Isovists for Orientation: can space syntax help us predict directional confusion?*

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Abstract. Focusing on its lessons for deriving and using space syntax measures, particularly those related to isovists, this paper explores the potential for identifying spatial predictors of people's orientation performance with a map. Matching a map to a visible scene, to decide in which direction one is facing, is argued to be a fundamental cognitive subtask which arises in a number of contexts beyond mere wayfinding. The challenge for space syntax is to supply readily computed measures that can adequately predict where this task is more difficult than average, based on analysing a 2D map. If this can be achieved then spaces may be automatically assessed for potential orientation difficulty, so that both the map and the environment can be enhanced to include cues to make it easier. We discuss some issues that arise in applying space syntax to this situation, and describe current progress towards this goal.

Keywords: isovists, space syntax, orientation, spatial cognition

1 Introduction

Space syntax research should have much to tell cognitive science concerning factors that predict people's movement in space, and that thus have (often subconscious) influences on the cognitive process of navigation. So far, however, space syntax has been silent on what happens when people stand still. If our focus is on human cognition of space rather than physical motion per se, then we might expect something about the space itself to influence our thinking about it in other ways than merely when wayfinding. For navigation, measures derived from both axial lines and isovists appear to hold strong predictive power in many situations. This is perhaps not surprising since wayfinding decisions are essentially two-dimensional (people can only walk on the ground), and have to consider the whole 2D space in choosing which

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way to travel. Yet different aspects of the space may well prove to be more relevant to other spatial behaviours, such as orientation (which we here define as deciding in which direction one is facing), aesthetic preference, subjective sense of safety or danger, tendency to linger in or pass through an area, the relative salience (and hence awareness) of local objects, factors inducing claustrophobia or agoraphobia, and so on. In most cases this may suggest a need to incorporate 3D, as well as 2D, aspects of the space, and hence perhaps new measures that exploit these effectively to predict behaviour.

1.1 Static orientation and maps

The behaviour that we have focused on in our current project is static orientation. Imagine any of these situations: you have just emerged from a bus, tram or subway; or you have just navigated yourself without a map to a point where you now feel less familiar and certain; or you are remotely viewing a current or a historical camera image of an outdoor scene. You have a map with you, and you now have a need to work out which direction on the map corresponds to a specific direction in the space (e.g. the direction in which the photograph was taken, or the location of a specific building). The context of your need to do this may be for further navigation, to identify specific objects or to make other judgments; the point is that various contexts, not only navigation, could lead to this problem scenario [1].

Why is it worth understanding and modelling this particular task? One reason is that its successful performance is critical to the 'legibility' of an environment: the ability for relative strangers to find their way around and feel comfortable doing so. This is important for economic and social reasons, as it encourages visitors to explore and spend money in a city without fear or frustration, yet it does not only depend on the design of the environment itself. Crucially, it also depends on the map (or other information source) that is consulted; where cues on the map can be easily matched to the scene, the task becomes trivially easy. Where this is less true, the task can be hard or even impossible. Future mapping could be better designed to aid this if we could understand - and automatically (i.e. computationally) predict - the locations where more help must be provided. This is why Ordnance Survey, Great Britain's national mapping agency, is interested in this quite fundamental task of matching maps to scenes.

Working collaboratively, we have approached this problem by initiating a series of (desktop-based) experiments. These ask people to indicate the direction in which they are 'facing' as they view an image of an outdoor scene, relative to a map of the area on which their location is marked. This kind of desktop simulation experiment, typical of cognitive science research, allows us to focus in a controlled manner on the key cognitive processes of the task and to exactly control both the scene and map stimuli, purposefully omitting the complex real-world contexts that would add extra 'error variance' to the data.

The initial experiment has attempted to show how people, when forced to rely on the overall spatial structure of scenes (e.g. continuous streets, dead ends, open spaces, large buildings) rather than any specific features of them (which would have to be specifically symbolized or labelled on a map to be usable for this task), was able to guess their direction of this scene within a map. In order to accomplish that, a simplified 3D model of the southern English city of Southampton was used. Using images from this, the experiment tested a variety of scenes corresponding to 16 different locations of the city, selecting as many different types of environment as possible. (see Figure 1). They included terraced residential streets, commercial and shopping areas, semi-enclosed green spaces and post-war high-density housing schemes (apartment buildings).

