Use of GIS for Planning Visual Surveillance Installations

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Abstract
Visual Surveillance is now commonplace in modern societies. Generally, the layout of observers in artificial visual surveillance (e.g., CCTV camera) involves an iterative, manual and gut-feel process of trying various layouts until a satisfactory solution has been found. This paper proposes how a GIS, can be used to identify the optimal number and locations of observers, ensuring complete visual coverage using an automated technique, namely Rank and Overlap Elimination (ROPE). The ROPE technique is a greedy-search method, which iteratively selects the most visibly dominant observer with minimum overlapping vistas. The paper also proposes measurements to characterise the shape of open spaces, relevant in assessing natural surveillance. The paper demonstrates an extension, called Isovist Analyst, to the popular ArcView for planning artificial and natural surveillance in indoor and outdoor open spaces, with arbitrary geometry and topology.

1. Introduction
A surge in the events of organised terrorism and other criminal activities in modern cities has given rise to the rather controversial phenomena of intrusive visual surveillance e.g., Closed Circuit Television (CCTV) and watch towers. It was estimated that in 2004 as much as $4.3 billion were going to be spent on various visual surveillance devices (Samerjan, 2000). However, the idea of creating an optimal and complete visual coverage in a guarded space (e.g. prison, forts) has been a topic of research for a long time. Some popular examples of such historical works on visual surveillance include the Panopticon Prison by Jeremy Bentham in 1787[1] and the design of fortified towns where the palaces were located at the highest point for a vantage view. The aim of visual surveillance is primarily to create an environment where the observers can monitor and regulate the targets. There are basically two main types of visual surveillance, namely Active or Artificial Surveillance and Passive or Natural Surveillance. Artificial Surveillance involves an intrusive direct monitoring of targets using a remote vision device e.g., CCTV. On the other hand, Natural Surveillance involves a space whereby the targets can self-regulate themselves under the impression of being observed by other targets (e.g., Panopticon Prison by Jeremy Bentham[1]).

Installation of Artificial Surveillance is a costly operation and therefore it is desirable that the least number of CCTVs are placed at key locations in the open space and yet provide complete visual coverage. Chvátal (1975) presented a more general form of this problem, proposed to him by Victor Klee, called the Art Gallery problem, which is one of the most well known NP-hard computational geometry questions. The challenge in art gallery problem is to find the minimum number of observers required for complete visual coverage of an art gallery. In actuality, it is expected that a robust solution to the Art Gallery Problem will be able to solve the challenge for an arbitrary open space. Therefore, by analogy an algorithm to solve the Art Gallery Problem could also be used to create an effective network of visual surveillance installations. A number of analytical solutions have been proposed to the Art Gallery Problem however most existing solutions are based on heuristics that are

[1] http://www.ucl.ac.uk/Bentham-Project/journal/cpwpan.htm

dependent on the geometry and topology of the gallery i.e. whether the gallery is convex, rectilinear etc.

Natural Surveillance originated from the concepts of Crime Prevention Through Environmental Design[2]. In short, natural surveillance involves the creation of spaces where there is an increased perception of being seen. Some examples of measures to increase the chances of being observed include removing blind spots and dark alleys, and landscape designing with restricted exposed routes. A typical natural surveillance planning involves an iterative process of evaluating the design of open spaces for properties such as shape of the open spaces, amount of visible area from vantage points and the connectivity between open spaces.

Traditionally, the design of artificial and natural surveillance has been done by architects and urban landscape designers, following an iterative manual, gut feel process using CAD software. This paper introduces novel solutions in artificial and natural surveillance within the GIS environment using an ArcView 3 extension, Isovist Analyst. We first demonstrate an approximate solution to the Art Gallery Problem that guarantees complete visual coverage in any arbitrary open space (even 3D spaces) and in some cases could even yield the minimum number of observers. Secondly, we demonstrate visibility measures that can be used to characterise the open spaces.

