

Supplemental Material 1: Detailed operationalised definition of the Embodied 3D Isovist model

Step (1): Partition all opaque surfaces in the environment into triangles. The reason for this is to simplify the following steps, because each triangle necessarily lies in (i.e. is embedded in) a single 3D *plane*, and projecting 3D triangles onto 3D planes (to calculate surface occlusion) is straightforward. Thus, any triangle partition algorithm will suffice.

Step (2): For each triangle t , compute the visible region t' of the triangle from the given eye position p by clipping regions of t that are occluded by the other triangles. Specifically this is done by projecting (with respect to p) every other triangle that lies *between* the eye position and t onto the 3D plane that t is embedded in, and then applying polygon subtraction between t and the projected triangles. A triangle t may be completely occluded, in which case it is ignored.

Step (3): Triangulate each visible region t' . The reason for this is that we intend to construct ‘pyramids’ by using the visible region as the base of the pyramid, but after clipping all occluding triangles, t' may have (polygonal) holes in it, making calculations such as pyramid volume more complicated. Splitting t' into a set of triangles avoids this problem. Again, any triangle partition algorithm will suffice.

Step (4): Each triangle in each t' now forms the base of a visible ‘pyramid’, with the eye at the apex of the pyramid. The concept of embodiment is now incorporated by considering the absolute orientation of the visible surface with respect to the eye (top, down, left, right, front, back). We define the orientation of each surface based on the magnitude of the vertical component of the surface normal, with respect to the environment’s spatial frame of reference. By ‘vertical component’ we mean the projection of the surface normal onto the vertical coordinate axis.¹ Vertical surfaces are symmetrical: a left-hand wall affords the occupant the same set of actions, and perceptual experiences, as a right-hand wall. However, horizontal surfaces are not. Floors are associated with different affordances than ceilings, both in terms of actions they allow and information they are correlate with. For this reason, we consider vertical surfaces to be qualitatively equivalent. Horizontal surfaces are classified as downwards facing surfaces (usually ceilings) and upwards facing surfaces (usually floors). In our prototypical implementation we defined: top surfaces (e.g. ceilings) having normals with $z < -0.8$; bottom surfaces (e.g. floors) having normals with $z > 0.8$; and vertical surfaces having normals with $|z| < 0.1$.

Step (5): Calculate the volumes of three-dimensional figures defined by the isovists’ vantage point and the three types of surfaces (all walls, all floors, and all ceilings).

For simplicity to explain the concept, suppose we omit triangulation in steps (1) and (3) because each surface is already *flat* (i.e. embeddable in a 3D plane) and occlusions never create holes in visible regions. In a cubic space, if the vantage point is placed in the centre of the cube, then these figures will have identical *pyramid* shapes. Their apex will always be defined by the vantage point. This is demonstrated in Figure 1 with triangulation steps omitted for clarity to help explain the concept (triangulation simply adds more of these pyramids; the total volume and pyramid base area are still the same).

¹Intuitively, the surface normal is an arrow pointing perpendicular, away from the surface, e.g. the top of a flat floor slab has a surface normal of $(x, y, z) = (0, 0, 1)$, where z is the vertical direction with respect to the spatial frame of reference. The length of surface normals are 1 i.e. they are normalized vectors. The ‘vertical component’ is the projection of the surface normal onto the vertical coordinate axis, e.g. given a surface normal $(0, 0, 1)$ then the vertical component is $(0, 0, 1)$ (the projection onto the vertical coordinate axis is the same as the original surface normal), and a surface normal $(0, 0.6, 0.8)$ has a vertical component $(0, 0, 0.8)$.