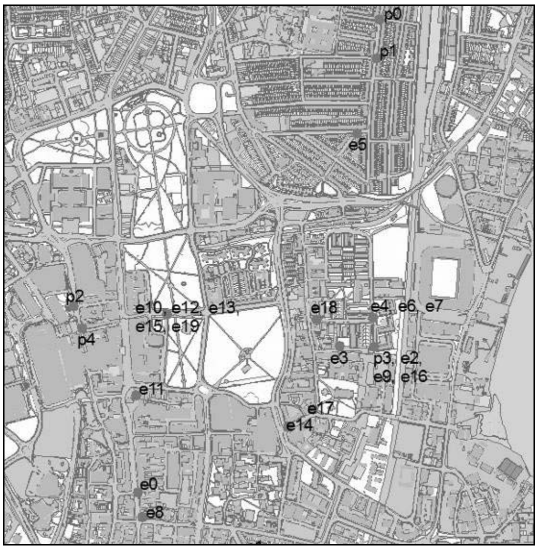

Fig. 1. Location of selected scenes in Southampton.
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An illustration from this first experiment, shown in Figure 2, illustrates the basic problem that participants are asked to solve. Individuals are shown one of the simplified 3D scenes and its respective map with a dot at the centre. Assuming they are standing at the dot (so that they only have to orientate, not locate themselves), individuals are then asked to indicate (by controlling a short revolving pointer around the centre dot, using a mouse) in which direction the photograph was taken.

A moment's reflection will confirm that if standing at a crossroads in a highly regular and enclosed environment, such as a Victorian terraced street network in a British city, the strong symmetry and simplicity of the isovist from that point may have some relevance to the potential difficulty of deciding which street one is looking down, when compared to a less regularly shaped environment. In the latter case one might expect to more easily identify a unique element or shape within the 2D geometry of the scene which, in the absence of any other cues, could be matched to the geometry depicted on the map .

The experiment tested 54 persons on 20 (plus 5 practice) scenes. Response time and angular direction were recorded. From a spatial perspective, the experiment analyzed the visual dominance of each location within its respective environment using a methodology called *isovist analysis* [2]. The idea was to compare the spatial and behavioural measures, to identify any strong spatial predictors of motionless orientation.

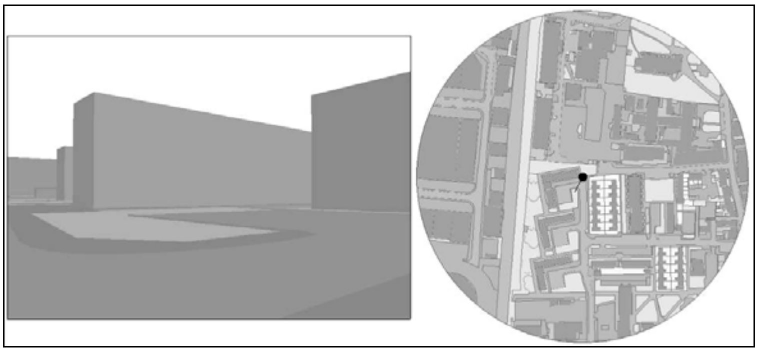

Fig. 2. Sample trial from initial orientation experiment. By moving the mouse over the map (right), the participant moves a line pointer around the marked centre point (centre, the viewpoint of the scene, taken from a simplified 3D model of a real city). When the line reflects the imaginary centre line of the scene image (left), the participant clicks to record a response.

1.2 Isovists and isovist measures

The term isovist has its roots in the seminal work of Gibson [3], who argued that "one can perceive surfaces that are temporarily out of sight" [3:50]. That is, by virtue of motion or deduction people can infer the existence of spaces beyond an isovist's occluding barriers. Although Gibson's work was three dimensional, it later influenced the work of Benedikt [2], who considered isovists as 'regions of space', which can be described by the shapes obtained from people's vision if they rotate through 360 degrees.

