A digital image of the city: 3D isovists in Lynch’s urban analysis

Eugenio Morello*, Carlo Ratti
SENSEable City Laboratory, MIT 10-485, 77 Massachusetts Avenue, Cambridge, MA 02139, USA; e-mail: eugenio@mit.edu, ratti@mit.edu
Received 12 December 2007; in revised form 16 May 2008; published online 6 April 2009

Abstract. New techniques to measure 2D and 3D visibility over urban spaces are presented in this paper. The concept of the isovist, that is, the visible space from a vantage point, could help in providing a quantifiable basis for Lynch’s urban analysis, as outlined in his book [Lynch, 1960 The Image of the City (MIT Press, Cambridge, MA)]. We also expand on the concept of 3D isovists and develop a new technique to calculate them on digital elevation models, whereby the same input information can be processed easily in pixel coordinates and in voxel space, that is, a 3D array of urban-visibility measures. The investigation of what we have called the ‘isovisimatrix’ seems to allow a very useful interpretation of visibility from a visual-perception viewpoint. The approach presented here suggests helpful applications for urban design, in particular for predicting the visual impact of new buildings on the physical context and understanding how open spaces may be used by people depending on visibility features.

1 Introduction
In this study we extend the concept of the isovist, that is, the visible space from a vantage point, in three dimensions and examine how it could help to provide a quantifiable basis for Lynch’s urban analysis, as outlined in his book The Image of the City (1960). Lynch’s visual elements will be reinterpreted through 2D isovists, isovistfields, and 3D isovists, allowing the calculation of maps and qualitative indications about the visual experience through open spaces in the city.

Since their introduction to the planning community by Benedikt (1979), isovists have been an active field of research. A number of authors have suggested techniques to calculate them over extensive urban areas and to describe their shape, thus gaining insight into urban morphology. However, the proliferation of analyses produces an endless number of outputs that are difficult to interpret from an architectural and urban standpoint. Furthermore, traditional calculation methods consider a model which is too far from real human visual experience: first, it does not take into account the vertical dimension—the analyzed space is 2D; second, traditional methods do not consider the dynamic participation of moving through space, which is a fundamental characteristic of visual knowledge.

The aim of this paper is twofold. First, it introduces, in addition to the well-known definitions of isovists and isovistfields, a 3D description of visible space from any given vantage point and shows how it can be calculated. This has recently become possible thanks to increased computing power and new image-processing techniques applied to very simple models of urban form, the so-called digital elevation models [DEMs (see, for example, Ratti and Richens, 2004)]. Outputs of the analysis are stored in a voxel space, that is, a 3D matrix of urban-visibility measures. The analysis of what we have called the ‘isovisimatrix’ seems to allow a more useful interpretation of visibility from a visual-perception point of view.

* Also at Department of Architecture and Planning, Milan Polytechnic, Via Bonardi 3, 20133 Milan, Italy; e-mail: eugenio.morello@polimi.it
Second, this paper aims to show how 2D and 3D visibility analysis could help to reinterpret the visual elements defined by Lynch. Lynch’s theory emphasizes the ‘legibility’ (and ‘imageability’) of urban spaces for both practical tasks, such as wayfinding, and as a feature of physical and emotional well-being in the city. Our attempt is indeed to assess the environmental quality of urban forms. The commonly considered visual elements are: path, landmark, edge, node, and district. It is surprising that, to date, there have not been many attempts to translate these into quantifiable measures, apart from Dalton and Bafna’s work (2003) on the framework of space syntax. Revisiting Lynch’s theory seems appropriate, as it provides a perceptual framework to orient the definition of visibility parameters, without following technique-led investigations. We are conscious that Lynch’s urban-image theory is not limited to visual aspects of the urban form, but also concerns structural aspects and relations between physical elements. However, we focus on providing a definition in terms of visibility for most of Lynch’s elements, and show their calculation, thus providing a new quantitative method to describe and compare the spatial qualities of urban textures.

2 The research context
The first attempts to assess the environmental quality of urban spaces on the basis of perception were presented in the late 1950s and in the 1960s as a result of interdisciplinary studies in architecture, psychology, anthropology, and sociology. The introduction of the discipline of proxemics by the American anthropologist Hall (1960; 1966) opened up a series of applications in architectural and urban design. Proxemics is defined as the study of spatial interrelationships between people as they interact. Hall investigated the cultural aspects that involve human behavior in space. In his theory the ‘social field of vision’ determines human behavior and communication in social spaces. The key descriptors for this discipline are the social distances that enable different types of human activity and different levels of intimacy in the interrelationship between human beings.

