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# Making isovists syntactic: isovist integration analysis

Alasdair Turner, Alan Penn

## Abstract
Isovists and isovist fields are of interest to space syntax in that they offer a way of addressing the relationship between the viewer and their immediate spatial environment, however, in the form described by Benedikt (Benedikt, 1979) they are essentially non-syntactic. All the measures he proposes and then plots as fields are locally defined, and are independent of the state of the field in other locations. This paper presents a method for integrating isovists, based on the connectivities of a set of isovists represented as a graph, and allows global relational measures to be developed which are attributable to each viewer location, but which are essentially relational and so syntactic in their definition.

We make a comparison of axial line and convex space integration analysis with the isovist integration analysis using case studies of both building and urban configurations. We show that isovist integration displays an excellent correlation with observed people movement, including a more detailed illustration of space usage than conventional space syntax analysis.

## 1 Introduction
The concept of isovists was introduced into spatial analysis by Tandy for analysis of landscape however it was Benedikt (Benedikt, 1979) who first treated isovists fully as a method for analysis of architectural space. Benedikt's main contribution was to develop various measures of the properties of isovists, such as area, perimeter, occlusivity (the proportion of the perimeter lying on the solid boundary of the environment) and various measures of the distribution of the distance from the viewpoint to the perimeter. Benedikt calculated the properties of point isovists at a grid of locations in the open space of a configuration and then interpolated to give 'isovist fields'. He also developed the representation of a contour map of an 'isovist field' to describe the variation in these different isovist parameters through the environment. This work was one of the most thorough attempts to put the representation of the spatial environment, as opposed to built objects, on a firm quantitative footing, and is still widely referred to in the literature on analysis of architectural space.

Isovists, in the guise of 'convex isovists' (the union of all point isovists within a given convex space) have been used for illustrative purposes in space syntax analysis since they provide a clear representation of the strategic views from (or of) a given location. However, their use has tended to rely on qualitative rather than quantitative assessment, and has tended to focus on the description of single isovists and the visual comparison; either of isovists from different locations or between isovists and empirical data on patterns of space use or behaviour (see for instance: HMSO 1994 and Peatross 1997 in their discussions of crime locations and control points in institutions respectively).

Although isovists seem to offer highly suggestive ways of interrogating spatial configuration, they have to date been of relatively limited application. We believe that there are two main reasons for this. First, the difficulty entailed in their production which has until recently been a time consuming procedure. Secondly, and possibly more importantly, that despite their sensitiveness to the shape of spaces isovists provide essentially 'local' measures of configuration, whilst the lessons of space syntax research suggest that it is the global properties of spatial configuration that are important in determining the functional consequences of design. Benedikt's measures of isovist fields are all local and capture the properties of a single visual field at a point in space, while both Peatross and the HMSO guide use isovists as a way of classifying observations of behaviour as being 'within sight' or 'out of sight' of a particular (single) location.

This paper describes the development of a substantially different way of using isovist polygons. We replace the axial or convex map from conventional space syntax with an isovist map constructed of point isovists at a grid of locations in open space in exactly the same manner as Benedikt. However, at this point we calculate space syntax measures of a graph constructed by considering each isovist as a node and their relationship of intervisability / visual accessibility as links. In this way we have developed a series of global measures of isovist fields where a point in space can be given a mean depth value that quantifies its accessibility to all other points in space in the configuration, whether or not these are directly visible locally. After giving a brief description of this new methodology, we show two examples of the use of the new methods, firstly at the urban scale, and secondly through a more detailed quantitative study of the Tate gallery. Finally, we review possible directions in which this form of analysis might be developed in the future.

## 2 Generating isovists

Generating isovists for the study of large systems has been problematic in the past due to the computational cost of constructing isovist polygons. Various methods have been tried including Peponis et al (Peponis, 1997), Penn et al (Penn, 1997). More recently, novel approaches such as Mitchel Resnick's parallel approach using Star-Logo to compute visual fields for flocking simulations have been adapted by Jiang and Batty (Resnick 1994; Jiang, 1999) to form the basis for isovist analysis. However all these methods have tended to be accurate to about 10° angular resolution, or take considerable processing time.

