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To take hold of space: isovists and isovist fields

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Abstract. The environment is defined as a collection of visible real surfaces in space. An *isovist* is the set of all points visible from a given vantage point in space and with respect to an environment. The shape and size of an isovist is liable to change with position. Numerical measures are proposed that quantify some salient size and shape features. These measures in turn create a set of scalar *isovist fields*. Sets of isovists and isovist fields form an alternative description of environments. The method seems relevant to behavioral and perceptual studies in architecture, especially in the areas of view control, privacy, 'defensibility', and in dynamic complexity and spaciousness judgements. Isovists and isovist fields also shed light on the meaning of prevalent architectural notions about *space*. In the latter role it is hoped that an information-field theory such as the one presented can help provide fruitful common ground for designers and researchers.

"To grasp space, to know how to *see* it, is the key to the understanding of building" (Zevi, 1957, page 23).

Introduction

Historically psychologists and architects have shared a vital interest in the nature and perception of *space*. Coinciding with the birth of modern experimental psychology, it was the late nineteenth century when space was first propounded as being of the essence in the experience of architecture (see van de Ven, 1974). From then until now (for example, Arnheim, 1977) one finds frequent reference in architectural writing about space to the perception psychology of the period. In sum though, one finds far greater emphasis on the traditional concerns and freedoms of aesthetic theory and criticism.

Recently, concerted attempts have been made to study the perception of architectural space empirically and experimentally (for example, Garling, 1969a; 1969b; 1970a; 1970b; Hayward and Franklin, 1974). For lack of an adequate way of describing architectural form and space as visually presented, however, these studies are necessarily still piecemeal and largely without theoretical framework. The purpose of this paper is to suggest a new and general way of describing architectural space: a way, it is hoped to show, that, although able to shed light on certain 'art-historical' concepts, makes architectural space, its description and perception, more easily quantifiable and more susceptible to scientific study.

A central difficulty in attempting to relate psychological research and theory in space perception to the knowledge and interests of architects is the fact that "the overwhelming bulk of perception research has been carried out in the context of *object perception* rather than *environment perception*" (Ittelson, 1976, page 142; my italics). Rooms, buildings, and groups of buildings seem if anything 'environmental' in our visual experience. By way of introduction to the investigations then, it is well to ask what makes objects 'objects' and environments 'environments'.

A number of related distinctions can be made between 'objects' and 'environments'. For example, objects are likely to be perceived as 'objects' on account of their seeming self-contained and movable, whereas environments are likely to be perceived as 'environments' for being open-ended and immovable (cars, airplanes, trains, etc. are interesting in this respect as they may be considered as objects or environments depending on one's viewpoint). But a third and major distinction, one upon whose implications I wish to focus attention, derives from what Ittelson terms "the surrounding character" of environments. Whereas in object perception one studies space in terms of the perceived distance, depth, size, or movement of isolated objects (often 'targets'), in environment perception one is called upon to regard space (a) as somehow substantial rather than empty, (b) as being defined by visible surfaces themselves not necessarily perceived as belonging to discrete objects, and (c) as having topological and formal qualities normally appreciated by continuous free movement through space by an observer always 'immersed' in the environment.

The unique approach of perception psychologist J J Gibson is of note here. Gibson (1966, page 221) defines the (visual) environment not as a collection of objects or as a chaos of stimuli upon which we impose sense, but as a surrounding "layout of surfaces" which gives *structure* to the light scattered from the surfaces. Environment perception, in his view, is merely *attention* to this structure: structure, or information, found everywhere one can see as a result of the 'sheaf' of light rays converging from all directions on the point of potential observation. This wavelength-and-intensity-structured sheaf of rays he calls the "optic array" (Gibson, 1966, page 188)[(1)].

Like Gibson's, the essence of the approach here is to ask about the information available about (or better, specific to) the environment (defined as a surrounding collection of surfaces) at a point in space. This entails seeking a description of the environment that is specific to a given position or path 'through' it. An observer's perception is thus circumscribed, if not determined, by the environment-as-presented at the point of observation. A cumulative understanding of the form of the environment is arrived at by perceiving variants and invariants in the transformation of the information available caused by the observer's movement. It follows that since points of potential observation are contiguous so then is the information available spread throughout space in a field-like way. The environment is then describable in an alternative fashion: fused with space, as it were, one might speak of the visual world as a *field of light-borne information* in which the observer is immersed and which he samples in accordance with his intentions and curiosities.

With this description as a goal, the interrelation of space, light, and visibility will be looked at closely. This will be done by means of *isovists*, location-specific patterns of visibility. Once suitable set-theoretic definitions of 'region of space' and 'environment' have been made, the isovist will be defined in relation to an environment and for each point in the region considered[(2)]. The nature of isovist boundaries will also be discussed. This in turn will lead to consideration of the capacity of isovist sets to specify completely an environment. The *shape* and *size* of the isovist become especially salient since these may change with position relative to the environment.

(1) Readers familiar with Gibson's work will see the affinity of *isovists* with *optic arrays*. I am not able to go more deeply into the connection in this paper. However, it is worth pointing out that in general Gibson's program for 'ecological optics' seems to offer new directions for the scientific study of space perception in the context of architectural inquiry, a fact that has not gone unnoticed by a few architectural theorists (for example, Boutourline, 1968; Lang, 1974; Hill, 1976; Thiel, 1970; 1972).

(2) The 'isovist' was presented as a method for recording landscape by Tandy (1967), based on an unpublished paper by A C Hardy of the University of Newcastle. To the best of my knowledge, however, the present exposition, analysis, and use of isovists is original. See also discussions of landscape visibility in terms of 'viewsheds' (Lynch, 1976; Amidon and Elsner, 1968) and 'intervisibility' (Gallagher, 1972).

It will be suggested that various perceptual and cognitive factors are well represented by certain numerical measures of shape and size attached to the isovist. These measures vary over space so as to create *fields* unique to a given environment. Potentially this may allow a number of spatial behaviors to be explained and predicted as field-dependent behaviors. Some examples will be discussed, as will some of the implications of the present approach for design, design theory, and the character of future research. The whole should be considered simply as an introduction to a new method of describing environmental or architectural space, and as an exploration of its potential.

The isovist

In euclidean three-dimensional space, E^3, let D be a simply connected region bounded by a smooth convex boundary, ∂D (figure 1). Let any connected subset of D consisting of points which happen to scatter visible light be termed a *visible surface*. In the case that this surface is an opaque, material, visible surface, humanly perceivable as such, we will speak of a real surface, S (this disqualifies the sky, glass, mirrors, mist, and perfectly black surfaces from being real surfaces). The (visual) *environment*, E, is defined as the collection of real surfaces in D, taking into account their spatial arrangement (figure 2). That is to say, any change in the position of one or more of these surfaces relative to the others and/or ∂D defines a new environment, E'.

For each point x in D, consider next the set

$$V_x = \{v \in D: \ v \text{ is visible from } x\}. \tag{1}$$

V_x is called the visible set or *isovist* at x; that is, the set of all points in D which are visible from the distinguished vantage point x. Note that the isovist is treated as a so-called pointed set, that is, a set V together with a distinguished point x such that $V_x = V$. It can happen that two different isovists correspond to the same subset V of D simply because one consists of the set V with the vantage point x and the other of the set V with the vantage point y ($y \neq x$). (A related way to specify V_x, in fact an alternative definition of the isovist, is as a point and a set of surfaces such that the surfaces are wholly visible from that point.) The vantage point of an isovist is of central importance since it represents the position of the observer whose spatial experience we are trying to explore. For clearly the shape and size of V_x depends on precisely which points in the region are visible from the vantage point, which of course depends in turn on the environment, E (figure 3).

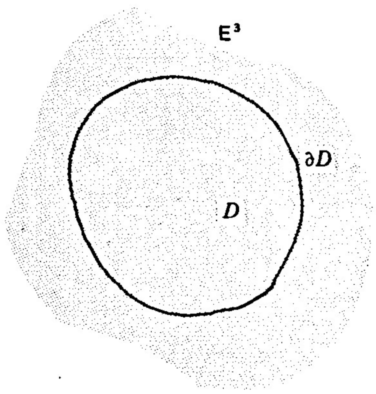


Figure 1. The region D in E^3.

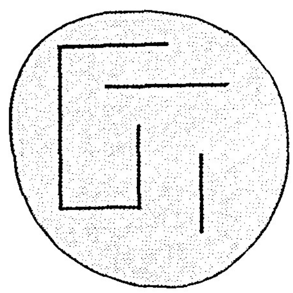


Figure 2. An environment E in D.