Many attempts to translate visual-perception research into architectural and urban design theory followed. The best known contribution in urban-planning studies is perhaps Lynch’s The Image of the City (1960). This book deals with the visual appearance of cities and recognizes that giving visual form to cities is a design problem. “We are continuously engaged in the attempt to organize our surroundings, to structure and identify them. Various environments are more or less amenable to such treatment. When reshaping cities it should be possible to give them a form which facilitates these organizing efforts rather than frustrates them” (Lynch, 1960, page 90). Everyone builds environmental images that are helpful in the process of wayfinding. These ‘city mental maps’ contain many elements that can describe our experience and the image of the environment; they can explain our tools for orientation and memorization, and also represent an evaluation of the ‘legibility’ of a built context. Legibility is the clarity of the cityscape, “the ease with which its parts can be recognized and can be organized into a coherent pattern” (Lynch, 1960, page 2). Lynch also introduces the derived notion of ‘imageability’, which is “that quality in a physical object which gives it a high probability of evoking a strong image in any given observer. It is that shape, colour, or arrangement which facilitates the making of vividly identified, powerfully structured, highly useful mental images of the environment” (Lynch, 1960, page 9). An important point in Lynch’s work is that he does not make a judgment on the value of different urban spaces, but he refers to legibility and imageability as evaluating parameters. In other words, Lynch attempts to determine the degree of orderliness of an urban structure, moving his attention away from other criteria for evaluation.
An attempt was made by Dalton and Bafna (2003) to translate Lynch’s theory into digital automatic parameterization using the space syntax technique. Lynch’s visual elements are redefined using spatial notations, basically the axial line and the isovist. As well as the concepts of legibility and imageability introduced by Lynch, the space syntax theory adds the notion of ‘intelligibility’, which represents the ‘quality of an environment as being comprehensible and easily navigable’ (Dalton and Bafna, 2003, 59.1). The notion of intelligibility was defined by Hillier (1996, page 129) as a key concept for space syntax:

“Intelligibility ... means the degree to which what we can see from the spaces that make up the system—that is how many other spaces are connected to it—is a good guide to what we cannot see, that is the integration of each space into the system as a whole. An intelligible system is one in which well-connected spaces also tend to be well-integrated spaces. An unintelligible system is one where well-connected spaces are not well integrated, so that what we can see of their connections misleads us about the status of that space in the system as a whole.”

To strengthen the meaning of accessibility in isovist analysis, Dalton and Bafna (2003) suggest a stronger relationship between the two concepts of imageability and intelligibility. The study by Dalton and Bafna (2003) is based on the reduction of Lynch’s visual elements through 2D syntactical variables. This approach is shown to be lacking, because space syntax theory does not consider the visual character and tries to translate visual features into structural features. For instance, some discrepancies emerge in the results, where the maps produced through space syntax differ from mental maps provided in the same case study of Boston analyzed by Lynch. Some paths which are not highly intelligible in space syntax theory play a major role in the visual maps provided by Lynch. This means that the agreement between well-connected spaces and visual character is not always verified. The same considerations can be seen with other visual elements, especially for those elements which are not properly georeferred, such as edges and landmarks. It seems that Lynch’s approach could benefit from the analysis of urban texture in terms of visibility and lines of sight. Different parameters are commonly used and they are outlined below.

2.1 Isovists

Originally the notion of the isovist was presented by Tandy (1967) in the field of landscape geography, but it was Benedikt (1979) who first introduced the concept in architectural studies. An isovist is defined as the field of view available from a specific point of view. An isovist can also be understood as the area not in the shadow cast from a point light source. Usually, in scientific literature, an isovist represents a horizontal slice through this field of view taken at eye height and parallel to the ground plane. In general, an isovist is a closed 2D polygon. Complementary definitions have been given more recently: an isovist “is defined as a set of points or vertices of a graph, \( j \in Z_i, j = 1, 2, ..., n_i \), where \( Z_i \) is the generic field associated with the vantage point or vertex \( I_i \), and \( n_i \) is the total number of points in \( Z_i \), including the vantage vertex \( I_i \)” (Batty, 2001, page 125). Or, translated into space syntax theory, “an isovist is the sum of the infinite number of lines of sight (or axial lines) that pass through a single point in space (usually at eye height) and occupy the same plane (usually parallel to the ground plane)” (Dalton and Bafna, 2003, 59.6).

Many characteristics and indicators describe an isovist. Numerous indicators and analyses around isovists were proposed by Benedikt (1979), de Floriani et al (1994), Batty (2001), and Turner et al (2001). If we concentrate our attention on more pragmatic applications of these studies, then the field of investigation decreases dramatically. As reported by Stamps (2005), only a few geometrical variables would be
significant for distinguishing between isovists. Our interest is in those identifiable characteristics that influence the use of space. Although isovist computation has been used mainly for analyses at the scale of buildings, and space syntax as a suitable technique to quantify environmental and spatial indicators at the urban scale, we argue that isovists can also be used successfully for architectural open spaces and large-scale spatial configurations. These latter applications represent the main field of action for urban designers, where the technique presented here reveals its highest potential.

