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Distance-weighted isovist area: An isovist index representing spatial proximity

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ABSTRACT

A method of calculating the isovist area weighted toward its origin point is presented. Although weighting area is a general idea, a specific method or its tangible implementation has been rarely established in the field of isovist analysis. The distance-based weighting is implemented by substituting the distance between the isovist origin and a point on the isovist boundary with a user-defined function. This substitution allows an arbitrary function to be used for the weighting. Emphasis on the proximate region results from, but not limited to, the use of a function with a non-increasing derivative. Three plausible attenuation functions are used to exhibit the effect of an attenuation function on weighting. The proposed weighted isovist area is compared with the conventional isovist area and other isovist indices. The comparisons show a noticeable difference of the proposed method. Therefore, the proposed weighted isovist is a potential tool for research in spatial cognition, and human behavior, in particular, when proximity to an observer needs to be considered. Work environments in a construction site and other issues involving proximity can be assessed as a part of construction site layout planning.

1. Introduction

An isovist is a spatial representation of how far and how much space can be seen from a viewpoint. Benedikt [1:47] defines an isovist as "the set of all points visible from a given vantage point in space." From a viewpoint, vertices and lines create a boundary to the observable area. This polygonal boundary represents the space as seen from the viewpoint. Turner et al. [2] developed applications for analyzing spaces through measuring isovists and demonstrated a systematic approach to apply the isovist concept in space. Batty [3] added a computation method for analyzing space using an isovist. In addition to defining isovists and explaining their properties [1–3], existing studies demonstrate the uses of isovists in analyzing the visual characteristics of built environments [2,3] and experimentally describe the relationship between isovists and user behavior [4]. In addition, studies of isovist-related measures have focused on developing the relationships between isovists in spatial fields. Turner et al. [2] developed models of spatial analysis based on the concept of an isovist. Spatial measures of isovists have been studied in relation to integrating isovists into the syntactic analysis of space [5].

The area of an isovist is a fundamental measure for analyzing spatial configurations. According to Benedikt's [1] geometric measures, the area as a spatial measure represents how much space can be seen from a given vantage point. Turner et al. [2] describe this spatial characteristic as neighborhood size. They argue that the area of the visible field, the isovist area, enables them to expand their arguments with regard to the measurement of spatial visibility. They also describe the isovist area as a local characteristic [2]. However, a further clarification regarding how local is local or the extent to which local boundaries can be included in the area of the visual field, is necessary. To answer these questions, an isovist measure that quantifies the local effect is needed. The conventional isovist area is ineffective in estimating proximity, as demonstrated by comparing concentrated and dispersed spaces (Fig. 1). The three spaces have the same area, but their local effect with regard to the center point may differ. Distance-based weighting recognizes such a difference.

The proposed method for calculating the isovist area adopts distance as a factor of the local effect, which is closely related to some sociological phenomena. Proximity with regard to a vantage point, which is estimated by the weighted isovist area, may represent the amount of available information at that point. Privacy, one of the major interests of spatial analysis, is closely related to personal information. Some isovist measures estimate the amount of information, which is hypothesized to reflect the degree of privacy. In addition, according to Jacobs' "eyes on the street" [8], security is also related to the amount of visibility in the built environment. An isovist-related index has demonstrated that crime

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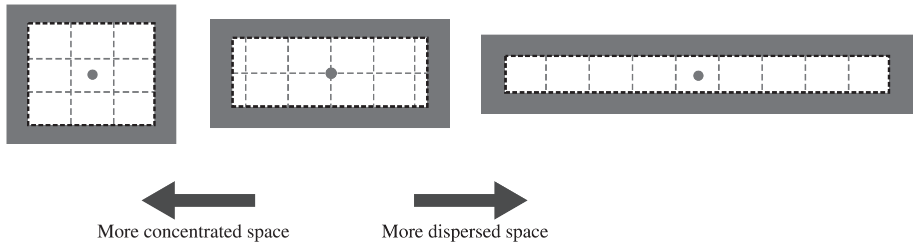

Fig. 1. Concentrated space versus dispersed space with the same isovist area.

locations are closely related to visual access and exposure in residential neighborhoods [7]. Because an isovist area represents the amount of visual field in its observing points, these isovist measures estimate the amount of information on visibility at a given place. For example, Davis and Benedikt [6] and Batty [3] mention area and perimeter as examples of such measures. According to them, the shape of an isovist is often estimated by ratio measures such as compactness and circularity. Previous studies have assumed that every point in an isovist has a uniform significance. In other words, the existing measures, including those mentioned above, exclude the effect of distance. However, being equally visible is different from being identical. For example, people may perceive the space close to them as more significant than spaces that are further away. The weighted isovist area proposed in this paper describes this situation. The concept of distance-based weighting is widely adopted in various disciplines [7,11–13]. In addition, studies of personal space and territory reveal that human perception continually interacts with the environment [9] and that environmental contexts distort visual perception [10]. Therefore, in addition to being included in many disciplines, weighting based on distance is reasonable because it can reflect proximity, which can explain some of the interaction between humans and the built environment.