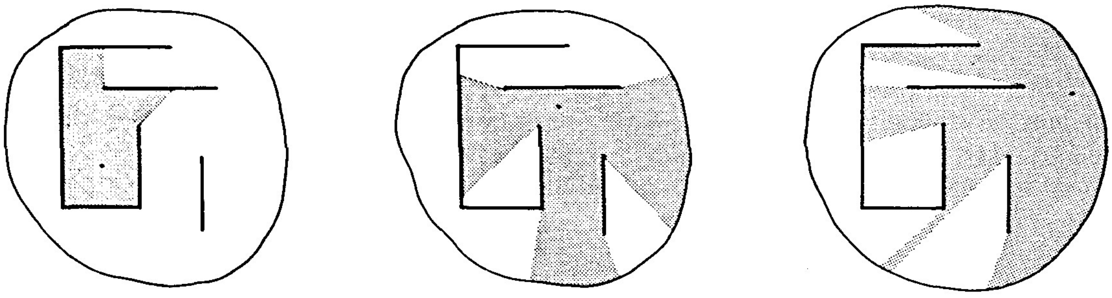
Now the boundary of an isovist can be decomposed into three parts: real surfaces, S_x, occluding radial surfaces, R_x, and region-boundary surfaces, ∂D_x (figure 4). Each of these boundary sets can have perceptual significance in its own right, as will be discussed.

For points x inside a solid body one has $V_x = \emptyset$. When one wishes to define the environment as a collection, E, of solids-with-surfaces inside D, one has that $E = \{x \in D\colon\ V_x = \emptyset\}$. The form of an environment is thus expressed by the set E or by the 'spatial inverse', $D-E$.

The reader may begin to see how isovists can be a tool for studying the spatial nature of environments. The character of V_x is specific to the vantage point x and the environment E, and changes from point to adjacent vantage point. This is interpretable as being correlated with the experience of an observer moving along a path Π in $D-E$. His view of and visual exposure to the environment will gradually and sometimes suddenly change with his position. *In fact describing an environment in terms of the position of its real surfaces in D (as is the typical procedure) is entirely equivalent to describing it by the set of all possible isovists corresponding to all points x in D.*

How many vantage points are required to see an entire environment E? Generally a finite and often a small number of isovists are sufficient. A set of isovists that satisfies these conditions is termed a *sufficient set*. (Environments can be devised with sufficient sets that are sufficient with respect to E and not sufficient with respect to $D-E$.) A given environment may have many sufficient sets. The number of isovists in the most economical (smallest) sufficient set(s) is termed the *sufficiency number* of that environment. For example, if the environment consists of a hollow sphere, then its sufficiency number is 5; a hollow cube or tetrahedron has a sufficiency number of 3; and so on.

Paths that connect the vantage points of the different isovists belonging to a sufficient set are termed *sufficient paths* [figure 5(a)]. The shortest such path is termed the minimal sufficient path or *minimal path* [figure 5(b)]. To illustrate this,



(a) (b) (c)

Figure 3. Three isovists in D, as created by E.

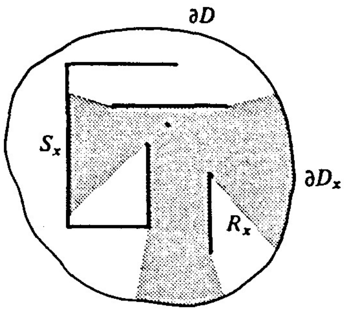


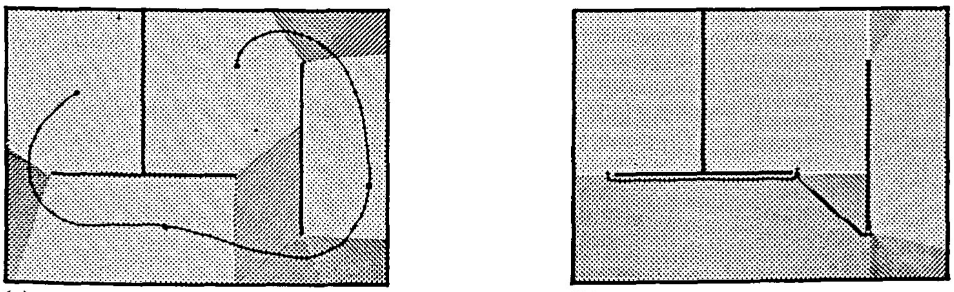
Figure 4. The boundary, ∂V_x, of an isovist V_x, decomposed into S_x, R_x, and ∂D_x.

one would expect a guard in a museum to discover and adopt if not close to the minimal path then at least a sufficient path with respect to the museum's interior.

If in D any two subregions (or paths for that matter) D_1 and D_2 are disjoint ($D_1 \cap D_2 = \emptyset$), they may be totally or partially concealed from each other. If the union of all the isovists in D_1 has a nonempty intersection with D_2 which does not contain the whole of D_2 then D_2 is *partially concealed* from D_1, and vice versa. If the intersection is empty then D_1 and D_2 are *totally concealed* from each other. (Notice that partial concealment can be asymmetrical—that is, D_1 might 'see' more of D_2 then D_2 can see of D_1. Extreme asymmetry of concealment is a characteristic of peepholes.) In similar vein, if the intersection of the unions of the isovists of both subregions is nonempty but does not contain the whole of $D_1 \cup D_2$ then one speaks of D_1 and D_2 as being *partially isolated*; if this intersection is empty then D_1 and D_2 are *totally isolated*. Total concealment of course does not imply total isolation, though the reverse implication does hold (figure 6).

Thus a description of an environment by means of isovists allows one to study not only the environment but also something of the visual experience of it. Space-contingent and spatial behaviors that are also isovist-related behaviors are thus open to discovery and investigation.

It is natural to begin by discriminating those attributes of isovists that are both perceivable and significant to some human motivation. For example, does the *size* (volume) of an isovist at x measure the felt potential or real visual exposure of an observer at x, as a pilot study seems to confirm[(3)]? Are there then behaviors



(a) (b)

Figure 5. (a) A sufficient path; (b) the (nearly) minimal path.

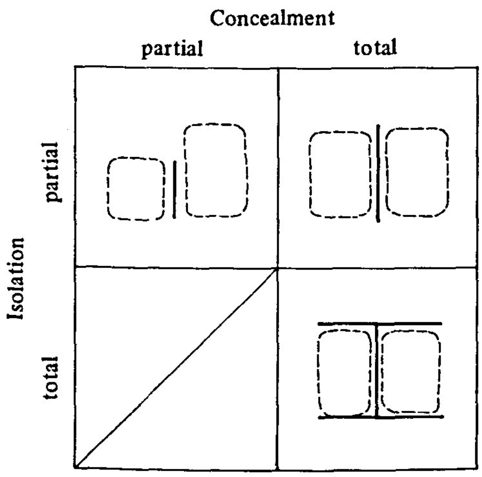


Figure 6. Concealment and isolation of subregions in D.

(3) Seven students individually inspected the interior of a large art gallery (Michener Gallery, University of Texas at Austin) and were asked to situate themselves in (a) the most exposed and then (b) the least exposed points. They performed well, very much in agreement, and chose primarily on the basis of isovist size. (The guard had placed his chair at the vantage point of the largest isovist.)

motivated by desired view or visual exposure which an examination of isovists could help to predict? Such behaviors as privacy seeking, search and flight, surveillance, and prominence seeking surely merit investigation from this point of view. For example, by quantifying the degree of concealment and/or isolation existing in given environments between selected subregions and paths (say by computing the areas/volumes of the relevant intersections), some useful measures of visual exposure and access may be developed that are specific to specific environmental configurations.

Other attributes of the isovist are equally interesting, such as *shape*. An isovist can be simple (in a circular room, say) or complex (in a forest or Eisenman house), symmetrical or asymmetrical, and so on. Can some objective numerical measures on isovists be found to correlate with human judgements of the spatial complexity of a given environment? Would such judgements vary from vantage point to vantage point? Can overall judgements be determined from a chosen path?

Before inquiring more deeply into how these and other related questions might be approached, it is important to be aware of some of the limitations and finesses involved in this kind of investigation. It is being suggested after all that some rather complex human spatial behaviors and cognitions may be related to some rather simple 'physical' properties of the environment. Clearly one would have to define *environment* more richly than has been done here in order to understand behavior and perception in it most fully. Certainly, as Gibson (1966) points out, much of the visual information we use is given by patterns in the illumination, color, and texture of (or on) perceived real surfaces—for example, print, shadows, materials, television. These are not accounted for in the isovist. But if one considers the environment spatially—indeed *as* space—and in particular 'isovistically', one is able (a) to predict trends, optima, and limits on a variety of possible spatial behaviors and perceptions in a given environment, (b) to assess some basic spatial qualities of environments whose conscious or unconscious apprehension may guide or underlie 'higher' cognitions and behaviours, and (c) to create a basis for or a contribution to a fuller description of the environment, be it precisely along the lines presented here or not.

To continue, the isovist as discussed hitherto could be either three-dimensional or two-dimensional. For simplicity, hereafter V_x will be considered as a horizontal two-dimensional plane section through x of the full corresponding three-dimensional isovist. Environments which are 'plan-organized', as many architectural ones are, can thus be studied often without great or unwitting loss of information or generality.

Light travels in straight lines. This enables one to reword definition (1) of V_x as the set of line segments joining the vantage point x to points v' on the boundary surfaces $\partial V_x - R_x$. Thus

$$V_x = \{[x, v']:\ v' \in (\partial V_x - R_x)\}\,.$$

These line segments have the vantage point x in common and 'radiate' out from x to the boundary. They will be termed *radials* of length

$$l_{x,\theta} = d(x, v') = \|v' - x\| = [(v_1'^2 - x_1^2) + (v_2'^2 - x_2^2)]^{1/2}\ ,$$

where x_1, x_2 and v_1', v_2' are the coordinates of x and v' respectively, and $0 \leqslant \theta \leqslant 2\pi$ represents the direction of the radial (figure 7). The length $l_{x,\theta}$, as a function, has a distribution function $L_x(\theta)$. This is one way of describing the isovist quantitatively, as will be done henceforth in this paper.