Benedikt [2] and Benedikt and Burnham [4] proposed some measures to assess isovists' shapes such as area, perimeter, compactness, skewness and variance, all of which inform the degree to which these polygons are self contained or dispersed in space. All of them refers to a given point x, which is understood as the isovist's origin. Compactness has been mathematically defined by a circle whose radius is equivalent to the isovist's mean radial length, and gives an account of how much the isovist's shape resembles a circle. Variance and skewness describe the degree of dispersion of the perimeter relative to x and the asymmetry of such dispersion respectively. Occlusivity measures "the length of the nonvisible radial components separating the visible space from the space one cannot see from point x", and therefore gives an idea of the degree of 'spikiness' of the isovist.

Benedikt's initial measures were extended by the work of Dalton [5], who proposed the measure of 'drift'. Like the previous measures, drift is a concept defined by the isovist's shape, and describes the vector that links the isovist's origin with its centroid. In addition, recent research by Wiener and Franz [6] has explored the role of isovists as predictors of spatial behaviour, suggesting the existence of strong correlations between some isovist measures and the way in which space is experienced. Among them the author proposed the measure of jaggedness, which is inversely related to the convexity of the isovist and is formally defined by the ratio between the isovist's square perimeter and its area. A very jagged isovist, therefore, would have 'spikes' that had relatively long perimeters relative to their area, whereas a less jagged one would be closer to circular. The more 'spikes', the more complex the shape of the isovist.

Within the Space Syntax area, more recent work based on isovists has been developed by Turner and others [7,8] who, while trying to give an account of human spatial experience, developed a software package (Depthmap) capable of performing *Visibility Graph Analysis* (VGA). VGA imposes a grid onto a space, and uses it to measure the relative mutual visibility among each of the squares that compose such a grid. A recent application of Depthmap incorporates Benedikt's initial isovist measures but adds 'drift'.

Dalton [5] used a similar VGA technique to test people's navigation in six virtual environments, recording their trajectories, pauses and time spent. They were able to demonstrate from this that pauses do not occur in a random manner but in those places where more visual information is available, usually junctions. In those places the isovists tend to be larger and often spread in different directions, permitting the observer to evaluate the information and to take spatial decisions based on it.

The potential relevance of isovists to orientation was initially suggested by Dalton and Bafna [10] who critiqued Kevin Lynch's [11] assumption that orientation at a given 'node' in a city depended solely on its having a distinctive local landmark. To Dalton and Bafna, isovist analysis might help to "differentiate between nodes that contribute to a sense of orientation and assist in way-finding, and nodes that may confuse or hinder it" [p. 59.13]. This potential has inspired our current work to assess the potential relevance of such measures to people's ability to orientate by matching a scene to a map.

1.3 Some initial assumptions and issues

The nature of isovist analysis depends on a clear definition of opaque boundaries; those are the barriers that would impede vision beyond them. However, when the urban scenes used for the current experiment were initially analyzed, some questions rapidly arose.

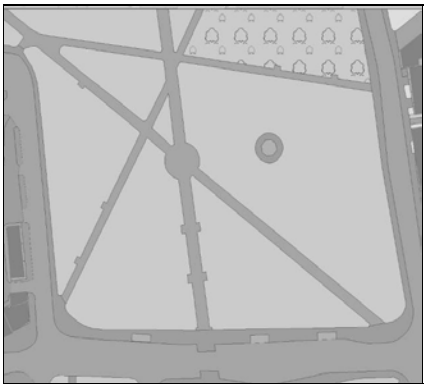

Fig. 3. Different types of opaque boundaries. Here the road surrounding a park is edged both with buildings (dark objects at right and left) and non-building structures such as bus stop shelters (along the bottom). The wooded area at top right is indicated on the map by a generic tree pattern, rather than showing the exact tree locations; all other trees and street furniture are missing. *© Crown copyright. All rights reserved.*

As can be seen in Figure 3, opaque objects exist both as buildings and non-building structures such as bus stop shelters. While convention suggested that the former were more likely to be considered as an opaque boundary, some questions remained over the latter. Isovist analyses were therefore performed in two scenarios: firstly as opaque barriers formed by buildings and shelters (as if one cannot see through), and secondly considering only the buildings as occluded boundaries (that is, assuming that all other objects are to some extent transparent). The resulting isovists were labelled 'dense' and 'diffuse' isovists, respectively.