2.2 Isovistfields
Enlarging these latter considerations to isovistfields would give much more significant results in analyzing large open or interior spaces. For instance, starting from the concept of the isovist we can derive the concept of the isovistfield, first introduced by Benedikt (1979). An isovistfield represents a collection of views accumulated at each point in an open space. It shows what is contained within each viewshed (or isovist) at every viewpoint in the space. In other words, it describes calculated values of isovists.

Table 1. Calculation of isovist properties from two different vantage points in the open spaces of the Milan Trade Fair site masterplan.

| Property of the 2D isovist | Isovist with viewpoint = (630,530) | Isovist with viewpoint = (730,700) |
|----------------------------|---------------------------------|---------------------------------|
| **Fundamental properties**  |                                 |                                 |
| Area of isovist (A) (m²)    | 119,104                         | 178,644                         |
| Perimeter of isovist (P) (m)| 6,824.00                        | 7,224.50                        |
| Solid perimeter (Ps) (m)    | 2,506.10                        | 2,840.50                        |
| Solid perimeter to perimeter ratio | 36.7250                      | 39.3171                        |
| Occluding perimeter (m)     | 4,317.90                        | 4,384.00                        |
| Maximal radial distance (m) | 524.3892                        | 604.7942                        |
| Minimal radial distance (m) | 72.0278                         | 99.2975                         |
| Average radial distance (m) | 260.8405                        | 287.6694                        |
| **Elongation properties**   |                                 |                                 |
| Compactness                 | 0.4974                          | 0.4756                          |
| Convexity—cluster index     | 0.1793                          | 0.2074                          |
| Concavity ($P^2/4\pi$)      | 31.1132                         | 23.2497                         |
| Ratio of eigenvalues         | 2.5454                          | 2.1746                          |
| **Radial variances**        |                                 |                                 |
| Entropy                     | 7.6276                          | 7.5785                          |
| Radial standard deviation    | 112.1557                        | 112.2225                        |
| Radial variance              | 40,541 818.0381                 | 40,073 812.7485                 |
| Radial skew                  | 1,815,692,803.6319              | 3,042,853,616.2578              |
| Skewness                     | 0.3997                          | 0.6772                          |
and assigns this value to each analyzed vantage point: for example the areas and
perimeters of the isovists. “Insofar as the fields represent potential experience,
philosophically one might lean towards the ‘idealist’ view of reality as nothing other
than the union of all possible experiences” (Benedikt, 1979, page 63). For instance,
isovist fields sum all single visual perceptions and offer an objective and unique
characterization of an environment.

In fact, the description of open spaces through maps visualizing isovist fields
allows the character of the space to emerge clearly. We have made the calculation for
all the previously defined properties of isovists, grouped into three macrocategories:
fundamental properties, elongation properties, and the radial variances, as classified
in many studies.

Table 1 shows a companion of two isovists in two different design schemes for open
spaces proposed for the redevelopment of the Milan Trade Fair site in central Milan.
The area selected for the analysis is a 1 km wide square. Considering that human
perception of space changes with distance, the size of the site does not require restrict-
ing the maximum extension of isovists. We have computed fundamental properties
for both isovists. More interesting for the analysis are the isovist fields calculated for
the public spaces in the winning design scheme shown in figure 1 and table 2. Diverse
characters of spaces emerge, thus contributing to a better understanding of the possible
uses by people.

![IVF of areas](image1.png)

**Figure 1.** [In color online, see http://dx.doi.org/10.1068/b34144t] 2D isovist fields (IVFs) for different
properties computed on the open spaces of the Milan Trade Fair site masterplan.
3 Isovists in space
3.1 3D Isovists

Another branch of research that aims to measure the qualitative experience of human perception tries to quantify the visual experience in the third dimension. Fisher-Gewirtzman and other researchers at the Technion–Israel Institute of Technology (Fisher-Gewirtzman, 1998; Fisher-Gewirtzman et al, 2000; 2003; 2005) developed a more realistic model for the translation of Benedikt’s isovist in space. First introduced by Fisher-Gewirtzman (1998), and later developed as an automated model (Fisher-Gewirtzman and Wagner, 2003; Fisher-Gewirtzman et al, 2003; 2005), the spatial openness index (SO) is defined as the volume of the part of a surrounding sphere which is visible from a given point of view. In other words, the visual perception is given through a spatial conical angle. The SO measures the net volume of open space.

The aim of this index is to describe the quality of both perception and comfort. In fact, it shows the openness to natural light, air, near and distant views, and is correlated to the concept of ‘perceived density’. To support their studies on the SO index, the researchers evaluated the perceived density by people responding to alternative spatial configurations, starting from the same built masses and comparing results with the SO index.

The SO index is a scalar, whereas our definition of an isovist in space is a shape in three dimensions. In fact, a 3D isovist defines the 3D field of view that can be seen from a vantage point with a circular rotation of 360° and from the ground to the sky. Compared with the definition of a 2D isovist, which considers a plan parallel to the ground, this new definition refers to the real perceived volumes in a 3D space. Adding the vertical dimension helps to simulate better the physical environment observed from the vantage point.