Now $L_x(\theta)$, the radial-length distribution function, is computable for a given x in a given environment and region. From it a number of statistical measures, $\mathrm{m}(V_x)$, can be developed which describe interesting qualities of the isovist V_x, some of which have been already mentioned. Work of this kind was done at the Hybrid Computer

Laboratory at the University of Texas at Austin by use of SDS-930 and SDS Sigma 5 computers, card or CRT light-pen inputs, Calcomp plots of V_x, and digital m(V_x) outputs. The measures considered were:
(a) the *area* of the isovist, $A_x = A(V_x)$;
(b) the real-surface *perimeter* of the isovist, $P_x = |S_x|$;
(c) the *occlusivity* of the isovist, $Q_x = |R_x|$;
(d) the *variance* of the radials, $M_{2,x} = M_2(l_{x,\theta})$;
(e) the *skewness* of the radials, $M_{3,x} = M_3(l_{x,\theta})$;
(f) the *circularity* of the isovist, $N_x = |\partial V_x|^2/4\pi A_x$.
Here, if C is a curve then $|C|$ denotes the length of that curve. A large but finite number of radials were used in the computations. The numerical values obtained were therefore close approximations to the true values of each measure (Benedikt, 1977).

The meaning of these measures may be elucidated as follows: (a) the area, A_x, of V_x measures how much space (area) can be seen from x, and conversely how much space x can be seen from; (b) the perimeter, P_x, of V_x measures how much environmental (real) surface can be seen from x; (c) the occlusivity, Q_x, measures the length of the occluding radial boundary R_x of the isovist V_x and indicates, as the name proposed by Gibson (1966) already suggests, the depth to which environmental surfaces are partially covering each other as seen from the vantage point (see also Koenderink and van Doorn, 1976). $Q_x > 0$ indicates the possibility of perceptual uncertainty about $D - V_x$; that is, about those areas which are just around the corner in the direction(s) of the occluding radial surface(s) (figure 8).

To continue: (d) the variance, $M_{2,x}$, is defined as the second moment about the mean of $l_{x,\theta}$, and measures the dispersion of the perimeter relative to x; (e) the skewness, $M_{3,x}$, the third moment about the mean of $l_{x,\theta}$, measures the asymmetry of the dispersion of perimeter relative to x. These latter two measures are associated

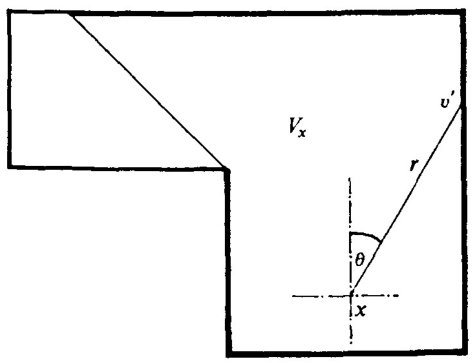


Figure 7. The isovist described in terms of radials $r = [x, v']$ of length $l_{x,\theta}$.

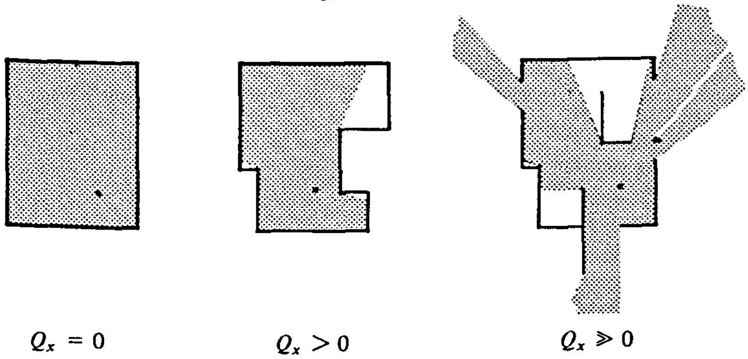


Figure 8. Isovists of increasing occlusivity, Q_x.

with the factor of 'compactness' of two-dimensional forms in general (Brown and Owen, 1967; Zusne, 1970, page 223). These researchers, however, always took (the equivalent of) x as the *centroid* of the form under regard, and of course took no special account of 'visibility from x'. Finally, (f) the circularity, N_x (= 1 when V_x is a disc and >1 otherwise), is another measure of compactness/complexity (Zusne, 1970, page 209). Note that A_x, P_x, and N_x depend only on the shape of the set V_x and not on the particular vantage point. This is not true of Q_x, $M_{2,x}$, and $M_{3,x}$. All the measures are invariant under rotation about x.

By no means does this list exhaust the possible measurable qualities of V_x. The measures here were selected for their comparative simplicity, clarity of reference, possible import, and relative independence.

Isovist fields

But to bring the study of environments by isovists closer to reality and maximum usefulness, one more step needs to be taken. We need to be able to go beyond the study of single isovists. One way is to create, for objective examination, all the isovists that belong to a given path through a given environment. This in turn can be achieved in a number of ways. For example, one can move a point source of light along a path through a model of an environment. The set of points illuminated at any one place is the isovist at that vantage point (figure 9). It becomes easy to see and appreciate the behavior of isovists in different environments.

Perhaps a more analytic way to examine directly the behavior of isovists is by constructing a 'Minkowski model'. Here, from drawings, (two-dimensional) isovists along a given path relative to a given environment are cut from some material, say card or plexiglass, and stacked one above the other in sequence (figure 10). (The stacking may register with the environment or the vantage points.) *Space* is thus read in the horizontal plane, whereas *time* is read in the vertical dimension. Changing the path (or the environment) gives a different Minkowski model. Examination of each model enables one to see 'when' and at what rate different parts of the environment become visible to the observer, to see which parts are obstructed (how and when), as well as to gain some appreciation of the transformation of isovist shape and size. It is a matter for further study whether such Minkowski model representations have formal qualities and laws in their own right and how these in turn relate to the environment and paths represented, either individually or typologically. My own observations are too preliminary to report here.

But it is desired to describe in some detail a way of handling isovists that leads on from the quantification of isovist attributes presented earlier, and which continues the program of finding a field description for environments.

It has already been remarked that the shape and size of an isovist is unique to an environment and a vantage point and is liable to change with observer movement. Therefore some or all of the quantities introduced earlier, bearing information about the surrounding surfaces, will change likewise. Now each x in the space $D-E$ is potentially part of some path Π 'through' the environment, and each x is characterized by the numerical values in the attribute vector $[A_x, P_x, Q_x, ...]$. Any *one* of these numerical quantities in turn is a *space-varying quantity* and as such defines a scalar field (Margenau, 1977). In this way every environment creates 'isovist information fields' or *isovist fields* unique to it, defined throughout the interior of D. This is because, for any given environment, any scalar measure $\mathrm{m}(V_x)$ is of the form

$$\mathrm{m}(V_x) = \mathrm{f}(x) = \begin{cases} \mathrm{f}(x_1, x_2) & \text{in two-space,} \\ \mathrm{f}(x_1, x_2, x_3) & \text{in three-space,} \\ \mathrm{f}(x_1, x_2, x_3, t) & \text{in four-dimensional space-time.} \end{cases}$$