2. Methodology

The most fundamental element of the proposed approaches is the concept of *isovist*. An *isovist* (Figure 1) is simply the space visible from an observer (Benedikt, 1979). The principle of isovist term is similar to *viewshed* and *visibility polygon* in terrain analysis and computer vision respectively. An *isovist* has a number of properties e.g., area and various shape ratios which can be used to characterise the open spaces (Rana and Batty, 2004). The distance to the isovist outline from the observer could also be sampled at equal angular intervals to study the statistical variation in the resultant *radial* and *diametric* lengths (see Figure 1).

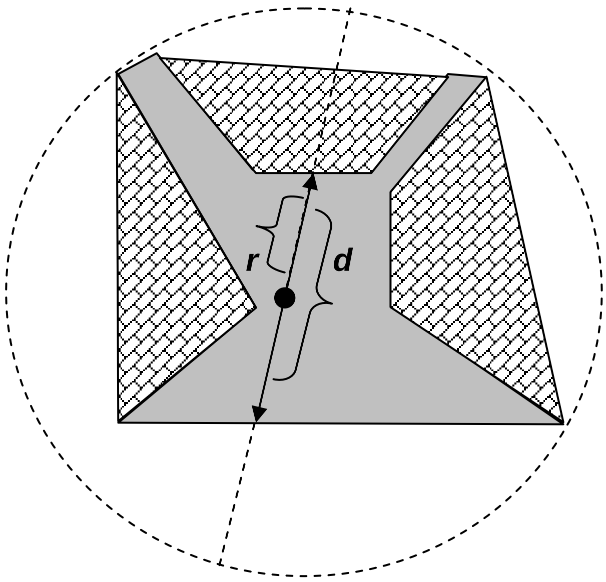


Figure 1. Isovist of an observer and the corresponding radial (*r*) and diametric (*d*) lengths.

[2] http://en.wikipedia.org/wiki/CPTED

In an arbitrary open space, the set of optimal observers required to provide complete visual coverage is unknown till a combination of all potential observers has been tested. As a solution to this NP-hard aspect of the problem, in this proposal, a dense mesh of potential observers is placed in the open space (Figure 2a), with the assumption that the union of the vistas from each observer is equivalent to the visible area of the open space. In other words, this approach basically discretises the open space and as will be shown later, guarantees a solution. The concept of isovist can now be expressed for the discretised open space accordingly as a set a_i where $a_i = \{v_i, v_j, \ldots, v_n\}$; $1 \geq i, j, \ldots, n \leq N$, $v_j, \ldots, v_n$ are observers visible from v_i and N is the set of all observers in the open space. $|a_i|$ is referred as the *rank* of the observer. Figure 2b shows the isovist of the highest ranking observer amongst the dense mesh of observers in Figure 2a. The following algorithm can now be used to reduce the dense mesh to the set optimal of observers to provide complete visual coverage.

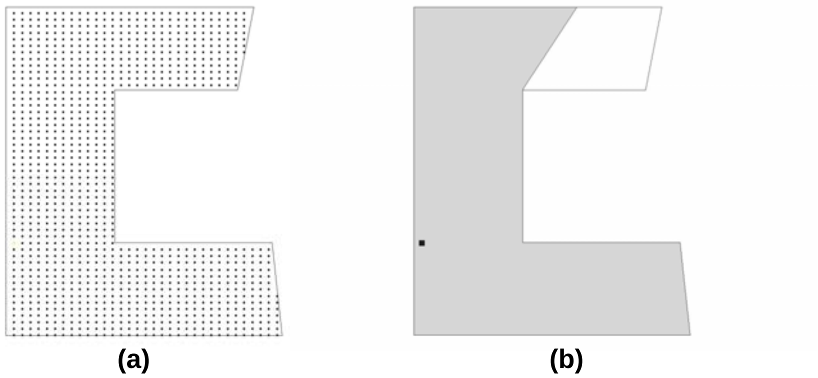


Figure 2. (a) A simple indoor open space with a dense mesh of potential observers, and (b) isovist of the observer with the largest isovist area

