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Isovist in a Grid

Benefits and limitations

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ABSTRACT

This paper aims to extend the investigation of the fundamentals of isovists grids to encompass a wider range of possible grids and hence determine whether there is an optimal grid type and, if so, what would it be. We initially discuss the problem of the selection of grid-spacing (or the interval between isovist generating locations) and will then show, with worked examples, how both the grid size, the orientation of the grid and the selection of its origin can produce variance in any resultant space syntax, i.e., relational, measures, when applied to real world spatial systems. We then go on to show how orthogonal grids can exhibit particular problems when the building or urban area contains curved walls, since the orthogonal grid often does not conform well to arbitrary curves. Another problem we discuss is that of small openings or narrow corridor-like spaces (often missed by larger grids) where there is a mis-match between the grid-spacing and aperture size. In the second half of this paper, we will explore alternative options to the cartesian, orthogonal grid, suggesting a number of alternative grid-types and then introduce a new form of visibility graph analysis that we are terming Restricted Randomised Visibility Graph Analysis, or R-VGA. By applying R-VGA analysis to some test cases, we demonstrate how this method of analysis has considerable advantages over the more commonly used, square-based grid of VGA analysis. Finally, we will present a new, proposed taxonomy, as an entire family of VGA and VGA-derived analyses.

KEYWORDS

Isovists, Visibility graph analysis, grids, non-standard grids, random isovists

1. INTRODUCTION

Having been inspired by Gibson's concept of the ambient optic array (Gibson, 1986), the term isovist was coined by Benedikt (Benedikt, 1979; 1985; 2019) and originated as a method to evaluate and represent the available visual field, or visual potential, at a specified point of interest, known as the isovist's generating location. Once isovists at individual locations were able to be quickly and easily computed, the next natural stage was to move from isovists as single entities at points of interest to isovists as being uniformly and contiguously present throughout all navigable space, and hence able to be used as a means to evaluate and represent the fluctuating visual field within a single spatial system (a building or urban area). Two ways of moving from the instance (one isovist) to the ubiquitous (a collection of isovists) is via either Benedikt's isovist contour maps or Turner's (Turner & Penn, 1999) visibility graph analysis (VGA).

To date, no study has specifically investigated whether the standard grid that forms the basis for all VGA analysis undertaken in space syntax research is the optimal layout for producing a network of visibility points or whether there may be alternative grids that could be more suitable for space syntax analysis. The aim of this study, therefore, is to extend the investigation of the fundamentals of isovists grids to encompass a wider range of possible grids and hence determine whether there is an optimal grid type and, if so, what would it be. We will start by briefly looking back on the history of isovists and the relationship between the instance (one) and the many (a grid of isovists).

2 LITTERATURE REVIEW

2.1. The Origins of Isovist Analytic Methods

The origins of the isovist as a means to represent what is visible from a single, specified location in space has long been of interest to many academics from a variety of different academic fields. For example, in landscape studies and geography, Tandy appears to have been the first person to both use and coin the term isovist (Tandy, 1967). However, this can be seen as being part of a long tradition by geographers to consider the viewshed (the geographical area that is visible from a position in the landscape) of a location and/or the concept of a vista (a view, typically from a high space). In psychology, the concept of the isovists can, perhaps, be held to be most closely aligned to Gibson's work on the ambient optic array (Gibson, 1986). The ambient optic array was considered to be the 'scene' that emerges as rays of light reach the eye and hence make information about the visible world available to a situated observer. Benedikt, however, is probably the person who has been most influential in bringing isovists to the attention of architects and built environment researchers through his work on applying isovists analysis to buildings, applying an array of isovists rather than single isovists and considering which attributes of isovists may be of architectural significance (Benedikt, 1979; Davis & Benedikt, 1979; Benedikt, & Burnham, 1985; Benedikt & McElhinney, 2019). Architects have, however, been long concerned with the views from, as well as the views to, a location such as is encapsulated in the formal concept of 'prospect'. Architects of eighteenth-century domestic architecture were particularly preoccupied with designing homes with a good 'prospect' or the views from a house to the countryside beyond. Therefore, a desire to understand, represent and analyse the view from a single location has long been of interest to architectural researchers. In figure 1, the basic concept of an isovist is shown as a single, horizontal planar slice through the visible field (see the next section for a fuller discussion of the representation of both a single isovists and arrays of isovists).