Using new techniques we have now developed a computer program called 'Vista' which generates isovists quickly from 3D CAD models. The program makes use of hardware based rendering routines on Silicon Graphics computers and at present is limited to this platform. When scenes are rendered in 3D computer graphics, not only is the scene colour displayed, but the distance from the eye point to the visible surface in the model at each pixel in the display is calculated, and stored in the computer's 'depth buffer'. Vista reads the depth buffer and records the eye to surface distance information for 360° panoramas from user specified viewpoints. Since this information is three dimensional we could actually construct a 3D isovist volume using the data, however, for the time being we have constrained ourselves to two dimensional isovist areas, although the user can specify the plane in which these lie, and so isovists at various heights or vertical 'section' isovists can be constructed.

The computer implementation typically allows us to generate isovists of a better than 1° resolution at about 2-3 per second. Hence a set of 20 000 isovists can be extracted from a CAD model in about 2 hours. The research to date suggests that at least this level of angular resolution is required within buildings or in urban space if key lines of sight are to be preserved in isovist polygons.

Figure1 shows a set of 48 isovist polygons taken at a grid of locations within a very simple T shaped configuration. Even in this simple space the isovist shapes and interrelations are highly complex and it is clear that a simpler representation will be needed in order to display the results in a meaningful way.

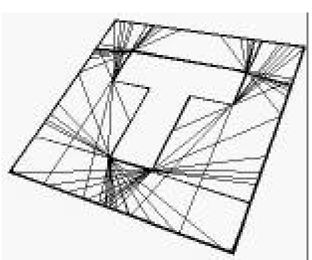

**Figure 1 Isovists generated from a T-shape model**

## 3 Developing relational isovist measures

### 3.1 Constructing an isovist graph

We define an isovist graph as a graph in which each node represents a point location within the open space of a configuration, and these nodes are linked according to one of two rules. The first rule creates a link in the graph between two nodes if they are mutually visible (type1 or 't1' relation - Figure X). The second rule creates a link if the isovist polygons from each node location intersect (type2 or 't2' relation - Figure X). For the sake of convenience the node points are located on a user-specified grid at a selected height above the ground plane.

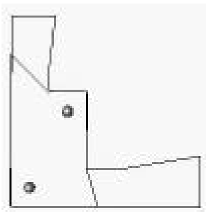

**Figure 2 Type 1 (t1) linkage - direct intervisibility of nodes**

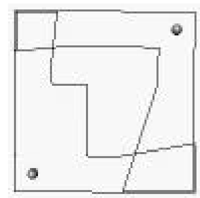

**Figure 3 Type 2 (t2) linkage - overlap of isovist polygons**

### 3.2 Syntactic measures of the isovist graph

Having created the isovist graph a number of graph measures can be produced. The simplest measures are of 'connectivity' or valiancy in the graph. These differ according to whether we are working with a t1 or t2 linkage rule. The t1 connectivity approximates the metric area of the isovist since it counts the number of other nodes located on grid points that can be seen, however the t2 connectivity approximates the metric area of all points in space within one change of direction from the origin node. Both measures are essentially local.

The simplest global measure is the mean depth of the graph. This measure is akin to global integration in the axial line analysis performed by Hillier and Hanson (Hillier, 1984). For the purposes of this paper we will define mean depth as:

$$m_i = \sum_{j=1:n} d_{ij} / n \qquad [1]$$

Where $d_{ij}$ is the number of graph connections traversed on the shortest path joining nodes i and j, and n is the number of nodes. This measure is used to analyse the space and will be loosely referred to as the 'isovist integration'. It should be noted that no relative asymmetry normalisation or d-value adjustment has been carried out since we are currently only considering the variation in configurational properties from location to location within a single spatial configuration.

Each level of depth in a justified t1 linkage graph can be considered as approximating the area of the configuration at that depth. Mean depth is therefore a measure of depth weighted by the metric area of the configuration at that depth, where depth represents the number of changes of direction from the origin node. The t2 linkage graph collapses depth since nodes are connected that are one change of direction apart. This linkage rule results in a very similar overall pattern to that shown by t1 mean depth, but the locations where axial alignments intersect are privileged.

