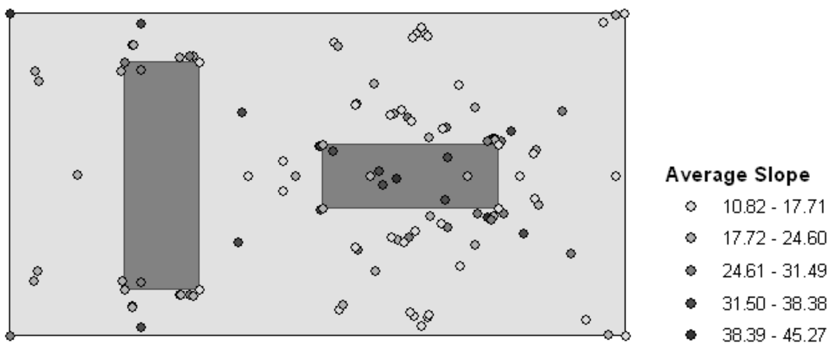


Figure 5. The set of intersection points coded by the average slope.

These points are then interpolated to create a visibility surface using Kriging (Figure 6). Kriging was selected as it allows for the points to be interpolated while taking into account the spatial correlation between the average slopes of the points. The example visibility surface, (Figure 6), shows that there is an area of poor or very limited visibility between the two buildings. Additionally, to the top and bottom of the smaller horizontal building there are large areas of high visibility.

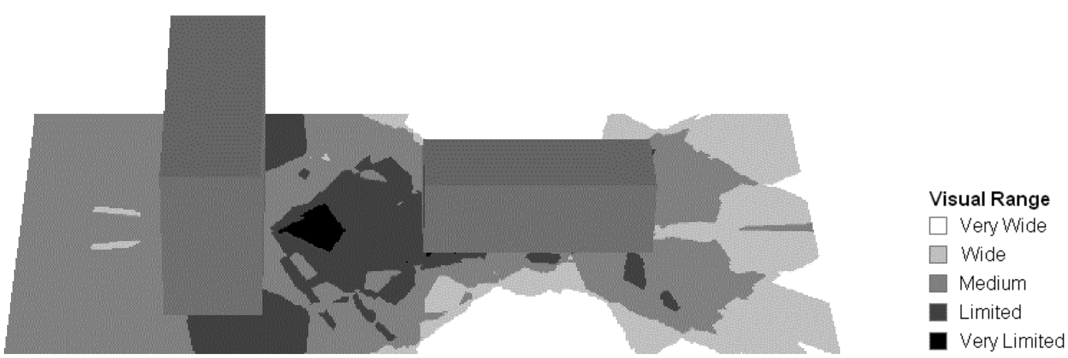


Figure 6. The visibility surface for the 3D all line axial map in Figure 3.

3.1 Limitations

The best solution in creating this visibility surface is to calculate the intersection points for all the 3D axial lines and construct the visibility surface using the complete set of intersection points. For large collections of buildings this proved difficult as ArcGIS, was unable to process the complete set (Schroder, 2006). For performance reasons the best approach was to take a random subset of the 3D axial lines and generate the intersection points and visibility surface from those lines. It was also noted from trial tests that there was a 'boundary edge effect' – whereby the algorithm could not take account of anything outside the boundary box (in effect assuming that no buildings lay outside the boundary box). One way to reduce the edge effect of the boundary box is to develop the visibility surface for an area larger than the one interested in and then disregard the visibility surface close to the edge of the boundary box.

4. Case Study Application

The algorithms described in sections 3 and 4 have been applied to a sample set of buildings from central Wellington, New Zealand (Figure 7). The buildings ranged from shorter buildings nearer the wharf and harbour area with the taller buildings being more prominent the further away one gets from the harbour. The sample dataset included 39 buildings ranging in height from 6.7 metres to 93.5 metres.

Figure 7. Map of the sample Wellington building set.

Once the sample buildings dataset had been created and simplified, the 3D all line axial map algorithm was calculated. In total, 2214 lines were developed by the algorithm. The slope of these 3D axial lines varied dramatically, ranging from 1.85 degrees to 89.8

degrees. Once the 3D all line axial map was calculated, a random subset of 400 lines were used to calculate the intersection points and the visibility surface (Figure 8).