### Table 2

Mean values obtained for the sixteen isovist field maps computed on three different design solutions proposed for the redevelopment of the Milan Trade Fair site. The values are obtained as the weighted arithmetic averages resulting for each map.

|                     | Winning design scheme | Design scheme 2 | Design scheme 3 |
|---------------------|-----------------------|----------------|-----------------|
| **Fundamental properties** |                       |                |                 |
| Mean isovist area    | 81 200.00             | 106 600.00     | 93 388.56       |
| Mean isovist perimeter | 4 691.10             | 6 681.20       | 5 437.37        |
| Mean solid perimeter | 1 924.30             | 2 814.60       | 2 145.56        |
| Mean solid perimeter to perimeter ratio | 41.35 | 42.57 | 39.75 |
| Mean occluding perimeter | 27 776.40        | 3 866.10       | 3 291.31        |
| Mean maximum distance | 563.79               | 675.04         | 639.28          |
| Mean average distance | 240.87               | 303.64         | 263.75          |
| Mean minimum distance | 25.49                | 46.06          | 26.35           |
| **Elongation properties** |                       |                |                 |
| Mean compactness     | 0.43                  | 0.46           | 0.42            |
| Mean convexity       | 0.22                  | 0.22           | 0.20            |
| Mean concavity       | 22.33                 | 22.70          | 26.12           |
| Mean max to min radial ratio | 4.25 | 3.72 | 4.45 |
| **Radial variances** |                       |                |                 |
| Mean entropy         | 5.83                  | 6.09           | 5.64            |
| Mean standard deviation | 129.19               | 141.75        | 143.22          |
| Mean radial variance | 10 390 000.00        | 18 277 000.00  | 14 809 657.03  |
| Mean radial skew     | 7 452 800 000.00     | 1 716 000 000.00 | 1 553 153 045.93 |
| Mean skewness        | 0.44                  | 0.34           | 0.50            |
3.2 Calculation of 3D isovists with DEMs
All visibility calculations performed with the above techniques were implemented in this study with the technique based on image processing of DEMs using MATLAB (http://www.mathworks.com) (figure 2). Although many other computation programs seem to have great potential and easy interfaces, and are dedicated specifically to isovist calculation, the technique we use permits many indicators to be analyzed with great flexibility and in a very short time: 2D isovists, isovist fields, and 3D isovists can be generated using simple algorithms based on the calculation of lines of sight. Lines of sight are calculated passing through the viewpoint and with circular rotation covering 360°. From the viewpoint, a series of arrays are generated and these stop when they find built pixels (pixels with value >0). Once the visible area is determined we can derive all other indicators presented above using simple mathematical formulae.

We choose a viewpoint in the open space of the DEM we want to analyze. A large number of lines of sight passing through the vantage point are calculated in order to obtain a good approximation for covering all visible pixels from this point. For each

![Figure 2](image_url)  
**Figure 2.** [In color online.] A 2D isovist calculated through image processing with MATLAB. (a) The isovist visualized in its urban environment. (b) The isovist with increasing distance from the vantage point. (c) The perimeter of the isovist with the distance values highlighted. (The contour was enlarged for visualization purposes.)

![Figure 3](image_url)  
**Figure 3.** [In color online.] Calculating the 3D isovist on a digital elevator model: (a) the axonometric view of the Milan Trade Fair masterplan; (b) the 3D representation of the isovist from a vantage point on the ground.
line of sight we compute the required information and store the results in different arrays (see figures 3 and 4). Namely, we calculate an array containing the heights of the objects through the line, and an array with the distances from the viewpoint. We then compute the tangents of the heights to the distances, which is another way to consider the urban horizontal angle. Starting from the vantage point along the array, we store just the tangent that is bigger or equal to the one calculated on the previous point of the array. This step allows buildings that are shaded by others inside the visual cone to be discarded. In the 3D isovist we then store the maximum values of the product of these maximum tangents with the corresponding distances to the viewpoint and the height of the buildings at the same point. This final step allows these buildings that are behind others but still visible inside the visual cone to be visualized, because they are higher than the tangent falling on their façades. Now we can distribute the heights in a voxel space, assigning to each $z$-layer the corresponding values. In figure 3 the isovist was computed from a vantage point located in the square in front of the three towers designed for the Milan Trade Fair site masterplan. The calculated isovist distinguishes pixels that are hidden from the view of the observer and pixels that are visible.

![Figure 4](image)

Figure 4. Calculating the 3D isovist on a digital evaluation model of visible and hidden spaces.

### 3.3 The isovisimatrix

This process can be repeated at every vantage point in the open space in a very short time. In so doing we obtain a 3D matrix, a sort of 3D field, where we store and sum all visible and hidden voxels from each viewpoint. For instance, a voxel space is a 3D matrix made by superimposing horizontal matrices taken at different heights. In this example, we collect in the voxel space all visibility measures inside a volume. In other words we have calculated the isovisimatrix which contains the values of visibility for each voxel in the space weighted on the considered viewpoints in the open space, usually the vantage points at street level.