Due to the large amount of overlap between isovists, colouring the isovist polygons themselves causes confusion. We therefore display a value for the node location at the centre of each isovist. If a fine enough grid spacing is chosen these maps can display a great deal of variation in spatial accessibility from location to location within a space or along the length of an axial alignment.

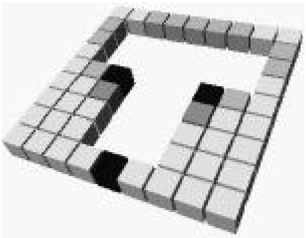

**Figure 4 Isovist integration for a T-shape model**

## 4 Isovist integration in urban space

Isovist integration is currently being tested on a number of urban areas, and is being used illustratively on live projects in the Space Syntax Laboratory. Our first tests suggest that there is a very close relationship between isovist integration in a small area model and the radius 3 integration of the axial map for the same area. Figure 5 shows isovist integration in the area of the City of London around the Baltic House site, which is currently being redeveloped. The map is composed of about 10000 nodes on a 6-metre grid. Figure 6 shows the same area of the radius 3 integration map for the whole of London. A visual inspection shows that there is a great degree of similarity between the two analyses. The isovist integration map, however, shows a considerably increased level of fine scale detail, especially in the changes in integration value along the length of streets, the increase I integration at street intersections and in variations across the body of open spaces. This is possible since the integration value is calculated for a node located at a single point in space.

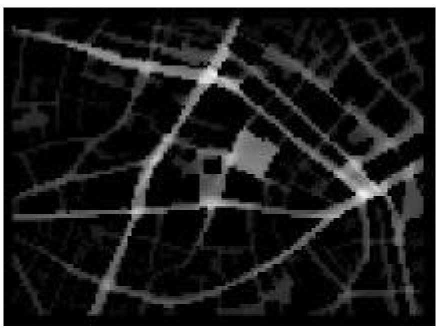

**Figure 5: t1 isovist integration for an area of the City of London**

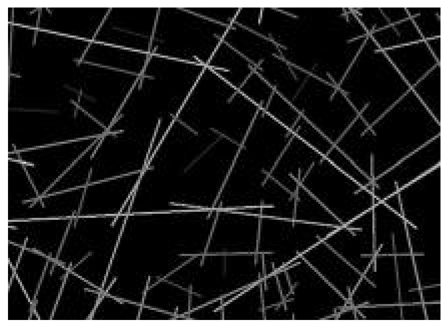

**Figure 6: Section of a radius-3 axial map for London**

Several further points can be made about these two figures despite the difference in the scale of analysis. The first thing to note is that the central region is favoured by the isovist integration, whereas because the axial analysis is just a section of a larger map, there are outer regions which are in fact more integrated, but which are peripheral in the isovist analysis. There is clearly a trade off which must be made of model size and resolution against processing time. However, since the resolution of grid locations and the resolution of the generation of the isovist polygons are not related — the polygons themselves are geometrically precise irrespective of the number of them that are computed — we can simply select a far coarser grid spacing for processing and still to obtain very similar results in terms of the final analysis.

## 5 Isovist Integration in building space

Substantial progress has been made in the validation of the new form of analysis at the building interior scale, and the methods are being used on large retail interior projects at present. In order to validate the methods a means of predicting pedestrian movement behaviour an analysis was made of the Tate Gallery in London which has been studied previously (Hillier, 1996b) and provides a well understood case for testing isovist integration. Isovist integration was applied to a model of the Tate, and the results are shown in Figure 7. Approximately 8000 isovists were constructed with a 0.92° resolution, on a 0.667 x 0.667 metre grid. The nodes are coloured according to a grayscale, ranging from black (least integrated) to white (most integrated).