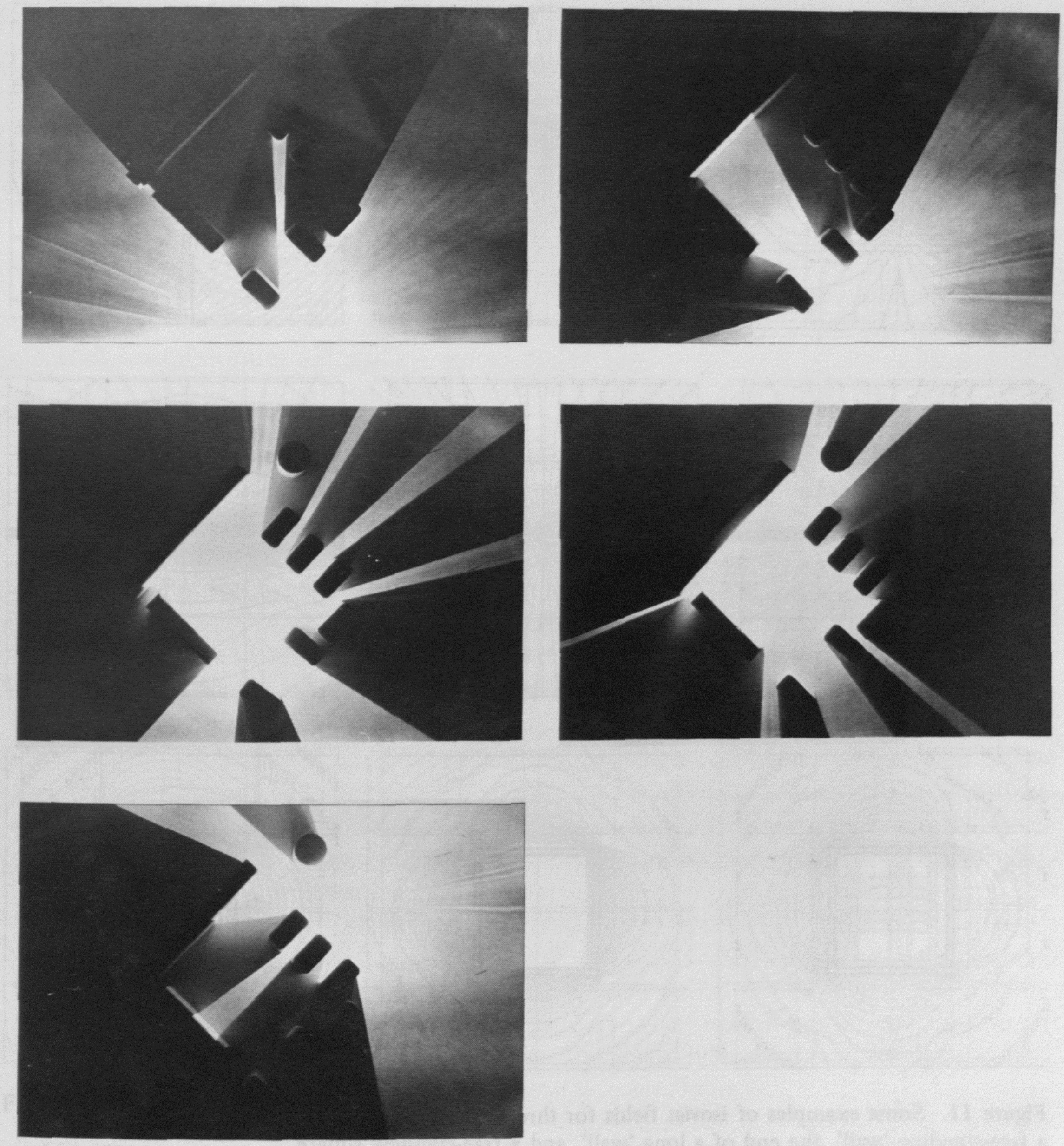


Figure 9. Analog production of isovists along a path by point-source illumination of a model.

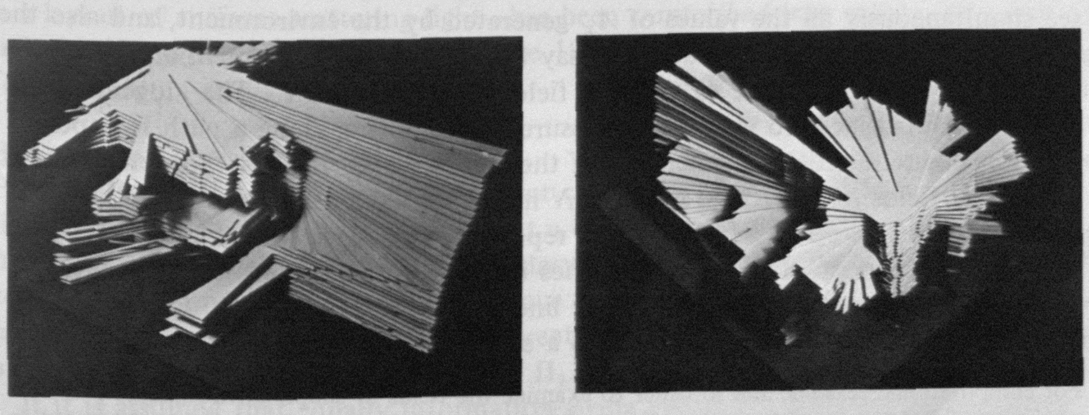


Figure 10. A Minkowski model of the isovists along a given path in a given environment [in this case, Michael Graves's Benacerraf house addition (Gandelsonas, 1972, page 75)].

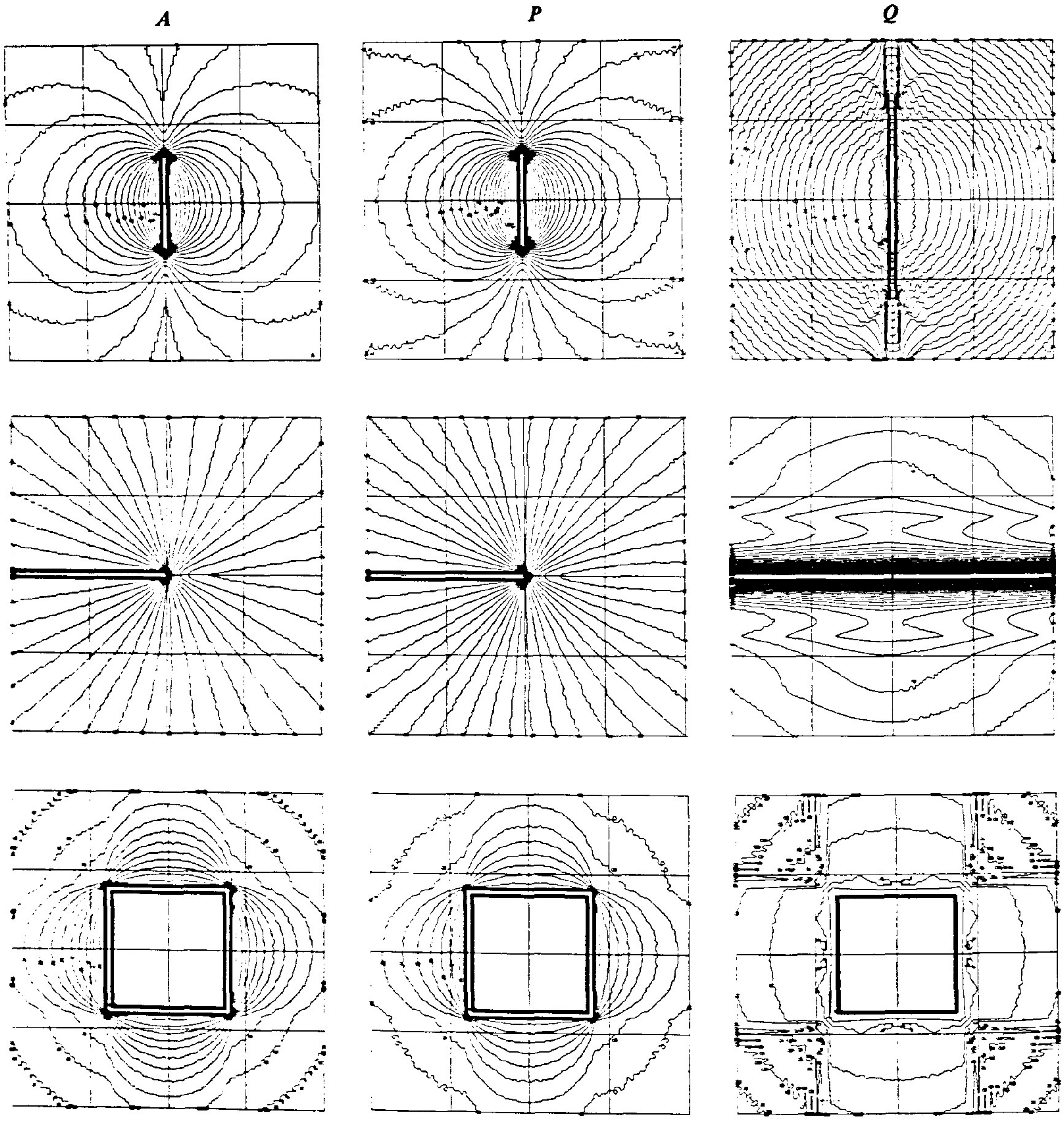


Figure 11. Some examples of isovist fields for three (two-dimensional) simple environments: a free-standing 'wall', the end of a long 'wall', and a free-standing square.

Let the symbols A, P, Q, M_2, M_3, and N denote the scalar *fields* of the corresponding measures. To see the field A corresponding to $A(V_x)$, for example, is to see simultaneously all the values of A_x generated by the environment, and also the spatial configuration of these values. To say that at a point x so much area is visible is the same as giving the value of the area field, A, at that point. The judgement of an observer with respect to view and exposure while moving along a path Π depends partially on his sequential apprehension of the values of the field at the points x of Π.

The isovist fields A, P, Q, M_2, M_3, and N have been computed for a variety of simple environments. Some examples are reproduced in figure 11. Fields are represented as a topography of contour lines (isoarea, isoperimeter, isoocclusivity, isovariance, isoskewness, and isocircularity lines of twenty-nine values: 1–9, A–T) along which the measure $\mathrm{m}(V_x)$ at hand is a constant[4]. Gradient vectors—

[4] For computational reasons, and in order to examine the fields of simple environments per se as cleanly as possible (that is, without the effects of a close region boundary), the fields illustrated in this article were generated with a large region and with a constant upper limit on the value of $l_{x,\theta}$ such that ∂D could never be 'seen'. Values of P_x include the 'traveling region' boundary.