The calculation of the isovisimatrixes over the design projects for the Milan Trade Fair site masterplan reveals itself to be very useful for understanding the visual impact of tall buildings on urban surroundings. In figure 5 a section through the towers represents the rate of visibility for the intersected façades, considering all computed vantage points at ground level.

### 3.4 Calculation of the isovisimatrix

The computation requires summing all 3D isovist into a new 3D matrix in voxel space and weighting results according to the number of open-space pixels. In other words, for every voxel contained in the 3D matrix, we assign a value that assesses the
percentage of times that this voxel is visible from street level. This is possible if we translate all z-values contained in every pixel of each isovist into voxels assigned to the corresponding z-levels in the 3D matrix.

Our interest is mainly to determine the rate of visibility of buildings. In order to do that, we have to discard voxels of open spaces and hold only built pixels. Results can be visualized by simply slicing the voxel space and highlighting those buildings that we want to analyze as shown in figure 5.

![Figure 5.](image)

**Figure 5.** [In color online.] (a) Slice through an isovistmatrix; (b) the section of the voxel space shows different levels of visibility of the façades of buildings. Red shows the most visible surfaces from all vantage points at street level.

### 4 Lynch's five visual elements: from qualitative to quantifiable indicators for defining environmental quality of urban structures

Through isovists, isovistfields, and 3D isovists it is possible to reinterpret Lynch's parameters for characterizing the legibility and imageability of the urban form. Criteria to assess the legibility of an urban environment are based on five well-known visual elements, "the building blocks in the process of making firm, differentiated structures at the urban scale" (Lynch, 1960, page 95). The following five visual elements show different qualities that make them easily identifiable (Lynch, 1960, pages 46–83): paths, nodes, districts, edges, and landmarks.

In the space syntax study by Dalton and Bafna (2003), the authors acknowledge that spatial representation using isovists could potentially be useful to overcome the simplications due to 1D axial lines. Isovists allow consideration of the spatial character and the boundaries of what can be seen from vantage points, enlarging simple results based only on connectivity of lines of sight. In general, the space syntax approach emphasizes structural aspects of Lynch’s theory, whereas our technique highlights visibility aspects. For instance, all analyses of the five visual elements can be conducted on the DEMs, calculating the isovists along specific directions. To interpret Lynch’s visual elements it is necessary to better understand their meaning and to try to apply specific calculations for each element. Some analyses might require, for example, calculations based on simple 2D isovists (nodes and districts), others (edges and landmarks) require a more complex voxel space. In any case, we provide calculations on 3D isovists which seem to be more faithful to actual visual experience and do not imply a more time-consuming computation. In table 3 all five visual elements are characterized and for each an example from the case study of the Milan Trade Fair site and a calculation method are presented. A brief explanation of each element follows.
Table 3. Lynch's (1960) five visual elements reinterpreted and computed using image processing on digital evaluation models and calculations of 3D isovists on the maps.

| Visual elements | Isovist analysis on digital elevation models |
|-----------------|---------------------------------------------|
| definitions     | examples                                    |
| **Paths**       |                                             |
| Channels for potential movement (page 47) | Main streets and boulevards | What is its rhythm? (on static and motional views) |
| Strong visual character Kinesthetic quality |                                             | → compute longest axial lines |
| The destination toward which it goes, clear focuses of origin and destination |                                             | → verify the sense of motion along the path; the dynamic shaping of the movement lines will give its identity and will produce a continuous experience over time |
|                 |                                             | → verify the visibility of the focus along the street. The continuity of the view is a characteristic of a clear position in a place for the observer |
| **Nodes**       |                                             |
| Lynch distinguishes two types of nodes: at major intersections and those characterized by concentration with a thematic activity Clear Shape Key points in way finding Contribute to the sense of orientation in the city Points with crucial route choices Nodes with strong visual character, distinctive in their surroundings and intensifying some of their characteristics (page 77) | The central square, the park, a place of urbanity, where more functions happen simultaneously | Does such a space have a sufficiently strong identity to contain and promote these functions? (on static views) |
|                 |                                             | → verify homogeneity or fragmentation of the boundaries: concave shaped nodes (star shaped) and proximity to highly integrated axial lines convex shaped nodes (compact shaped) |
|                 |                                             | → compute area to perimeter ratio |
|                 |                                             | → compute mean isovist length |
|                 |                                             | → compute circularity (Benedikt, 1979) |
|                 |                                             | → compute entropy (Turner et al, 2001) |

→ count on a pixel per pixel basis the number of visible voxels along the path, in order to establish a constant visual recurrence of built masses
Table 3 (continued).