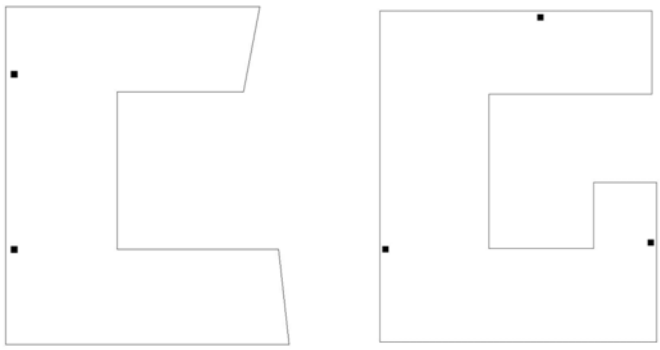
2.1 Rank and Overlap Elimination (ROPE)

Originally developed for the extraction of the structure of architectural open spaces, ROPE (Rana and Batty, 2004) is essentially a greedy-search method. The ROPE technique starts with the selection of the highest ranking observer and removal of lower ranking observers present in the isovist of high ranking observer. This step is then repeated with the next remaining highest ranking observer and continued so till a set of observers with a minimal overlap of isovists in the open space is achieved. The following pseudo-code shows how ROPE can be used to derive complete visual coverage with few observers:

while $(N \neq \emptyset)$ {
    Get $v_i \in N$ *with maximum rank i.e.* $|a_i|$
    Add v_i *to* α
    Remove a_i *from* N
} *loop*

where α is the set of optimal observers.

Figure 3a shows the output of the ROPE method revealing the location of 2 optimal observers for the simple block shape shown in Figure 2a. While for many open space shapes the ROPE method will successfully yield the location and number of optimal observers, in certain shapes it will produce a reduced set of observers which although guaranteeing complete visual coverage of the open space may not necessarily be the minimum optimal observers. The open space in Figure 3b, which is a slight modification of the open space in Figure 2a, is such an exceptional shape. As seen in Figure 4b the ROPE method suggests 3 optimal observers, however only 2 are needed. One of the possible ways to resolve these problematic shapes include the Combinatorial Set Coverage (CSC) technique (Rana, 2004), which exhaustively searches for a smallest combination of observers (which can not be more than the observer numbers derived from ROPE technique) which provide complete visual coverage. Various heuristics are currently under investigation to reduce the computational load of the CSC technique and to further refine the ROPE technique.



(a) (b)

Figure 3. (a) A simple indoor open space with two optimal observers and (b) three optimal observers identified by ROPE for a simple indoor open space although only two are required

Admittedly, the output from ROPE technique does not always guarantee the minimum number of observers however, it has three important qualities which still make it an ideal technique to derive a complete visual coverage e.g.,

- ROPE doesn't depend upon the geometry and topology of the open space.
- ROPE reduces the otherwise non-trivial spatial problem into one of trivial set union and inequality tests.
- The output from ROPE technique always guarantees a quick and complete visual coverage and the number of optimal observers was found to be close to the theoretical minimum set of observers.

In addition to the number of optimal observers for visual coverage, the characteristics of the location of the optimal observers are also crucial in artificial surveillance. The location of artificial surveillance installation is not arbitrary and generally involves some geographic logic e.g., the CCTVs at a railway station are mostly installed above the platform for ease of maintenance. Therefore, it is desirable to have a technique which allows a form of pre-selection of observers based on their geographic location.

2.2 Morphological Measures of Isovist

It is natural that the views from different parts of an open space provide varying levels of visual coverage of the open space. In natural surveillance it is crucial to quantify the quality of visibility from various parts so as to ensure optimal visual connectivity across the whole space. For example, the rank of an observer is a measure to indicate the visibility dominance of an observer. In addition to the area of the isovist, there are several ways of characterising an isovist based on its shape and overlap with adjoining isovists. For this purpose, it is assumed that an isovist is a continuous polygon (i.e. with no holes and self-intersections). Some of the morphological measures of isovist[3] and their respective relevance to natural surveillance are as follows:

i) *Area* or *Neighbourhood size* is the simply the amount of visible space from an observer. It can be represented in terms of the area of the visibility polygon or the number of elements in the isovist set. Clearly, open spaces with higher isovist area make people feel more safe (e.g. market squares) than alleys.

ii) *Maximum Diametric Length*[3] is the length of the longest straight line in the isovist. It has been proposed that humans subconsciously follow the direction of longest visibility (e.g., corridors) while exploring an open space. This aspect of human navigation has been used in pedestrian and crowd dynamics (Batty, 2005).

iii) *Circularity* (Conroy, 2001) is a measure of the resemblance of the isovist shape to a perfect circle. Numerically, given r is the average radial length of an isovist with an area p then circularity is defined as follows:

$$\text{circularity} = \frac{\pi r^2}{p}$$

An observer with an isovist of higher circularity values (i.e. closer to 1) could be used to locate meeting points and resting spots so as to remain in view from most directions.