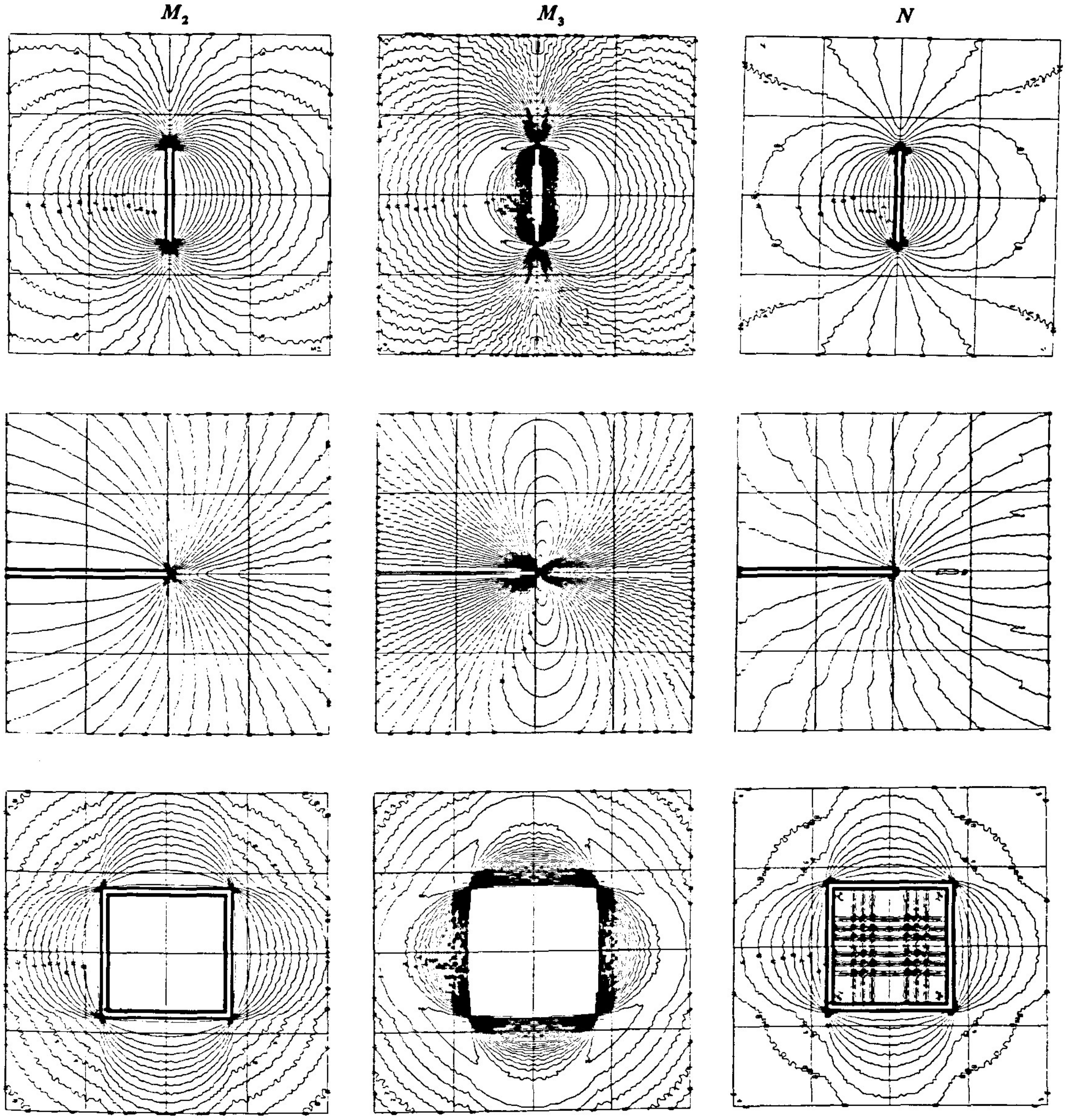


Figure 11 (continued).

grad $[m(V_x)]$ is a vector field for each measure $m(V_x)$—are indicated by the closeness of the contour lines and point at right angles to them. Maxima and minima (hills and valleys) are also discernible from the contour lines. In this way the environment —a layout of surfaces scattering light—has been *transcribed* into space; into fields of information about, as Gibson (1966, page 192) has it, "the permanent possibilities for vision".

Behavior and perception

Figure 12(a) depicts A for an environment consisting of a long surface running left–right and a close parallel surface which at a certain point turns at right angles away from the first surface. The region boundary, ∂D, is outside the picture. This configuration simulates a long narrow space adjoining a large open space and might represent, say, a hallway and lobby or street and open square. Compare the gradient of A for the three paths, $\Pi_{1,2}$, $\Pi_{3,4}$, and $\Pi_{1,4}$ [figure 12(b)].

If it is assumed that equally information-giving events (or objects) are uniformly distributed in $D-E$, then the area, A_x, of V_x, is proportional to the amount of information available at x. Towards the end, an observer choosing the path $\Pi_{1,2}$

would be likely to experience a sudden rush of information—a sudden dilation of his view and exposure too—which may (or may not) suit his intentions or his capacity to process information. An observer following path $\Pi_{3,4}$, on the other hand, receives new information more gradually. One would expect preferences in this regard to be expressed by the path actually chosen. The commonly observed behavior of a pedestrian rounding a street corner by taking a path such as $\Pi_{1,4}$ may result from an attempt to reduce the consequences of too steep a rate of change in A. (An equivalent behavior, of course, would be to slow down the *speed of movement* relative to A.)

In some similar analysis one may wish to consider environmental information to be uniformly distributed not throughout space but rather *on* real surfaces, say in studying the design of a shopping mall or art gallery. Then the more relevant field would be P.

A number of authors have recently come to view the problem of *privacy* as one of regulation of personal information, that is, as the achieving of "... an optimum balance ... between the 'information' which comes to a person and that which he puts out" (Canter and Kenny, 1975, page 140; see also Altman, 1975, pages 25–31). Again, when we consider sources of (visual) information to be distributed in some definite way in space, then each isovist 'covers' a definite subset of those sources. The isovist-size measures, such as A_x and P_x approximate the (potential) amount of information available at x as well as the (potential) 'audience size' or exposure of a person at x. Therefore one would expect that privacy-related path and location choice (and the definition of 'public' and 'private' spaces in general) will pay much attention, at least unconsciously, to the maxima, minima, and gradients of fields such as A and P, as well as to the isolation and concealment properties of given regions as defined (see also Archea, 1977).

There are situations and environments in which one typically wishes to see much without being overly exposed. Here A alone will not suffice and it is better to consider too the skewness, $M_{3,x}$, of the distribution $L_x(\theta)$. It is associated with the extent to which radials of unaverage length are concentrated in a certain angular region[5] and tends to be positive close to real surfaces and in corners. In a given

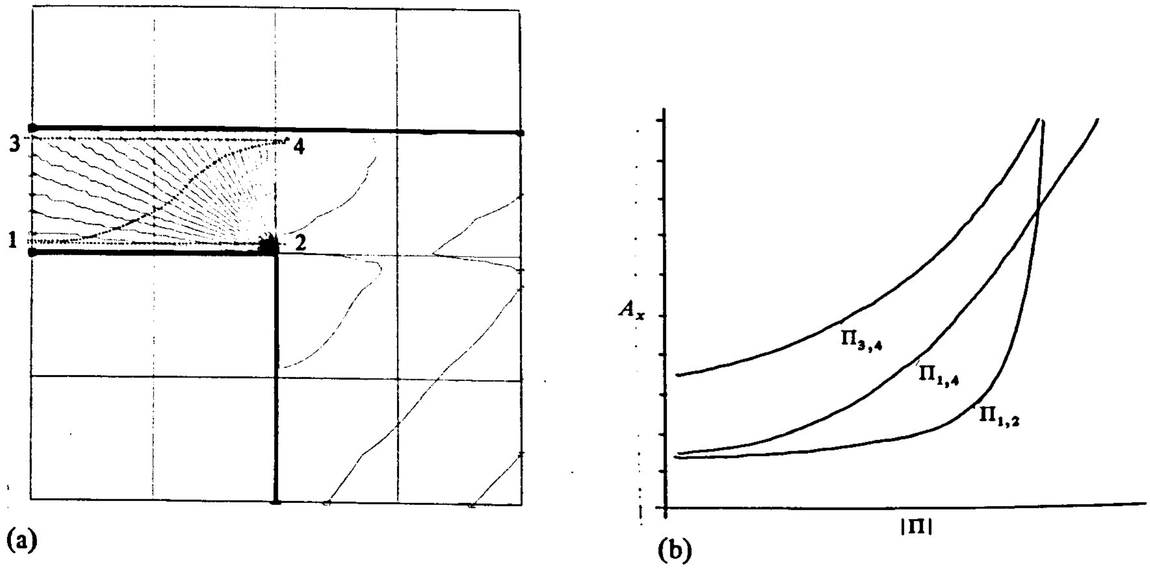


Figure 12. (a) The isovist area field, A, of the corner condition of a 'street and square' (E extends outside the figure); (b) gradients in A along three paths.

[5] High $M_{3,x}$ does not invariably entail this condition; further conditions (relatively low Q_x and N_x) are also relevant.

environment, points in space characterized by high A_x and $M_{3,x}$ thus tend to fulfill the conditions for good view and low angular exposure.