In the same vein, it did not seem logical to extend the measured isovist beyond the end of the map (which was circular to avoid giving the user greater information in any one direction and hence biasing the experiment). Information that could not be matched between map and scene could not be used to help the user to orientate, and hence could not affect the performance of the task. Furthermore, it was considered that spatial decisions regarding orientation may rely on more proximal information than on information located at the border of the selected radius. For this reason, the original circle of 400m diameter was halved into a concentric circle of 200m diameter, and the isovist portion within this circle was also measured. Figure 4 shows the results of varying these parameters.

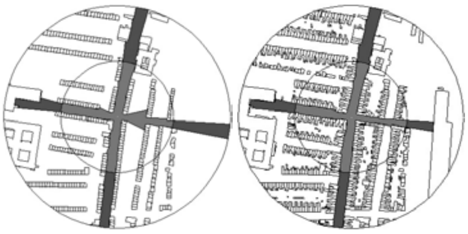

Fig 4. Left: isovist extents at 200m (light grey) and 400m (light+dark) from one sample location, excluding non-building objects. Right: the same isovist, but taking account of non-building structures.

Once the barriers were defined, isovist analysis was carried out using Depthmap version 6.0818, developed by Turner [12]. Assuming that the circle's central point was the origin of the isovist (or person’s head), the software traces rays in 360 degrees until each of them encounters an opaque barrier. The result is a specific shape, corresponding to the potential field of view of an individual standing at this location.

Examples for different scenes are shown in Figure 5.

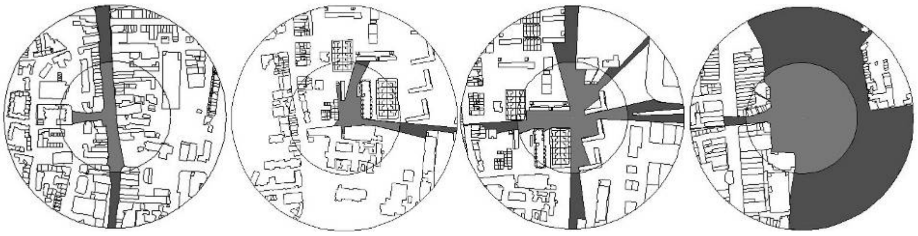

Fig. 5. Some examples of isovists, from left to right: at a location in the city centre; two different points in a post-war residential housing estate; in a city park.

2 Preliminary results

2.1 Isovist measures

This initial study raises a number of important issues concerning the measures. First, it is clear that in less built-up areas the boundaries of isovists became less certain. Even when using a detailed large-scale map such as Ordnance Survey's OS MasterMap®, in the absence of 3D information it is not possible to tell whether and when walls, fences, foliage or street furniture restrict the view. Other factors requiring consideration are the height of the observer and the degree of transparency of borders that might be considered as visual boundaries. An example of this is the location of five scenes that consisted of views in different directions from the same point, at the side of a road running across one of the city's central parks (the rightmost isovist shown in Figure 5) . Treated as an open space without trees, the isovist almost covers the 400m circle that surrounds it. However, as can be seen in the photographs (upper row of Figure 6), the existence of trees and bushes obscures the perception of distant objects, which appear barely recognisable. Worse, in summer, the distant objects are completely hidden by foliage – so the true isovist actually varies with the season.

The same can be said for the scene shown in the lower row of Figure 6, where the view of a church is partially obscured by a short wall, and by trees which are barely noticed in winter but which overwhelm the view in summer. These examples clearly illustrate the important issues of realistically accounting for significant foliage, and for apparently minor architectural features such as walls and fences.