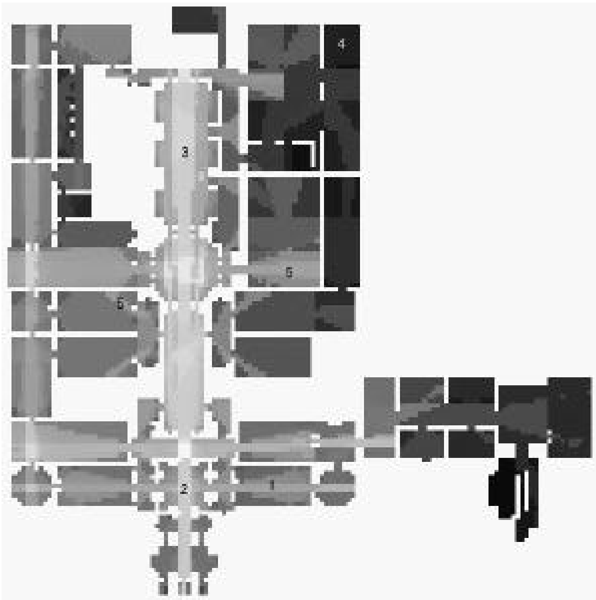

**Figure 7: t1 isovist integration for the Tate Gallery, Millbank**

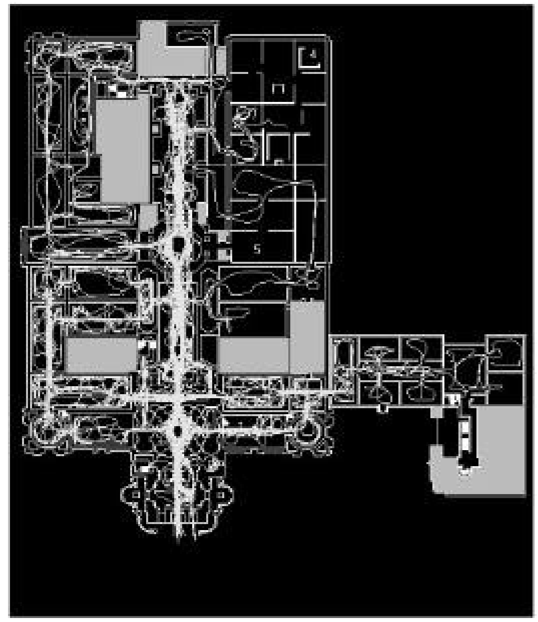

**Figure 8: Real people movement, first 10 minutes, in the Tate**

There are several immediate comparisons that we can draw simply with traces of people, followed from the entrance for the first 10 minutes of their visit (see Figure 8, taken from Hillier 1996b). Overall, the general movement pattern seems close to the isovist integration results, possibly with the exception of the room marked 5. However, a closer look at the real movement pattern shows people avoiding an object in the central corridor. This turns out to have been a large statue in the centre of the building, and was not included in our model that was of the built fabric but excluded artworks. We believe that this obstruction may account for the lower than expected rate of pedestrian movement for room 5. Other than this, there are remarkable consistencies: the left-hand side of the building has been identified as being dominant for people movement and is substantially better integrated than the Clore gallery (to the lower right) and the upper right sections which are notably much less visited. This is reflected in the isovist integration analysis.

At a finer scale a series of diagonal 'axial' alignments are apparent linking the side galleries and the central axis (numbered 6 on plan). These alignments result from offset doorways, but appear also to be mirrored in terms of the predominant movement patterns within these galleries (see figure 9). It seems possible that people moving along the main gallery axis catch a glimpse of pictures, or people or space through the doors, and follow that alignment.

Having made an initial qualitative assessment, we now look at a statistical analysis of our results. The first issue that we face is that since isovist integration values vary from point to point in the open space of the configuration we must adopt a method for attributing an isovist integration value to the observation data. The Tate study (Hillier 1996b) provides information on mean total room occupancy per minute. This occupancy rate was compared with isovist integration by averaging the isovist values for all the isovists taken in that room and plotting this against the logarithm of the occupancy rate (figure 9). This gives us good correlation with an $R^2$ value of 0.585. However, the room occupancy rate must bear some relation to the physical properties of the building. For example, by the mere factor of amalgamating some rooms into a single area, but not others, we can increase the occupancy of this area. This increase in occupancy would not be mirrored by an average isovist integration value, as this would still correspond to an average for the whole area. Therefore, the metric cannot justifiably be used on arbitrary sized rooms.