There are several other morphological and graph theoretic measures of isovist that can be used to represent the level of accessibility in different parts. For example, Depth is the average of the shortest path lengths from an observer to all points in the dense mesh of observers. All the observers, say set j_i, within the isovist of an observer j are at depth 1, the observers within the isovists of the elements (the other potential observers) in j_i are at depth 2 from observer j and so on. Depth indicates the *visual accessibility* of a location therefore junctions in the centre of open spaces will have higher depth values than locations in the peripheries.

2.3 Isovist Analyst extension for ArcView

Isovist Analyst[3] is the first GIS extension for ArcView 3, which computes isovist and several other visibility measures. The unique aspects of Isovist Analyst are as follows:

- It allows the use of arbitrary topology and geometry of open spaces e.g. non-convex, line segments.
- It allows an arbitrary placement of observers, which can be controlled by the user using the standard ArcView mapping tools. Thus, a user is able to generate hypothetical vistas quickly and easily.

[3] http://www.casa.ucl.ac.uk/sanjay/software_isovistanalyst-new.htm

Figure 4 shows a view some of the main dialog boxes of the extension. There are mainly following four steps in the proposed methodology to derive the optimal set of observers using Isovist Analyst,

- Generate the dense mesh of observers,
- Compute the visibility,
- Generate the preferred set of observers,
- Perform ROPE.

The primary inputs to the extension are point (observers), and line (floor plan) and/or polygon (floor plan) shapefiles. The current version of the Isovist Analyst extension does not incorporate any industrial standards or practises for installing CCTV installation. It is assumed that an observer (e.g. CCTV) is able to view all around its location i.e., it has 360^{o} view, and can view to infinity. Each observer is considered as a potential observer. However, it is fairly trivial to incorporate these limitations in the extension.

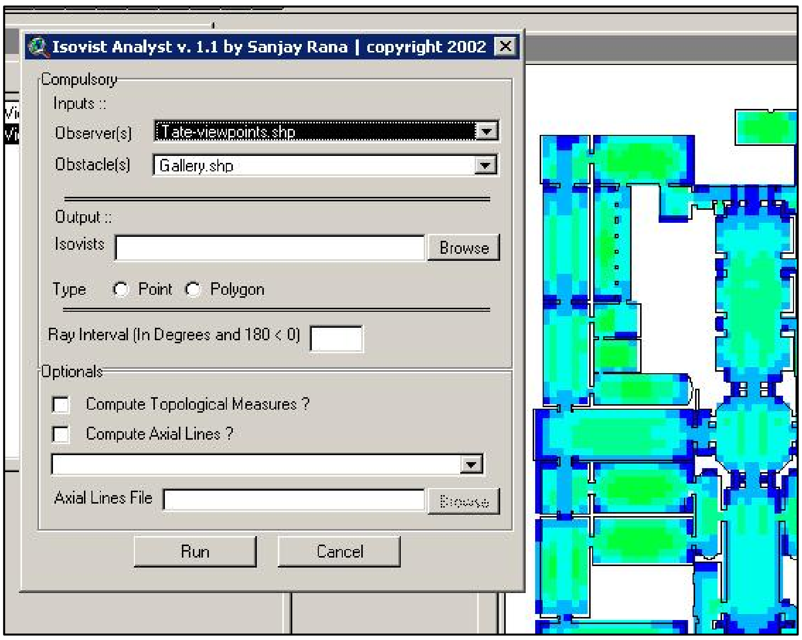


Figure 4. Graphic User Interface of Isovist Analyst extension

3. Two Case Studies

Figure 5a shows the floor plan of the Tate Britain Gallery in London and the dense mesh of 4298 observers. The amount of open space, shape of the long corridors and resting places in the exhibition rooms can be seen in the maps of the isovist area (Figure 5b), area, maximum diametric length (Figure 5c) and circularity (Figure 5d) measures. According to the ROPE algorithm, a complete visual coverage can be achieved by 90 observers shown in Figure 5e. Clearly, this is a significant number of observers, in particular too many observers posted near the entrance of the gallery at the bottom on the figure due to the complicated architecture. This aspect of the output highlights the sensitivity of the ROPE algorithm to the geometry of the floor plan.