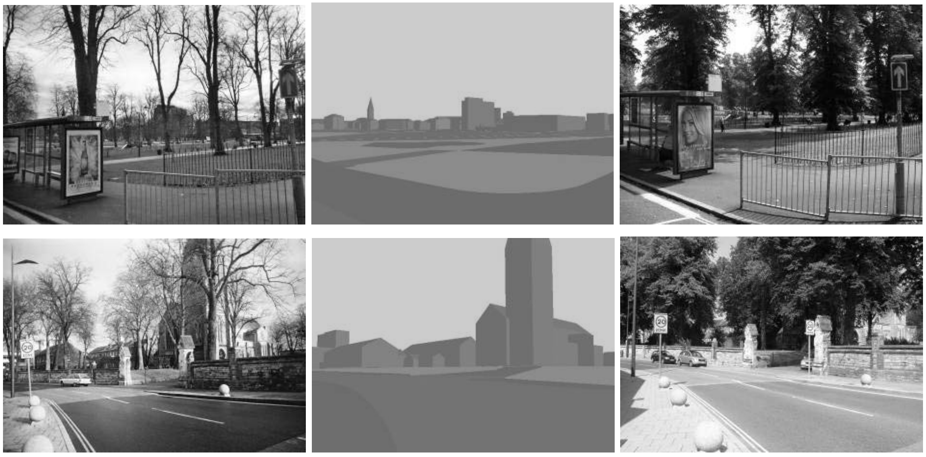

Fig. 6. Two of the Southampton locations, as photographed in January and in June 2006. Middle images show the same scenes but taken from a buildings-only 3D model (overlaid on OS MasterMap® Topography Layer, draped on an OS Land-Form PROFILE® terrain model). *© Crown copyright. All rights reserved.*

The initial analysis revealed very low correlations among the measures. Even measures that are normally well correlated, such as Area and Perimeter [4, 5, 7], did not show correlations above .25, neither for diffuse nor dense isovists calibrated for either 200m or 400m. Higher correlations were found between Jaggedness and Compactness, although these measures are themselves very similar due to their dependence on the isovist's perimeter. To determine whether these low correlations were due to the specific features of the five park scenes, because of the location's near-circular isovist, these scenes were removed from the sample. This resulted in a markedly increased correlation between Area and Perimeter, and also among several other measures (shown in Table 1).

Table 1. Correlations among the scene isovist measures

"Dense" isovist, radius 400		Without park location						
		area	perimeter	occlusivity	drift angle	drift magnitude	compactness	jaggedness
With park location	area		**0.75**	0.69	0.01	0.17	0.12	0.18
	perimeter	**0.21**		0.78	0.00	0.31	0.52	0.66
	occlusivity	0.00	0.36		0.04	0.07	0.28	0.43
	drift angle	0.12	0.10	0.13		0.13	0.04	0.02
	drift magnitude	0.05	0.18	0.03	0.01		0.19	0.25
	compactness	0.66	0.02	0.13	0.04	0		0.87
	jaggedness	0.27	0.17	0.14	0	0.02	0.74	

The correlation between Area and Perimeter for 400m isovists, both diffuse and dense, was much larger (.76 and .75 respectively) than that for 200m radius isovists (.56 and .2 respectively). In general, both for the 'dense' and 'diffuse' isovists, more correlations were found among the measures when using the 400m than the 200m diameter, owing to the greater proportion of 'artificial' (circle-bounded) perimeter in the latter.

Meanwhile, there was little difference in most measures between the 'dense' and 'diffuse' isovists, partly because most non-building structures recorded in the OS MasterMap® data were either behind buildings and hence invisible from the street, or were too sparsely distributed to be a frequent feature of the scenes.

2.2 Isovist and behaviour measures

Correlations among isovist measures have important implications when one is trying to build them into a predictive model of behaviour. Ideally we would predict outcomes as well as possible, by taking as few measurements as possible. Where two measures closely correlate, therefore, it implies potential redundancy – one can (and should) probably be dropped from a predictive regression model to avoid overspecification.

With this in mind, initial analyses of the data have focused on optimising a multiple regression model to explain the number of participants responding correctly to each scene (within 30 degrees, i.e. within the visible scene). This analysis should be viewed as tentative, since it is based on only 20 scenes. However, the dependent variable (number of participants performing correctly) probably had low measurement error, being based on 54 participants and showing a close fit to a normal distribution.

As with all such analyses, the issues faced in inspecting and evaluating the variables prior to the regression are an important part of the lessons we can learn about the study. In this case, two of the street scenes tended to have particularly low rates of correct response (18 or 20 out of 54), and thus formed outliers that could severely distort the apparent relationships between the independent (predictor) and dependent (behavioural) variables. At the same time, as mentioned above, the open space of the five park scenes also showed quite different patterns of correlations among the predictors, although it had no apparent consistent effect on people's performance. It is difficult under such circumstances to decide which scenes, if any, to exclude from analysis; such issues would probably disappear if a much larger number of scenes was included that varied the extent of open space and the number of appropriate cues available for solving the task (which appeared to be the problem for the two lowest-scoring scenes).