It is a matter for further research whether such commonly observed behaviors as, in a restaurant (or institutional dayroom—Sommer, 1969, page 85), preferring a table with a view and which is in a corner, against a wall, or against a pillar, or waiting in railway stations close to pillars in areas of good visibility (Canter and Kenny, 1975), are amenable to analysis and prediction based on occlusivity, area, and skewness fields. Again the concealment and isolation properties of specific regions are salient, particularly with respect to asymmetry of concealment.

Consider another related example. Newman (1973, pages 30–34), reporting on the incidence of crime in and around urban residential buildings, pointed out the significant relationship of visibility to crime incidence. The intending criminal is interested in three things with respect to spatial characteristics of the environment: (1) being inconspicuous, (2) being safe from sudden detection, and (3) having an avenue for escape. The first two factors are describable in good part as attributes of the isovists A_x and Q_x respectively. The hypothesis that crime such as vandalism, burglary, or assault will tend to occur in regions of coincident local minima in A and Q seems to be borne out in Newman's data. He reports a high incidence of crime in elevators and certain types of lobbies and corridors. But for less intuitively obvious cases, only more detailed data about the spatial location of incidents of crime will serve to confirm or reject this hypothesis. If confirmed, computer generation of the area and occlusivity fields of a proposed environment might well help to predict likely trouble spots and be a guide in redesign. [It is not meant to imply that visibility criteria are the sole or even the most salient determinants of crime in a 'defensible space' theory—see Mawby (1977).] Optimal surveillance paths of course correspond to minimal sufficient paths, as already defined.

Most studies of the (visual) complexity of the physical environment tend to stress the complexity of information *on* real surfaces (for example, Anon, 1973; Mehrabian and Russel, 1974; Sanoff, 1974; Vigier, 1965). This seems a somewhat too pictorial and static approach. Few studies have attempted to quantify purely spatial complexity under dynamic conditions. One attempt was made by Pyron (1972), but he was not able to find a significant appreciation by lay subjects of the spatial complexity of different simulated low-rise housing-development layouts. Perhaps he could not study the problem more sensitively because he lacked the descriptive tools we now have in isovist fields. For, of the nine experimental environments used, only the stimulus categorization one can now see to be 'isovistically' salient [namely his "court" and "non-court" (Pyron, 1972, pages 92 and 110)] showed any significant correlation with the subjects' judgement of spatial complexity.

The direct empirical testing of how some human behaviors and perceptions might correlate with isovists, isovist measures, and isovist fields, however, remains to be done. Suitable data are not extant, and obtaining such data will require experiments and techniques specifically directed at the problem. At present I am engaged in research on isovists funded by the National Science Foundation. The problem chosen for investigation and as a partial test of the theory is that of the perception of 'spaciousness': of how large or small an environment appears on account of its shape and/or the observer's position and path of movement. Two series of experiments are involved, preceded by a statistical analysis of the behavior of isovist measures relative to each other, with and without 'architectural constraint'. The first series of experiments employs model and the second full-size environments as independent variables. In both, the perception of spaciousness is tested against systematic variation of isovist measures in architectural environments of objectively equal size (area/volume).

Design and aesthetics

It was mentioned at the outset that some light may be shed on certain 'art-historical' concepts. So much architecture has been explicated and discussed in terms of *space*, however, in forums ranging from classic texts to popular articles, that here no more can be done than to make some informed observations and perhaps outline the directions of future, more close, investigations.

Giedion (1971) proposed that architecture passed through three "space conceptions", namely "architecture as space radiating volumes" (Greek), "architecture as interior space" (Roman and Classical), and "architecture as both interior space and space radiating volumes" (Modern) (figure 13). Of course these are simplifications, but

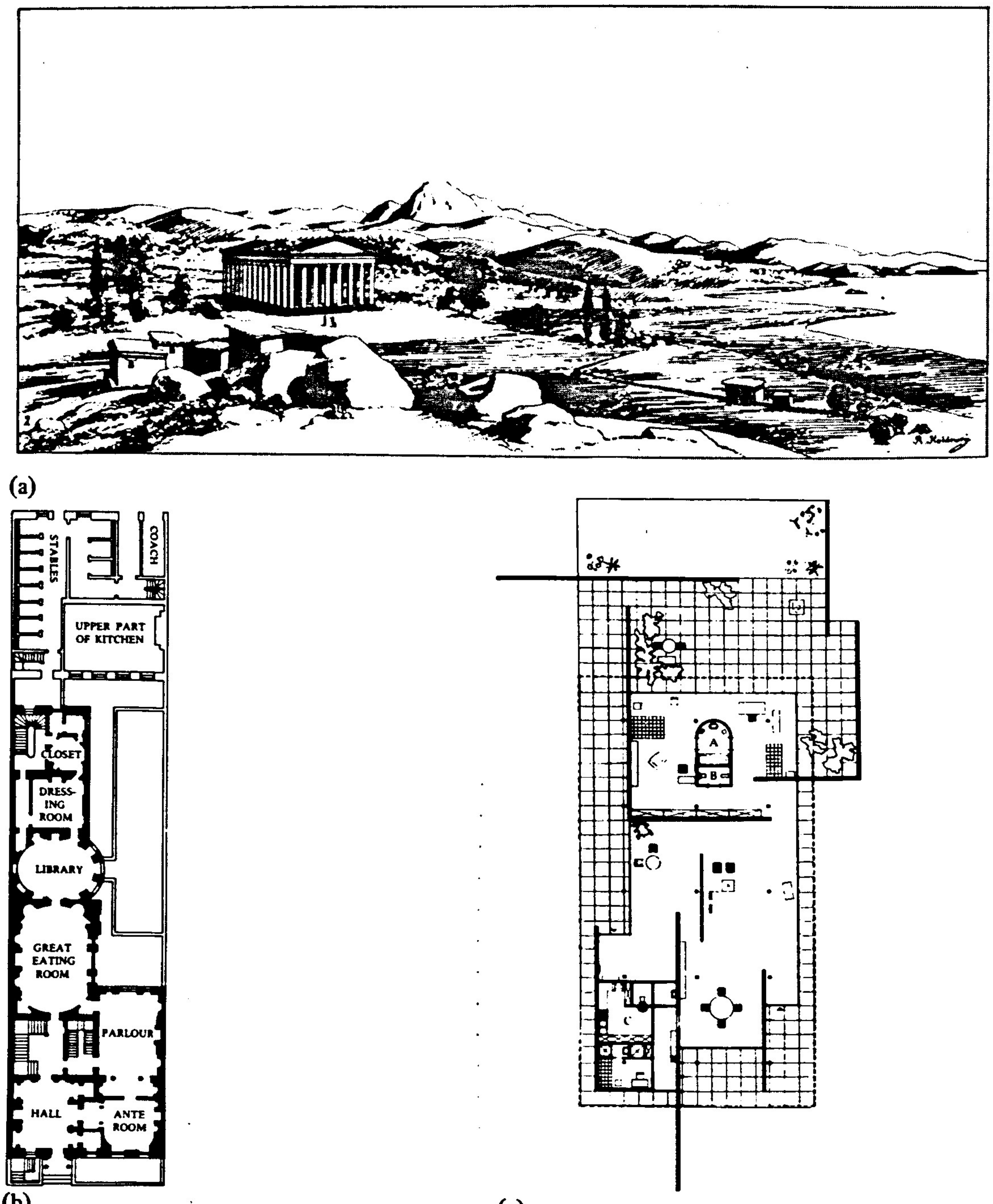
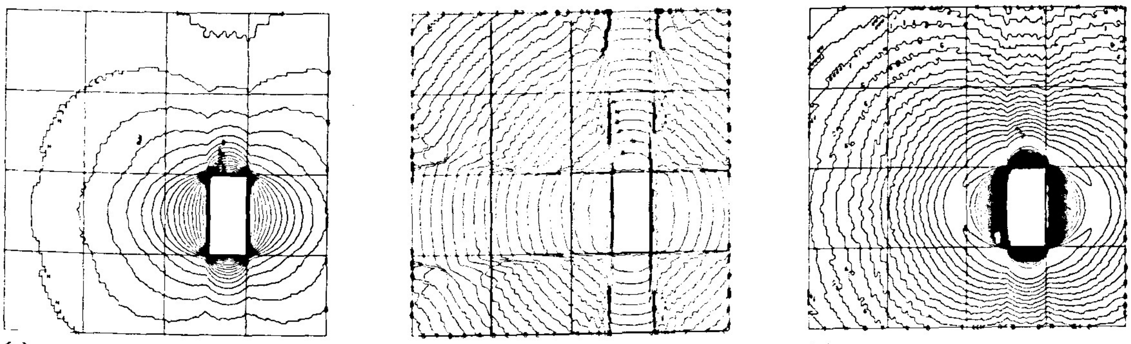


Figure 13. (a) Temple of Aphrodite, Lesbos (reconstruction); (b) Lord Derby's London townhouse by Richard Adam, 1773-1774 (plan); (c) exhibition house in Berlin by Mies van der Rohe, 1931 (plan).