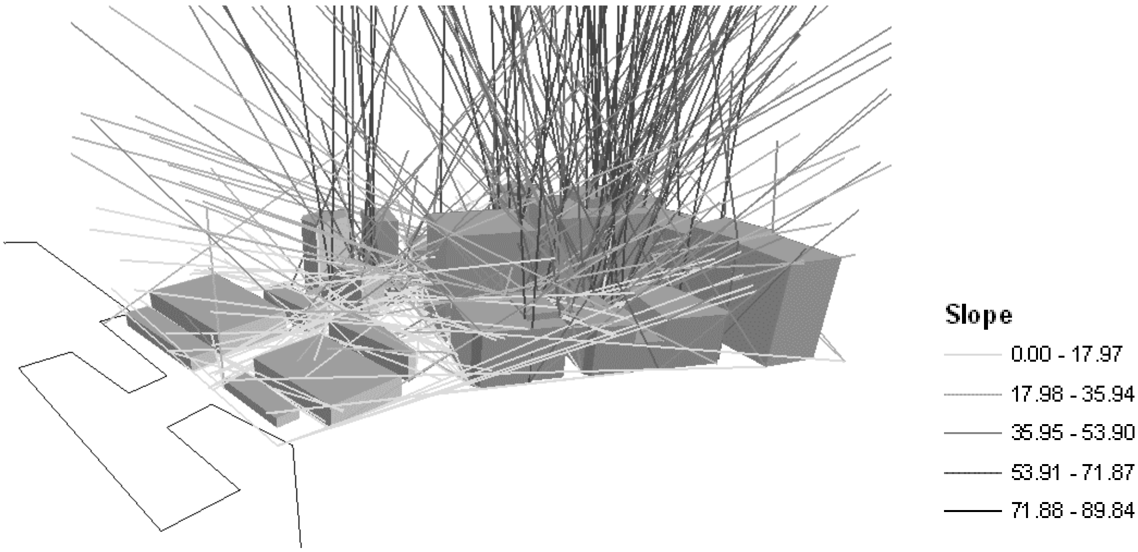


Figure 8. The subset of 400 3D axial lines illustrated in 3D.

The resulting surface is shown in Figure 9, in which the darker the area the more limited the visual range is from that position, whilst the lighter the area the wider the visual range is from that position. The surface can be compared to images of the space (Figure 10).

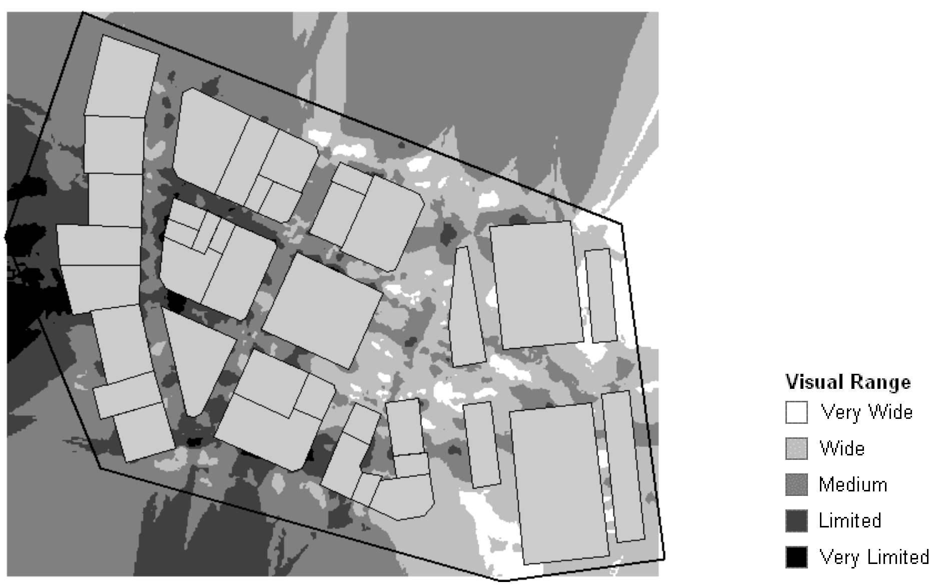
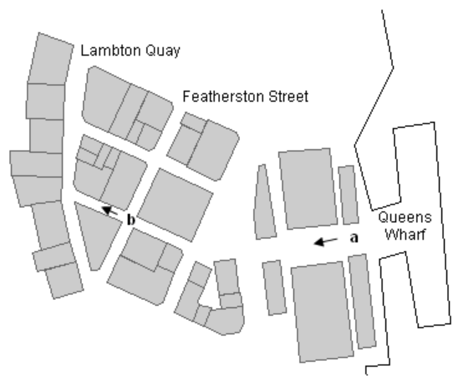


Figure 9. The visibility surface with the sample building set from Wellington superimposed.