Other issues which have to be tackled for a meaningful regression model are linearity; relationships between variables are not always a straight line. For instance, as well as isovist-related measures, our analysis also includes the bearing (angle) from north of the correct response, since previous studies (e.g. [13]) have shown that this has a curvilinear relationship to orientation performance in simple environments when the map's north-up orientation does not match the direction of vision. Such relationships need to be handled by applying transformations to variables, or by using more sophisticated regression models.

To date, a great deal of variation has appeared when choosing different methods and criteria for running a multiple regression using the set of isovist measures (plus angle of correct response) as independent measures. Jaggedness appears to be a fairly significant predictor, regardless of the form of analysis chosen; most other isovist measures tend to cause collinearity or show low correlations with people's orientation performance. As explained earlier, jaggedness is a measure that ultimately reflects the isovist's shape complexity, and therefore high jaggedness implies that there is more environmental information available to be used in spatial decisions. Further analyses are continuing.

Meanwhile, in separate qualitative analyses we have been investigating the apparent strategies used by participants to solve the orientation task. Initial tentative conclusions suggest that the role of isovists may always be limited, since most people seem to pick out a single conspicuous feature and match that to the map, rather than deducing the overall isovist. However, often the 2D scene geometry is the best 'feature' available for this, so it is still likely to play some part in people's solutions under some circumstances.

3 Discussion

This research seeks to answer a fundamental question concerning the application of VGA to the information used by people orienting themselves in the environment, but this experiment has revealed a number of complicating factors. Although it may be expected that orientation decisions are typically taken based on proximal (nearby) information, from the point of view of an isovist analysis it seems more realistic to include the largest area possible, in order to simulate the field of view of an observer. This is especially relevant in this experiment, where no contextual clues (cars, street furniture, shops) are observable. In fact, it seems likely that several judgments were based on the spatial structure of the scene (in the absence of distinctive individual features that could be matched), which may be easier to use when more extensive isovists are seen. However, we have seen that in real environments distal cues are more likely to be obscured by non-mapped objects such as street furniture and trees, suggesting that a more restricted isovist could be more realistic. At the same time, features that are not shown on a map cannot help with orientation performance – but restricting the isovist to the extent of the map introduces an artefact into its shape.

Further artefacts, of course, arise due to the nature of this initial experiment. These include the way that the task required rotating a single pointer (while not being able to rotate the map), matching the scene's centreline (rather than its extents or specific objects), and being able (to a limited extent) to match colours between the scene and map (while not being exposed to the same number of depth cues as in real spaces). These limitations on generalisability are now being addressed through further experimental work. However, we are confident that the same basic cognitive processes are involved in matching the scene to the map under any circumstances where the abstraction of the 2D geometry from the 3D scene is necessary (that is, whenever other cues such as labelled landmarks or street names are unavailable or ambiguous on the map).

Another apparent artefact is actually often a factor in real-life situations. It may be desirable to distinguish the ‘forward facing’ part of the isovist from the total 360-degree view, since people tend not to rotate (or may not be able to, as in the above experiment, or for example when driving a car or viewing a photograph). It is possible that certain aspects of the task are predicted by measures of the partial isovist indicated by the scene image (which in the case above covers a 60 degree angle – 30 degrees either side of the centreline), while other aspects are better predicted by the overall isovist, for example the extent of the ambiguity in interpreting potential directions from the map. We are currently working to investigate how these two levels of isovist relate to each other, with respect to predicting participants' behaviour in the orientation task.

The park example given earlier raises important questions concerning the application of VGA to open, semi-natural spaces, where ‘complexity’ in VGA terms may be far less closely related to the distinctiveness of the different vistas. Open spaces, when considered treeless, are transformed into near-infinite isovists, although this is far from true in the real world. It seems therefore that isovist analysis requires well-defined borders in order to be realistic, which only occur in built-up areas. Similarly, terrain (e.g., hills, terraces and landscaping) are not taken into account in standard VGA (although this made little difference in the current case because Southampton is relatively flat).

Furthermore, even when 3D data is available that may help to define the isovist in terms of building and terrain constraints, it is quite possible that it may be incomplete (e.g., not including street furniture) or out of date (due to building demolitions, additions and alterations). These issues arose with the 3D model and map used in the current study, even though they were both created within the past three years. We believe that analysts may need to start to take these issues into consideration when applying isovists in real-world scenarios.

Acknowledgements

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Disclaimer

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