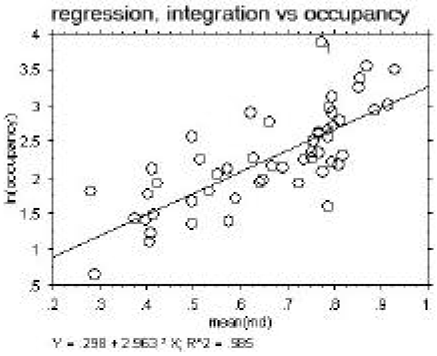


**Figure 9: Scattergram plot of average isovist integration versus occupancy**

In order to take area into account we have looked at a direct area-occupancy correlation. The result is shown in figure 10. The distribution is bifurcated showing that the shop and its entrance space (marked 1 and 2 on plan) gain higher levels of occupancy than their area alone would merit, whilst the largest single space at the northerly end of the main axis (marked 3) gains a relatively low level of occupancy. Note that when both scales have been logged a better correlation is obtained, but that this is still unconvincing with an $R^2$ value of about 0.32.

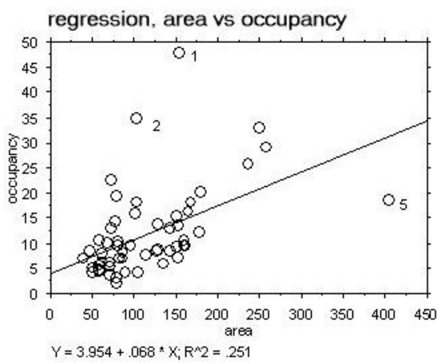


**Figure 10: Scattergram plot of area versus occupancy**

Room area, however, is not necessarily related to how many people might enter that room. For example, if we are looking at general through movement in a room we might be more interested in the length of traversal of the room; or standing occupancy in the Tate might be related to the number of pictures in the room (or some other psychological phenomenon). In order to take area into consideration we have adjusted isovist integration by multiplying by the logarithm of the room area (Figure 11).

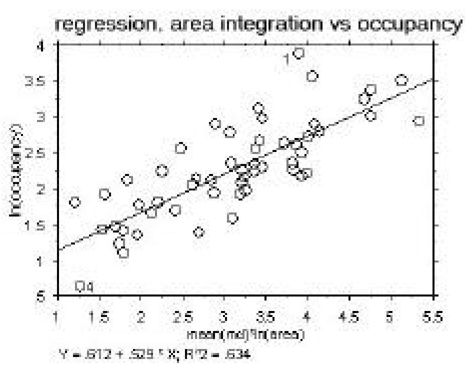


**Figure 11: Scattergram plot of adjusted average isovist integration against occupancy**

By including area in the equation the $R^2$ value rises to 0.634. The overall scatter is much improved; for example the small area of the adjoining space (room 2) is compensated for by the very high integration of the entrance area. However, the shop (room 1) has much higher occupancy than expected, and room 4 has an unusually low occupancy (see figure 7 in the top right hand corner). For room 4, if we look at the true plan including the exhibition installation (see figure 8), we see a large obstruction in that room – this was not modelled for our integration study, and hence the true integration is actually much lower than the figure shown.

In the shop area the standing occupancy is twice as high as in any other area. Although some of the occupancy may be due to spatial effects, it is an exceptional room within the Tate as it serves an entirely different function to the other rooms, and it is therefore reasonable to look at results with this area excluded. Removing the shop from the scattergram on this basis, we find that the $R^2$ value is increased to 0.66.

The statistics we have presented have concentrated on the total occupancy of the rooms (i.e., including both movement through rooms and the numbers of people standing in rooms). These results surpass the occupancy correlation found in Hillier et al's original study; however Hillier et al's best results are actually for movement rates against pesh analysis, where they found a 0.68 $R^2$ correlation. For isovist integration, initial experiments suggest that in order to look at the through-movement rates of rooms, the isovist integration of the gates (where the movement is measured) rather than the mean depth within the rooms should be used.