| Visual elements | Isovist analysis on digital elevation models |
|-----------------|---------------------------------------------|
|                 | definitions | examples | questions | 2D | 3D |
| **Districts**   | Clear edges of districts | Neighbourhoods with clear boundaries and with strong character and containing similar urban functions | Is this district coherent? Does it have a clear structure? (on motional views) → verify the homogeneity or the fragmentation of the boundaries → for describing the internal character of districts, verify the uniform distribution of isovists values, in particular the length of average radials → for understanding the external character of districts, verify if the supposed boundary pixels of a district act as paths or as edges | → compute the number of visible voxels that appear on each pixel of open space and verify if its distribution reveals some homogeneity on a larger scale of the district |
| **Edges**       | “Linear elements not considered as paths” (page 62) “Boundaries between two kinds of areas” (page 62) “Visually prominent, ... continuous in form and impenetrable to cross movement” (page 62) “Tend to fragment (the environment)” (page 63) | Urban barriers like infrastructures, or long and uniformly built prospects along streets | Is the edge continuous? Is it readable as a strong element in its surroundings? (on motional views) → verify the uniform increase or decrease in the radial length (distribution of radial variances) → compute the areas of visible vertical surfaces that appear on each pixel of open space and verify if isolines reveal edges | → compute the number of visible voxels that appear on each pixel of open space and verify if isolines reveal edges |
| **Landmarks**   | Primary quality: ability to be visible over long vistas (far and near), where easy to be seen | Paradigmatic buildings and monuments | Is the landmark located in the correct position? | → verify the visibility (occlusivity) of the landmark from far and from near distance (at the base) → verify the homogeneous visibility of the object from far away → calculate the rate of visibility from street level through isovisimatrix |
4.1 Paths, nodes, and districts

Below we summarize the definitions given by Lynch (1960):

1. Paths (streets, walkways, transit lines, canals, railroads) are channels along which
the observer customarily, occasionally, or potentially moves. Paths are predominant
elements and people observe the environment while moving through paths. They are
characterized by: continuity, directional quality, gradients (for example, gradient of use
intensity, prolonged curves).

2. Nodes (junctions, places of a break in transportation, crossing of paths) are points,
strategic spots in a city into which an observer can enter, and are the intensive foci
to and from which he is travelling. Otherwise they can represent concentrations.

3. Districts (city regions, neighborhoods) are the medium-to-large sections of the city,
conceived of as having 2D extent. Districts have common character: shape, texture,
class, ethnic area.

The first two georeferred visual elements can be computed easily with simple
analyses of 2D isovists; the analysis of districts, however, requires a more complex
interpretation that does not exclusively concern the study of the visual aspect, but also
deals with structural aspects of the city at a larger scale. Isovist fields can highlight
special isolines on open spaces revealing boundaries, paths, or edges; summed together
these elements can characterize the district.

A more accurate visibility analysis can be conducted, for example, on paths. An
attempt to obtain information about variation in the landscape when moving along
a path was conducted by Weitkamp et al (2007). Their graphs describe gradual changes
versus abrupt changes in relation to the size of visible areas along the road. Among
other analyses introduced in their study, the view from the road represents the most
promising application for understanding the variety and complexity of perceived open
spaces.

In general, paths are characterized by different measures derived from each isovist:
the areas, perimeters, maximum, minimum, and average lengths of the radials, and the
compactness and convexity indexes. All these values represent different arrays and can
be displayed in the form of histograms (figure 6) or can be superimposed on the plan.
These diagrams interpret the visual rhythm and character of the path. For instance,
we can recognize paths with a regular and controlled rhythm, others with a crescendo
effect due to the increasing visual openness, and those with no controlled visual quality
and high fragmentation. Finer investigations benefit from the computation of 3D
isovists along the path, adding more specific information about the quantity of built
façades—or voxels—visible along the way. For instance, a path can be characterized
by an elevated number of visible surfaces along it. Figure 7 shows a sequence of top
views of 3D isovists along a path: gray pixels represent visible horizontal surfaces
computed at eye level and white pixels reveal visible façades from each viewpoint.
This latter information is very useful in determining whether a particular object of
interest is visible, or when it becomes visible, along a path. In fact, instead of simu-
lating more sophisticated visualizations, these maps give an immediate understanding
about the visibility of façades in urban space.

In particular, the cumulative opening of vistas can be displayed in the form of
histograms or in a more diagrammatic plan (figure 8), enabling a high degree of control
on projects. In fact, we can easily define when a hidden object will reveal itself along
a path or, in contrast, which objects we want to keep hidden from view. In figure 8
the comparison of two design schemes proposed for the same urban site shows very
different visual experiences along the path that connects two main attractions and
crosses the entire site from southwest to northeast. The open areas of the project
in figures 8(a) and 8(b) reveal a more intimate character, whereby the pedestrians
Figure 6. (a) The path (in red) which connects the subway station to the Vigorelli Stadium in the project proposed by the architect Renzo Piano for the redevelopment of the Milan Trade Fair site. (b) Maximum distances for each isovist along the path (40 steps) (Batty, 2001); (c) minimum distances (Batty, 2001), (d) areas; (e) perimeters; (f) convexity cluster index for each viewpoint; (g) compactness index for each viewpoint (Batty, 2001).
experience new panoramas at different stages (see the more distributed peaks on the histogram); whereas the project in figures 8(c) and 8(d) immediately present a surprise effect on entering the park (see the peak at steps 9–11) when the majority of the open spaces are perceived at once.