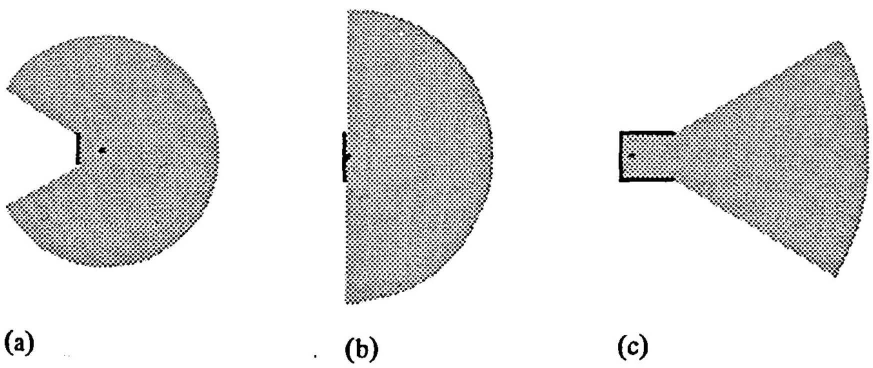
there is wide agreement with Giedion that the architecture of the Modern movement is characterized by its physical realization of 'space-time', more prosaically by its integration of indoors and outdoors, its free placement of visual space definers—freed from load-bearing duty—and the resultant ever-changing visual experience. "Boundaries become fluid, space is conceived as flowing—a countless succession of relationships" (Moholy Nagy, 1928, page 63; quoted in van de Ven, 1974, page 314). Previously architectural space had typically been contained, as it were, in chambers joined by portals.

Let us look at Giedion's three 'space conceptions' by means of isovist measures and fields. Figure 14 shows the area field, A, the occlusivity field, Q, and the skewness field, M_3, around a single free-standing rectangular-plan object or building. (Note that isovist fields have the scale assigned to the environment. Time-rate changes of $m(V_x)$, $d[m(V_x)]/dt$, depend on the velocity of the observer and the space gradient of the field, $\mathbf{grad}\,[m(V_x)] = \{d[m(V_x)]/dx_1, d[m(V_x)]/dx_2, d[m(V_x)]/dx_3\}$, itself a vector field.) The area field dips sharply down in value as it approaches the object; along the contour lines, of course, it remains constant. One way of reading this is as a measure of the visual intrusion of the form in otherwise free space—its visual size (see also Hopkinson, 1971). The occlusivity field, Q, shows a jump in value across the lines extending from the form's faces. It is here that there is an abrupt change in the length of one of the occluding radials, a difference equal to the length of the side of the object. (Note: a curvilinear form would not exhibit abrupt changes in Q.) The skewness field can in general take on positive or negative value, as shown in figure 15. In the case of the free-standing single form [figure 14(c)], M_3 has a consistently negative value, tending to zero at and with distance from the form. Figure 16 graphs the relative values of A_x, Q_x, and $M_{3,x}$ along a path in the isovist field of the free-standing form in figure 14.



(a) (b) (c)

Figure 14. Isovist fields of a free-standing rectangle: (a) the area field, A; (b) the occlusivity field, Q; (c) the skewness field, M_3.



(a) (b) (c)

Figure 15. The skewness of isovists, some examples (A_x constant): (a) $M_{3,x} < 0$; (b) $M_{3,x} = 0$; (c) $M_{3,x} > 0$.

Are these fields not a glimpse of 'architecture as space radiating volumes'? What else could be meant by the 'radiation of space' than the structure of spatial visual experience created by an object, peculiar to it, and permeating space all around it?

Compare the two area fields in figure 17, one of Mies van der Rohe's Barcelona Pavilion, the other of a closed room off a hallway. Notice the ever-present gradients in A in the Pavilion (the deeply shaded glass walls of the Pavilion were taken to be real surfaces); by comparison notice the concentration of the gradient at the entrance to the 'chamber' and the relative flatness of the field within. In fact, in general, along a typical path, 'chamber and portal' space (Giedion's 'second space conception') and 'modern' space would be characterized by the graphs in figure 18. In the former, space 'opens up' and 'closes' in a definite and marked way as one moves from chamber to chamber; in the second, one almost swims, rocking amongst ever-obscuring ever-revealing surfaces.

> "The new architecture ... does not strive to contain the different functional space cells in a single closed cube, but it throws the functional space out from the centre of the cube, so that height, width and depth plus time become a completely new plastic expression in open spaces. In this way architecture acquires a more or less floating aspect which, so to speak, runs counter to gravity" (van Doesburg, 1924; quoted in van de Ven, 1974, page 268).

The legacy of the de Stijl and Cubist movements of course continues to this day in such architects as Peter Eisenman's and Michael Graves's 'handling of space' (Gandelsonas, 1972).

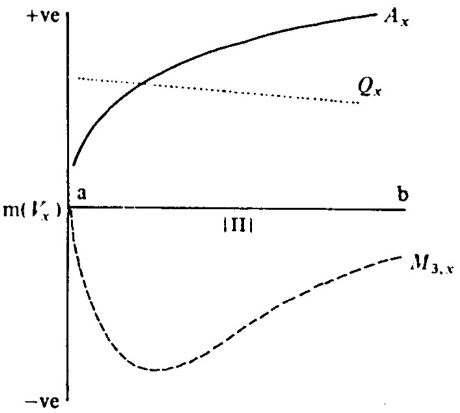
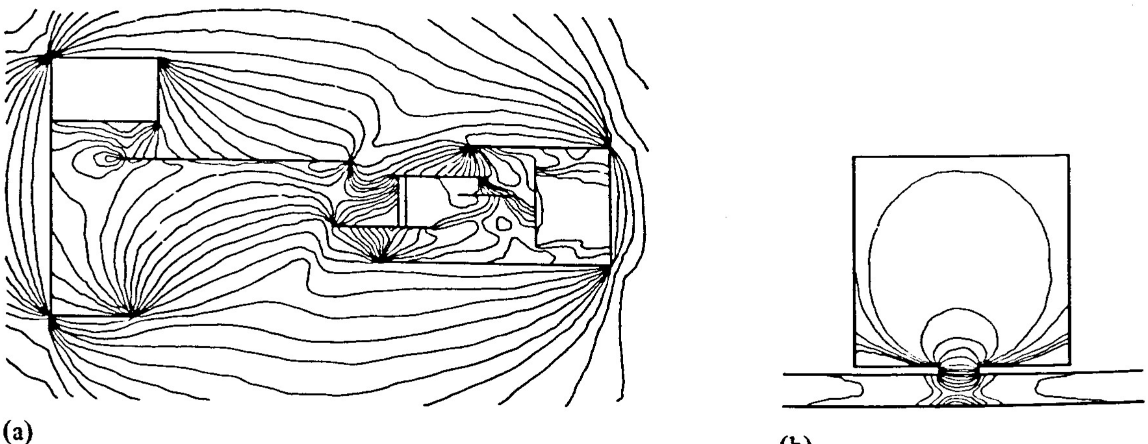


Figure 16. A_x, Q_x, and $M_{3,x}$ on a straight line normal to a 'wall' of the free-standing form in figure 14, starting at the 'wall'.



(a) (b)

Figure 17. (a) A for Mies van der Rohe's Barcelona Pavilion; (b) A for a room off a hallway.

Consider Frank Lloyd Wright's Guggenheim Museum. Here the shape and size of the isovist remains virtually unchanged as one moves along the helical ramp (the isovist is cyclically constricted, passing by the toilet and utility stack on each revolution, and swelled by the opening of the side gallery on the lower levels). Unlike many museums which constantly engage the viewer in their spatial variety, the Guggenheim rapidly 'disappears' to leave the viewer engaged with the art. "In the harmonious fluid quiet ... of the unbroken wave," wrote Wright (1960, pages 16–17; quoted in Jordy, 1976, pages 281 and 331), "no meeting of the eye with abrupt changes of form ... the new painting will be seen for itself." Tiring of the art—perhaps missing the accustomed sense of progress and place—with a few steps in the radial direction inward, the observer moves steeply 'up' the area (actually volume) field to gasp at the central air, at the unoccluded view of the whole and his position in it. Wright created an interior both vanishingly boring and dramatically engaging; a matter of the observer's crossing or following contour lines in isovist fields such as A.

Finally one should note that 'kinds of space', such as 'hall', 'corridor', 'colonnade', 'court', 'plaza', and so on, might in good part be *definable* in terms of the kinds of isovists and isovist fields they generate. For example, a 'forest' is typified by medium values of A, relatively high P, Q, M_2, and N, low M_3, and low gradients in all these; a large 'hall' is characterized by high values of A, medium P, low Q and N, low values for the gradients of A, P, Q, and N, and covarying gradients in M_2 and M_3. The earlier observation that an environment E is spatially uniquely described by its isovists or a sufficient set thereof is now extended to include isovist fields. Insofar as the fields represent permanent and inherent properties of space, and insofar as they also represent potential experience, philosophically one might lean towards the 'idealist' view of reality as nothing other than the union of all possible experiences. What then is the status of information fields such as isovist fields? Are they less 'real' than the environments they are unique to? Are isovist fields and environments, as defined, commutable?