Work is currently in progress at the Space Syntax laboratory using a geographic information system to give a mean isovist integration value for nodes within a 'buffer' of each gate, and these results look very promising. Figure 12 shows the isovist integration analysis for several rooms on the ground floor of a large department store. In this case, the more integrated areas are given darker shades of grey. For the study, axial line analysis was also used to produce a conventional axial map for the ground floor of the store. Figure 13 shows the correlation between axial integration and observed movement flows (giving $R^2$ = .324). We contrast this with figure 14, which shows the correlation between movement flows at each gate and the mean isovist integration value of nodes within a 1.5m buffer of each gate location. The correlation at $R^2$ = .579 shows a significant improvement over the axial result.

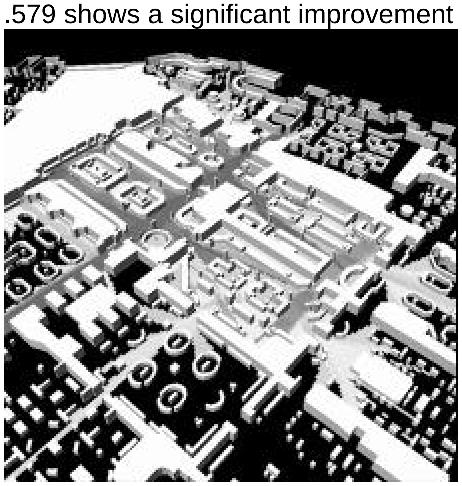

**Figure 12: t1 isovist integration for a section of the ground floor of a large department store**

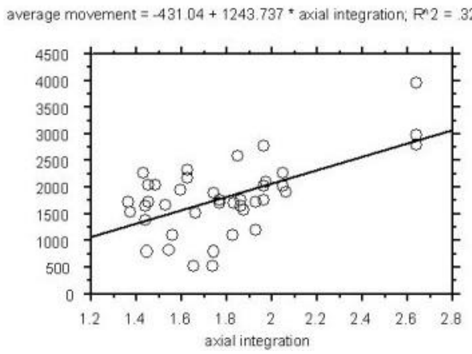

**Figure 13: Axial integration results for the analysis of a department store**

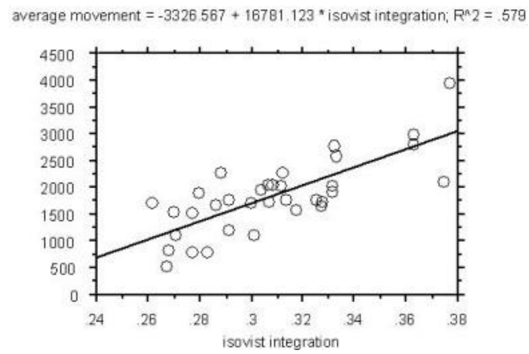

**Figure 14: Isovist integration results for the analysis of a department store**

## 6 Conclusion

This paper has described a new method for syntactic analysis of isovists that complements existing space syntax methodology by allowing the automatic generation of integration values from 3D CAD models. The method constructs a graph of physical locations in a space, relating each location to the others through the interaction of the isovists taken from those locations. Isovist integration improves on existing method firstly by allowing a fully automatic and objective analysis of space, and secondly, by facilitating fine scale analysis which has simply not been possible in the past.

We stress that we have presented the very earliest results of the use of the method and that these have yet to be validated through intervention and repeat observations. In the paper we have looked at three examples of using isovist integration. The example of the area around Baltic House in central London shows that the results are at least visually similar to axial line maps in urban space, although we have not yet completed a full statistical study. Using the example of the Tate gallery, where extensive axial and convex studies have been made, the results of using isovist integration have so far proved competitive, giving the same order of correlation as pesh analysis. Finally, with the example of a large department store, we have shown that we can be optimistic that future results may well surpass those achieved with axial integration.

The automatic nature of the process allows us to take a 3D CAD model of a building or urban space and then formulate an isovist integration map within a few hours. The stages involve simply taking isovists over a grid of locations, then constructing the relationship graph by testing isovist intersections, and finally using a standard graph analysis program to find mean depth values for the graph.

The increased resolution afforded by isovist integration allows us to analyse, for example, the internal movement patterns within a single convex space, or to give an integration value to the location of each observation gate along the length of a single axial alignment. The results we have obtained so far give us considerable confidence that isovist integration may prove to be the more sensitive methodology, allowing us to give an integration value to a display cabinet or a till location in a department store.

## 7 Acknowledgements

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