In general we distinguish two types of analyses of sequences: sequences based on a motional view (paths, such as the analysis presented above) and sequences computed on a static view (for example a panorama of 360° from a fixed vantage point).

Figure 7. Top views of 3D isovists calculated along the path which connects the subway station to the Vigorelli Stadium in the winning design scheme, highlighting the visible open areas at ground level.

Figure 8. [In color online.] The cumulative opening of vistas along the path which connects the subway station to the Vigorelli Stadium computed in 40 steps on the winning design scheme (a) and in (c) for the project proposed by Renzo Piano shown in figure 6. Histograms (b) and (d) show the square meters of discovered areas along the paths in (a) and (c), respectively.
Static views can be evaluated by calculating the maximum, minimum, and average lengths of the radials of the isovist, and derived parameters from their sequences (for example, standard deviation). This last typology of analysis, on the basis of static views, is indicated particularly when dealing with Lynch's nodes. The visual quality of nodes derives mainly from the analysis of the boundaries of these spaces.

4.2 Edges

Edges (shores, railroads, cuts, edges of development, walls) are linear elements not used or considered as paths by the observer. In general they are represented by boundaries between two phases: barriers or seams, important organizing features. Edges can be detected quickly with the image processing of DEMs by measuring their continuity along a motional view. This can be addressed with 2D isovists by verifying the distribution of radial variances (regular increase or decrease) and with 3D isovists through the computation of the variability of built barriers—in terms of square meters of vertical surface or the number of visible voxels—on open space pixels.

4.3 Landmarks

Landmarks (buildings, signs, stores, mountains) are external reference points, where the observer does not enter. Landmarks are simply defined as physical objects, identified by uniqueness, specialization, and singularity. They are often distant, and symbolize a constant direction. As a visual element, a landmark seems to be more complex to parameterize and the space syntax approach gave an inadequate description.

The main characteristic of a landmark, such as presented by Lynch, is its ability to be visible over long vistas (from far and near). In other words, a landmark must be easily intercepted by lines of sight from different viewpoints in its environment and must represent a clear reference point. More than other visual elements, the landmark is explicitly defined by its visual components in the surroundings. The analyses presented here, on the basis of 3D isovist calculations are particularly suitable to our purposes.

First, we compute an ‘isovisivoxelspace’ which assigns to every voxel a value of visibility: voxels with 100% visibility are the ones that can be seen from all vantage points on the ground. We can therefore consider the voxels tangent to the façades of buildings and determine which buildings have a major potential for visibility in their environment.

We can also verify the homogeneity of the rate of visibility given by different buildings from the ground to the top. The problem with many skyscrapers presented in Lynch's case study is that they lose their role as a landmark from nearby, when the base is no longer identifiable and the building is mainly hidden to the pedestrian visual cone.

Another analysis aims to verify if the supposed landmark is easily visible from strategic points in the city. For example, we can investigate if a landmark can help people in wayfinding in important places in the city (gates, mobility nodes). In short, we might ask if the building represents a constant reference or, on the contrary, if it is mainly hidden from view.

Conclusion

In this paper we have introduced a technique to calculate 3D isovists and isovisimatrixes. The technique reveals itself to be particularly efficient for visual perception analysis on open spaces and over large urban areas. We have thus proposed a reinterpretation of Lynch's urban analysis on visual elements, highlighting how the use of 3D isovists could provide a more precise interpretation of the visual elements by considering the physical layout of the built environment as a main variable. We have seen that
the use of 3D isovists is not always necessary and a combination with 2D isovist analysis is compatible with the proposed technique, because all implemented tools require the same input, that is, the DEM of the urban texture.

Starting from these separate analyses of visual elements in the urban texture, further work should provide synthetic maps that can identify the prevailing character for each point in space, depending on careful weighting of the main indicators at these locations. As well as the identification of Lynch’s visual elements, we could provide maps with other indicators that can explain the use of space by people. For instance, we could distinguish the use of different areas in a public square, where the configuration of space defines different perceptions and different senses of control over the whole space, and where areas defined as ‘soft edges’, areas of high safety, high visibility, and high legibility can be mapped easily. Furthermore, geometric features of isovists, such as maximum radials calculated from vantage points, combined with the analysis of social distance as defined by Hall (1960) could add more information about the type and vocation of spaces. This form of synthetic plot containing the prevailing perceived experiences could represent a very helpful strategic tool for urban designers.