Figure 6a shows a sketch of the street layout around Aldwych area in Central London and the mesh of 8427 observers. Figures 6b, 6c, 6d respectively show the plot of isovist area, maximum diametric length, and circularity measures. These plots highlight the larger vistas at junctions and the lack of exposure along back alleys and small streets. This area is a typical example of long street network intersected by lanes. As a result, the 43 optimal observers are spread across the area widely in comparison to the dense clustering of observers in the Tate Gallery (Figure 5e).

4. Computational Performance

The majority of the computational load of the proposed approach originates from the visibility computation and ROPE algorithm. The impact by the difference in visibility computation algorithms can be seen in the performance of the Isovist Analyst v. 1.x and Isovist Analyst 2.0b. Isovist Analyst v.1.1 employs non-optimised ray tracing algorithm for visibility computation, as a consequence it is much slower than the Isovist Analyst v. 2.0b, which uses much faster Binary Space Partition (BSP) approach. For example, it took nearly 2 hours for Isovist Analyst 1.1 to compute the visibility polygons for the Tate Britain Gallery while Isovist Analyst 2.x completed the same in under 3 minutes on a 1GHz Pentium III machine with 512 Mb RAM. Isovist Analyst 1.1, however, doesn't suffer from the occasional errors in the BSP algorithm.

However, the computational load of the ROPE algorithm is not so straightforward as it depends upon the number of observers, which is known, but also the unknown number of sorting iterations. The number of sorting iterations depends upon the extent of overlap between isovists. In general, no overlap and lot of overlap between isovists, will produce faster outputs.

5. Conclusions and Future Work

Despite being an unpopular issue, owing to various social disorders visual surveillance is now routine in modern society. Installation of artificial surveillance technology such as CCTV is expensive and generally follows an iterative, manual and gut-feel process. Therefore, techniques to identify the minimal number and locations of such installations (like an observer) with the most visual coverage of open spaces are highly desirable. However, this is a NP-hard problem because a solution to the problem would involve exhausting all possible locations of such observers, rendering it non-heuristic. In this work, we have addressed the issue by discretising the open space with a dense mesh of potential observers so that the upper limit to the number of optimal observers is always known. The large number of potential observers is reduced to the set of optimal observers by using a greedy-search algorithm, namely Rank and Overlap Elimination (ROPE). ROPE algorithm provides a near-optimal solution to the problem by iteratively selecting the most visibly dominant observer with minimum overlapping vistas. Although, the output of the ROPE may not be the minimum number of observers to cover an open space, it could serve a quick and simple way to ensure complete visual coverage.

An alternative to the intrusive artificial surveillance, natural surveillance involves design of communal open spaces, where people feel safe due to generous lighting, accessibility, and openness. The paper demonstrates measures to quantify the openness and shape of an open space by measuring properties of an isovist e.g. area (space visible from a point), maximum diametric length (length of dominant lines of sights), and circularity (resemblance to a circle).

Two case studies, the indoor open space in the Tate Britain Gallery (London), and the outdoor open space around Aldwych (London) are analysed using a GIS application called Isovist Analyst.