(b)

(a)



(c)

Figure 10. (a) Photo looking towards the sample set of buildings from Queens Wharf. (b) Photo looking towards the Lambton Quay area. (c) Map showing the location of where the photos were taken and in which direction.

5. Conclusion

The use of the third dimension within space syntax has only begun to be recently explored. This paper has demonstrated ways of extending the current concept of the axial map to the third dimension. This extension of the axial map and the development of the visibility surface provide a richer picture and compliment the information being gathered from 2D analysis. This application illustrated the appropriateness of the results with the algorithms correctly identifying areas that are fairly open with a wide visual range and also identifying the areas that are quite closed in. Incorporating the third dimension into space syntax and representing the space in the way that the individual sees it, will allow researchers to gain a better understanding of the urban environment and improve the understanding of how social processes operate within these 3D spaces.

6. References

ASAMI, Y., KUBAT, A. S., KITAGAWA, K., and IIDA, S. (2002). Introducing the third dimension on space syntax: application on the historical Istanbul (CSIS Discussion Paper No. 44). Tokyo: Center for Spatial Information Science.

HILLIER, B. (1999). Special issue: space syntax. Environment and Planning B: Planning and Design, 26(2), 159-316.

HILLIER, B., and HANSON, J. (1984). The Social Logic of Space. Cambridge: Cambridge University Press.

HILLIER, B., PENN, A., HANSON, J., GRAJEWSKI, T., and XU, J. (1993). Natural movement: or configuration and attraction in urban pedestrian movement. Environment and Planning B: Planning and Design, 20, 29-66.

HILLIER, B., and SAHBAZ, O. (2005). High resolution analysis of crime patterns in urban street networks: an initial statistical sketch from an ongoing study of a London borough. Paper presented at the Proceedings of the 5th Space Syntax Symposium on Space Syntax, Delft, Holland.

JIANG, B. (1999). SimPed: simulating pedestrian crowds in a virtual environment. Journal of Geographic Information and Decision Analysis, 3(1), 21-30.

NUBANI, L., and WINEMAN, J. (2005, June). The role of space syntax in identifying the relationship between space and crime. Paper presented at the Proceedings of the 5th Space Syntax Symposium on Space Syntax, Delft, Holland.

PENN, A., and CROXFORD, B. (1997, 16-18 April). Effects of street grid configuration on kerbside concentrations of vehicular emissions. Paper presented at the Proceedings of the 1st International Symposium on Space Syntax, University College of London, London.

PENN, A., HILLIER, B., BANISTER, D., and XU, J. (1998). Configurational modeling of urban movement networks. Environment and Planning B: Planning and Design, 25, 59-84.

PEPONIS, J., WINEMAN, J., BAFNA, S., RASHID, M., and KIM, S. H. (1998). On the generation of linear representations of spatial configuration. Environment and Planning B: Planning and Design, 25, 559-576.

PEPONIS, J., ZIMRING, C., and CHOI, Y. K. (1990). Finding the building in wayfinding. Environment and Behavior, 25(5), 555-590.

RATTI, C. (2005). The lineage of the line: space syntax parameters from the analysis of urban DEMs. Environment and Planning B: Planning and Design, 32, 547-566.

SCHRODER, C. J. (2006). Quantifying urban visibility using 3D space syntax: technical report. Unpublished Unpublished MSc Thesis, University of Edinburgh, Edinburgh.

TURNER, A., PENN, A., and HILLIER, B. (2005). An algorithmic definition of the axial map. Environment and Planning B: Planning and Design, 32, 425-444.

VAUGHAN, L., CHATFORD CLARK, D. L., SAHBAZ, O., and HAKLAY, M. (2005). Space and exclusion: does urban morphology play a part in social deprivation? Area, 37(4), 402-412.