All suggested applications on visibility analysis work well at the scale of architectural open spaces and large-scale spatial configurations, according to the limits of human vision. Therefore, tools are intended for urban designers in order to predict and to evaluate design schemes at the scale of masterplans. In general, the techniques presented here could have many applications in architectural design, for example, predicting in advance the impact of a building on the urban form. The rate of visibility and the visual presence of a building intended as a landmark could be evaluated depending on the initial targets of the project itself.

The implementation of isovist field analysis considering the third dimension could provide a more precise model, where the distinction of high versus low buildings might open up stimulating architectonic arguments for planning studies. More powerful computers will allow entire districts to be mapped, and general maps of visibility and visual accessibility of urban structures to be calculated.

Finally, returning to the general tasks of this research and as suggested by Benedikt at the conclusion of his paper, we should ask again, what it would be like if we could try to invert the process and “design environments not by the initial specification of real surfaces but by specification of the desired (potential) experience-in-space in the first place”? (Benedikt, 1979, page 63). For instance, the visual perception as form giver through the implementation of new tools for environmental prediction opens up a series of new strategies in the field of architectural and urban design and gives back to people a new central rule for their well-being in urban space.

Acknowledgements. We would like to thank the Fondazione Rocca and its president, Gianfelice Rocca, for providing generous funding for this research and for supporting the fellowship together with the DiAP Department of the Politecnico di Milano (in particular Sergio Porta). We are also indebted to many people at the Massachusetts Institute of Technology for their feedback and for providing an extremely stimulating research environment. Acknowledgements go to the Fondazione Fiera di Milano, in particular President Dr Luigi Roth, who provided the drawings of the design projects we used as case studies in this research.

References
Batty M, 2001, “Exploring isovist fields: space and shape in architectural and urban morphology” Environment and Planning B: Planning and Design 28 123 – 150
Benedikt M L, 1979, “To take hold of space: isovists and isovist fields” Environment and Planning B 6 47 – 65
Dalton R C, Bafna S, 2003, “The syntactical image of the city: a reciprocal definition of spatial syntaxes”, in International Space Syntax Symposium, London, http://www.spacesyntax/symposia/SSS4/fullpapers/59DaltonBafnapapers.pdf
de Floriani L, Marzano P, Puppo E, 1994, “Line-of-sight communication on terrain models” 
*International Journal of Geographical Information Systems* **8** 329 – 342

Fisher-Gewirtzman D, 1998 *A Method for Measuring in Dense Urban Environments* PhD thesis, 
Faculty of Architecture and Town Planning, Technion – Israel Institute of Technology, Haifa

Fisher-Gewirtzman D, Wagner I A, 2003, “Spatial openness as a practical metric for evaluating 
built-up environments” *Environment and Planning B: Planning and Design* **30** 37 – 49

Fisher-Gewirtzman D, Wagner A I, Zelman I, Zinger Y, 2000 *A Spatial-Openness Online Calculator* 
a Java/VRML applet, http://www.cs.technion.ac.il/~wagner/pub/soprog/SpatialOpenness.html

Fisher-Gewirtzman D, Burt M, Tzamir Y, 2003, “A 3D visual method for comparative evaluation 
of dense built-up environments” *Environment and Planning B: Planning and Design* **30** 575 – 587

Fisher-Gewirtzman D, Shach Pinsly D, Wagner I A, Burt M, 2005, “View-oriented three-dimensional 
visual analysis models for the urban environment” *Urban Design International* **10** 23 – 37

Hall E T, 1960 *The Silent Language* (Doubleday, New York)

Hall E T, 1966 *The Hidden Dimension* (Doubleday, New York)

Hillier B, 1996 *Space is the Machine* (Cambridge University Press, Cambridge)

Lynch K, 1960 *The Image of the City* (MIT Press, Cambridge, MA)

Ratti C, Richens P, 2004, “Raster analysis of urban form” *Environment and Planning B: Planning 
and Design* **31** 297 – 309

Stamps A E, 2005, “Isovists, enclosure, and permeability theory” *Environment and Planning B: 
Planning and Design* **32** 735 – 762

Tandy C R V, 1967, “The isovist method of landscape survey”, in *Methods of Landscape Analysis* 
Ed. H C Murray (Landscape Research Group, London) pp 9 – 10

Turner A, Doxa M, O’Sullivan D, Penn A, 2001, “From isovists to visibility graphs: a methodology 
for the analysis of architectural space” *Environment and Planning B: Planning and Design* **28** 
103 – 121

Weitkamp G, Bregt A, van Lammeren R, van den Berg A, 2007, “Three sampling methods for 
visibility measures of landscape perception”, in *Spatial Information Theory: Proceedings of 
the 8th International Conference, COSIT 2007 Melbourne, Australia, September 19 – 23* 
Eds S Winter, M Duckham, L Kulik, B Kuipers (Springer, Berlin) pp 268 – 284
Conditions of use. This article may be downloaded from the E&P website for personal research by members of subscribing organisations. This PDF may not be placed on any website (or other online distribution system) without permission of the publisher.