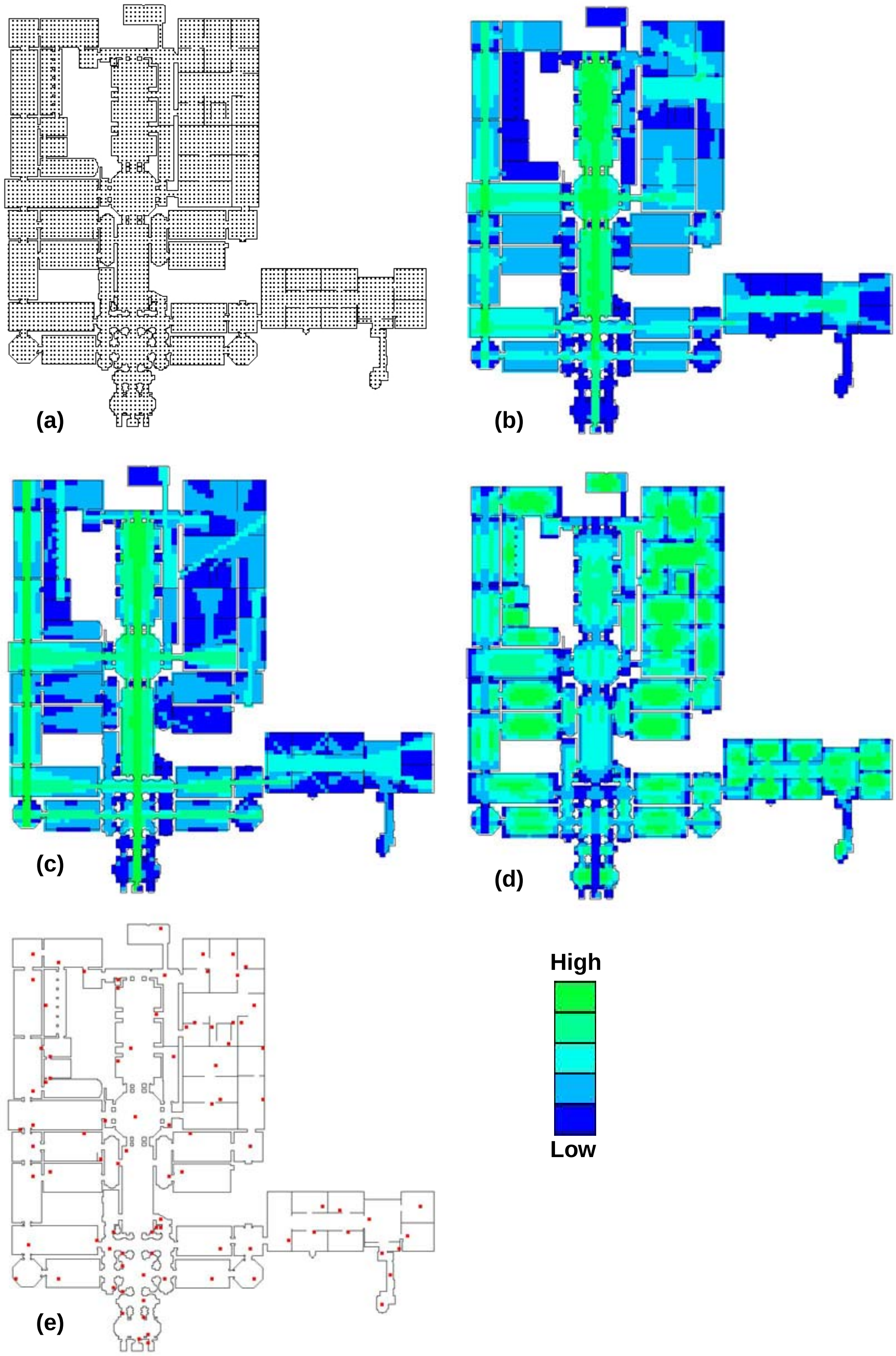


Figure 5. (a) Tate Britain Gallery with the dense mesh of observers, and the maps of (b) isovist area, (c) maximum diametric length, (d) circularity, and (e) optimal observers from ROPE algorithm.