This last question is purely empirical. One might well ask: *when is it possible, given one or more isovist fields over some subregion (or path) in D, to (re)generate E as a whole?* Do parts of isovist fields contain the environment much as holograms contain in every part a whole image? Even if this 'inversion' process were computationally possible partially or within certain limits, as should often be the case, a direction seems clear: to design environments not by the initial specification of real surfaces but by specification of the desired (potential) experience-in-space in the first place; that is, by designing fields directly. [Compare Thiel's (1970) program for "envirotecture" and Boutourline's (1970) "environmental management"; see also

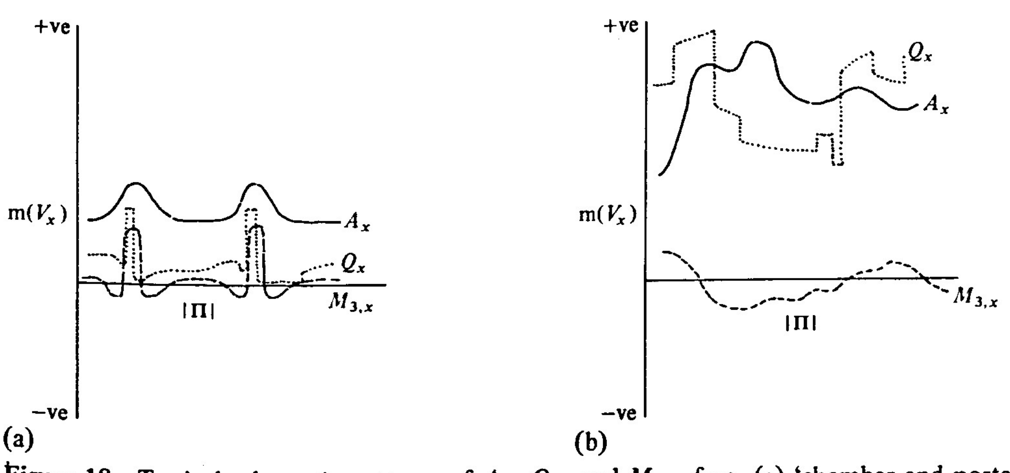


Figure 18. Typical schematic patterns of A_x, Q_x, and $M_{3,x}$ for: (a) 'chamber and portal' space; (b) 'modern' space.

Sommer (1972, page 132).] This would surely be a significant further step in realizing the modern architect's persistent ideal: "... the conscious manipulation of space" (Banham, 1975, page 50).

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References

Altman I, 1975 *The Environment and Social Behavior* (Brooks/Cole, Monterey, Calif.)
Amidon E L, Elsner G H, 1968 "Delineating landscape view areas: a computer approach" Forest Research Note PSW-180, US Department of Agriculture, Berkeley, Calif.
Anon, 1973 "How many bits?" *Architectural Review* **914** 251-252
Archea J, 1977 "The place of architectural factors in behavioral theories of privacy" *Journal of Social Issues* 33(3) 116-137
Arnheim R, 1977 *The Dynamics of Architectural Form* (University of California Press, Berkeley, Calif.)
Banham R, 1975 *Age of the Masters* (Harper and Row, New York)
Benedikt M L, 1977 "Path-dependence and position-dependence in isovist fields" research report for the Council of Advanced Transportation Studies, University of Texas at Austin, Austin, Texas
Boutourline S, 1968 "Notes on the 'object-oriented' and 'signal-oriented' approaches to the definition of the physical world" unpublished manuscript, Department of Architecture, University of Washington, Seattle, Wash.
Boutourline S, 1970 "The concept of environmental management" in *Environmental Psychology* Eds H M Proshansky, W H Ittelson, L G Rivlin (Holt, Rinehart and Winston, New York) pp 498-499
Brown D R, Owen D H, 1967 "The metrics of visual form: methodological dyspepsia" *Psychological Bulletin* **68** 243-259
Canter D, Kenny C, 1975 "The spatial environment" in *Environmental Interaction* Ed. D Canter (International Universities Press, New York) pp 127-163
Doesburg T van, 1924 "Tot een beeldende architectuur" *De Stijl* XII(6/7) 78-83; translated into English as "Towards plastic architecture" in Baljen J, 1974 *Theo van Doesburg* (Studio Vista, London) pp 142-147
Gallagher G L, 1972 "A computer topographic model for determining intervisibility" in *Simulation Councils Proceedings Series 2. The Mathematics of Large Scale Simulation* Ed. P Brock (Simulation Councils, La Jolla, Calif.) pp 3-16
Gandelsonas M, 1972 "On reading architecture" *Progressive Architecture* **3** 68-86
Garling T, 1969a "Studies in visual perception of architectural spaces and rooms: I. Judgement scales of open and closed space" *Scandinavian Journal of Psychology* **10** 250-256
Garling T, 1969b "Studies in visual perception of architectural spaces and rooms: II. Judgements of open and closed space by category rating and magnitude estimation" *Scandinavian Journal of Psychology* **10** 257-268
Garling T, 1970a "Studies in visual perception of architectural spaces and rooms: III. A relation between judged depth and judged size" *Scandinavian Journal of Psychology* **11** 124-131
Garling T, 1970b "Studies in visual perception of architectural spaces and rooms: IV. The relation of judged depth to judged size of space under different viewing conditions" *Scandinavian Journal of Psychology* **11** 133-145
Gibson J J, 1966 *The Senses Considered as Perceptual Systems* (Houghton Mifflin, Boston, Mass)
Giedion S, 1971 *Architecture and the Phenomena of Transition* (Harvard University Press, Cambridge, Mass)
Hayward S C, Franklin S S, 1974 "Perceived openness-enclosure of architectural space" *Environment and Behavior* **6** 37-52
Hill E J, 1976 "The scale and metric of architectural space" doctoral dissertation, Department of Architecture, University of Pennsylvania, Philadelphia, Pa
Hopkinson R G, 1971 "The quantitative assessment of visual intrusion" *Journal of the Town Planning Institute* 7(10) 445-449
Ittelson W H, 1976 "Environment perception and contemporary perception theory" in *Environmental Psychology* 2nd edition, Eds H M Proshansky, W H Ittelson, L G Rivlin (Holt, Rinehart and Winston, New York) pp 141-154

Jordy W H, 1976 *American Buildings and Their Architects* (Anchor Books, New York)
Koenderink J J, Doorn A J van, 1976 "The singularities of the visual mapping" *Biological Cybernetics* 24 51-59
Lang J, 1974 "Theories of perception and formal design" in *Designing for Human Behavior: Architecture and the Behavioral Sciences* Eds J Lang, C Burnette, W Moleski, D Vachon (Dowden, Hutchison and Ross, Stroudsberg, Pa) pp 98-110
Lynch K, 1976 *Managing the Sense of Region* (MIT Press, Cambridge, Mass)
Margenau H, 1977 "Fields, Theory of, in Physics" in *Encyclopaedia Brittanica: Macropaedia. Volume* 7 (Encyclopaedia Brittanica, Chicago, Ill.) pp 293-295
Mawby R I, 1977 "Defensible space: a theoretical and empirical appraisal" *Urban Studies* 14 169-179
Mehrabian A, Russel J A, 1974 "A verbal measure of information rate for studies in environmental psychology" *Environment and Behavior* 6 233-252
Moholy Nagy L, 1928 *The New Vision* translated by D M Hoffman (Wittenborn Shulz, New York)
Newman O, 1973 *Defensible Space* (Macmillan, New York)
Pyron B, 1972 "Form and diversity in human habitats: judgemental and attitude response" *Environment and Behavior* 4 87-119
Sanoff H, 1974 "Measuring attributes of the visual environment" in *Designing for Human Behavior: Architecture and the Behavioral Sciences* Eds J Lang, C Burnette, W Moleski, D Vachon (Dowden, Hutchison and Ross, Stroudsberg, Pa) pp 244-259
Sommer R, 1969 *Personal Space* (Prentice-Hall, Englewood Cliffs, NJ)
Sommer R, 1972 *Design Awareness* (Holt, Rinehart and Winston, New York)
Tandy C R V, 1967 "The isovist method of landscape survey" in *Methods of Landscape Analysis* Ed. H C Murray (Landscape Research Group, London)
Thiel P, 1970 "Notes on the description, scaling notation, and scoring of some perceptual and cognitive attributes of the physical environment" in *Environmental Psychology* Eds H M Proshansky, W H Ittelson, L G Rivlin (Holt, Rinehart and Winston, New York) pp 593-619
Thiel P, 1972 *Towards an Envirotecture* unpublished manuscript, Department of Architecture, University of Washington, Seattle, Wash.
Ven C van de, 1974 "Concerning the idea of space: the rise of a new fundamental in German architectural theory and in the modern movements until 1930" doctoral dissertation, Department of Architecture, University of Pennsylvania, Philadelphia, Pa
Vigier F C, 1965 "An experimental approach to urban design" *Journal of the American Institute of Planners* 31 21-31
Wright F L, 1960 *The Solomon R Guggenheim Museum* (The Solomon R Guggenheim Museum, New York)
Zevi B, 1957 *Architecture as Space* (Horizon Press, New York)
Zusne L, 1970 *Visual Perception of Form* (Academic Press, New York)