2. Method

2.1. Research strategy and objectives

An abstract method to weight the isovist area is derived from the area equation in the two-dimensional polar coordinate system. Three distance-weighted models of an isovist area are proposed based on the abstract method. In total, four models are examined: three distance-weighted models with attenuation effects and a reference model without attenuation. These models are applied in two hypothetical cases: a building floor plan and an urban layout. Based on the results of the case studies, the effects of the weighted-area models are then quantitatively compared. The proposed models are also compared with the existing measures of Davis and Benedikt [6] and Batty [3].

2.2. Fundamentals

A model of a distance-weighted isovist is derived from an equation of area. In the polar coordinate system, the area of a plane region is defined as:

$$\left| \int_{\theta_{LB}}^{\theta_{UB}} \int_{r_{LB}(\theta)}^{r_{UB}(\theta)} r dr d\theta \right|$$

Eq. (1). Area of a region in the polar coordinate system

where r and θ are the distance and angle, respectively, and LB and UB stand for the lower and upper bounds of a variable. The area of a polygon is equal to the sum of all triangular subdivisions in the polygon. For example, in Fig. 2, a quadrilateral polygon in the two-dimensional coordinate system comprises four functions: $f_0(\theta), f_1(\theta), f_2(\theta)$, and $f_3(\theta)$.

Supposing that a point (0,0) is located in this quadrilateral polygon and the distances from this (0,0) point to four vertexes on the quadrilateral polygon are θ_0, θ_1, θ_2, and θ_3, then the area of the quadrilateral polygon is:

$$\int_{\theta_0}^{\theta_1} \int_0^{f_0(\theta)} r dr d\theta + \int_{\theta_1}^{\theta_2} \int_0^{f_1(\theta)} r dr d\theta + \int_{\theta_2}^{\theta_3} \int_0^{f_2(\theta)} r dr d\theta + \int_{\theta_3}^{\theta_0+2\pi} \int_0^{f_3(\theta)} r dr d\theta \quad (\theta_0<\theta_1<\theta_2<\theta_3).$$

Eq. (2). Area of a quadrilateral polygon

Thus, the area equation of a region (Eq. (2)) shows how an area that comprises four functions can be calculated from a given viewpoint (0, 0). The proposed isovist-area measure is developed using this example equation.

3. Model development

In the polar coordinate system, the area of a region can be defined as the absolute value of $\int\int r dr d\theta$ (Eq. (1)). The distance-based attenuation effect is implemented by substituting the term r in the equation with a different function. The equations of the conventional isovist area and the three proposed models are labeled (a) through (d) as listed in Table 1. Model (a) is a reference in which the isovist area is measured without attenuation. Models (b), (c), and (d) include attenuation effects that increase in the order of $r^{0.5}$, $\log_e(r+1)$, and $1-0.5^r$, respectively, as illustrated in Fig. 3. Model (a), with no attenuation effect, stands for the case where the importance of a region of identical area to a vantage point remains the same as the distance increases. Model (b), with an attenuation effect of $r^{0.5}$, increases more than model (c), with an attenuation effect of $\log_e(r+1)$, relative to distance. Similarly, model (c) attenuates the area more than model (d) relative to distance. These proposed functions are devised such that $f(r) - f(r-\Delta)$ is greater than or equal to $f(r+\Delta) - f(r)$ for a non-decreasing function and any positive value Δ smaller than r. This criterion is equivalent to a non-decreasing derivative for differentiable functions. A non-differentiable function can also be used as long as it meets the criterion. The weighting method

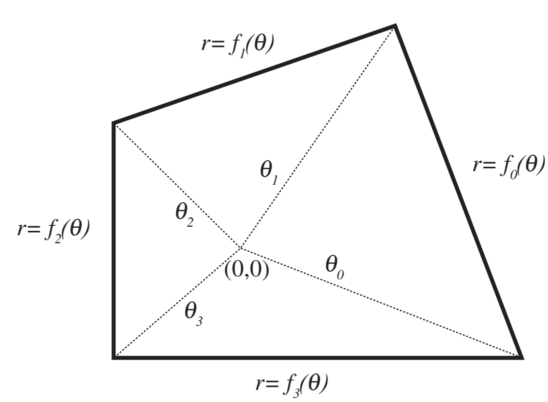

Fig. 2. Triangular subdivision of a quadrilateral polygon in the two-dimensional coordinate system.