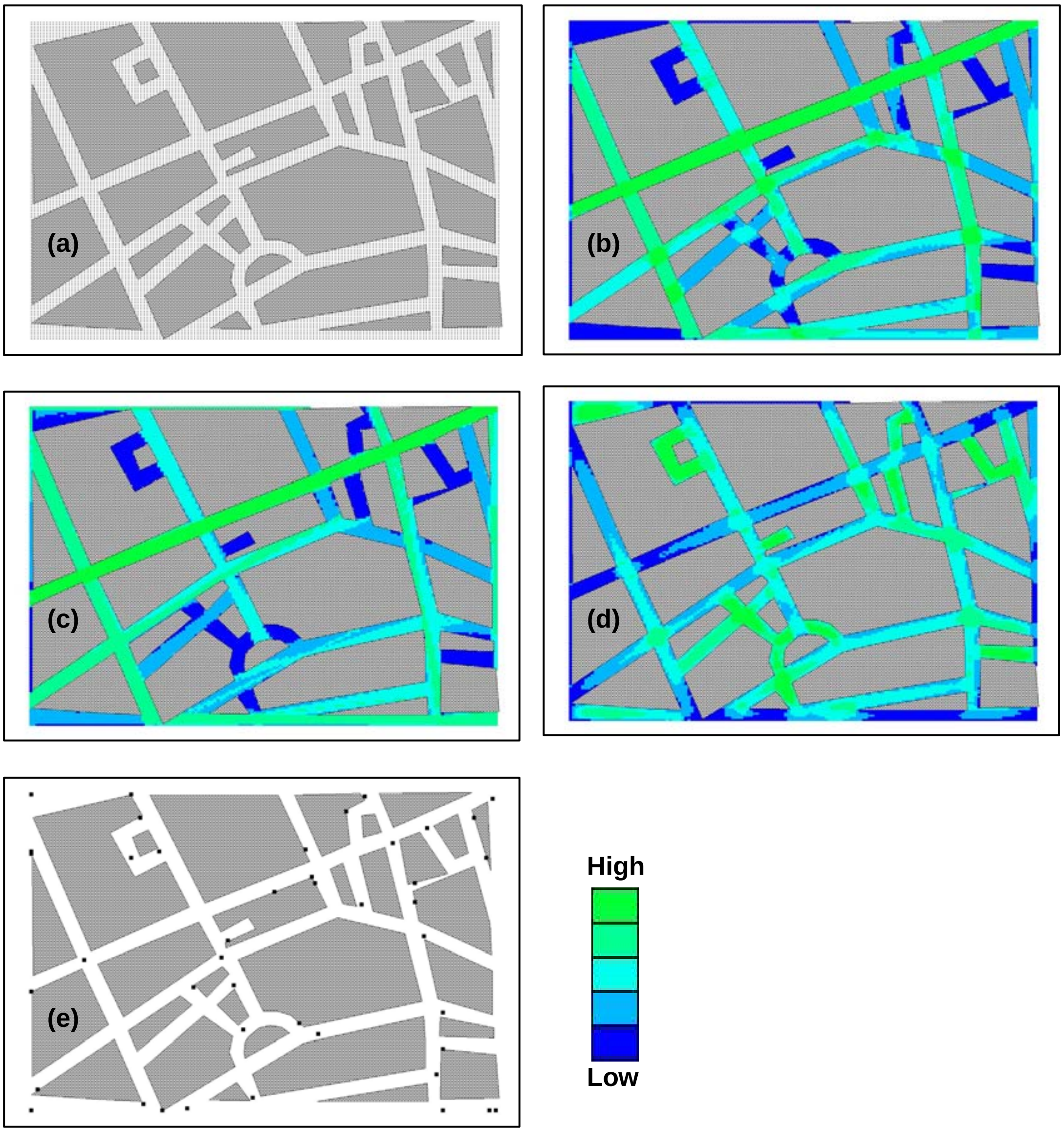


Figure 6. (a) Aldwych area in Central London with the dense mesh of observers, and the maps of (b) isovist area, (c) maximum diametric length, (d) circularity, and (e) optimal observers from ROPE algorithm.

The current work lacks a treatment of the practises and standards involved in surveillance planning in the industry and planning organisations. The implementation of ROPE technique in Isovist Analyst could be improved by practical considerations such as camera viewing distance, preferred location, and analysis of 3D open spaces.

Acknowledgements

We would like to thank Yiorgos Chrysanthou, Frank Warmerdam, Peter Wonka, Bill Hillier for providing intellectual and materials support at various stages of this research. Tate Britain Gallery floor plan is derived from the article by Conroy and Dalton (2001).

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