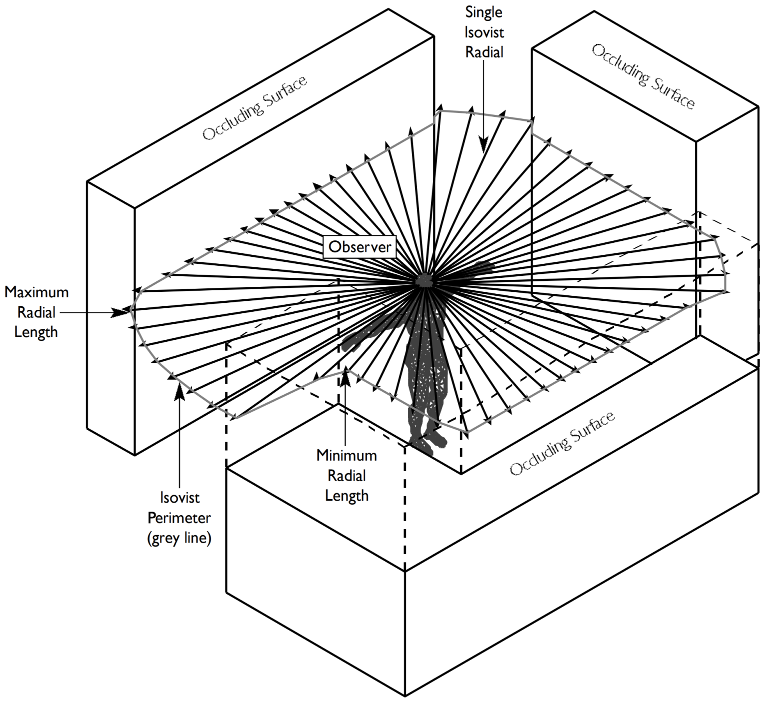

Figure 1 The classic isovists and its primary attributes (source: Conroy, 2001)

2.2 Representations of Isovists

For the most part, individual isovists are uniformly represented by a single-line, closed polygon representing the extent of the 2d, horizontal planar slice through the available visible field. However, as soon as we move from single instances of isovists to numerous isovists, en masse, the ways in which these can be calculated and represented varies considerably since it is simply not possible to merely duplicate the representation of a single isovist in multiple locations as any resultant visualisations would rapidly become indecipherable.

During the history of isovist research, isovists en masse have been represented in different ways. Benedikt favoured the contour map, inspired by representations of geographic terrain, employing a contour line connecting points that share the same value. Sudden increases in the value being represented becomes immediately evident through how closely spaced are the contour lines; equally, areas of isovist homogeneity are evident through the wide spacing of contour lines. Another way of representing isovists, regularly spaced along a path, was the Minkowski model, named after the mathematician, mathematician Hermann Minkowski. Minkowski was famous for combining three-dimensional space with time: the regular spacing of isovists generating points along a path is indicative of the progression of time as an imaginary, situated observer moves along this path (see Dalton, 2005). Turner et al. (1999; 2001a' 2001b), conceived of the idea of both generating and choosing to represent isovists using a regular grid, when he wrote the Depthmap software. Depthmap superimposed a regular grid of isovist-generating locations onto a map or plan, the user being able to control only the grid-spacing. Different values of the isovists can be selected and represented via the colour of a single dot placed at the generating location of that isovist. Thus, the isovist-grid, whilst lacking some of the elegance and nuanced-reading of Benedikt's contour map, had the advantage of being sufficiently flexible for representing multiple isovist attribute values, using the same form of representation. See also Batty's paper on isovists fields (Batty, 2001). Fundamental to Turner's, and Depthmap's approach is the underlying grid of the isovists. What, however, is a grid and can there be more than one kind of grid? In this next section we will explore grids, at their most general level, to determine all possible alternatives to the standard isovist grid.

2.3 What is a Grid?

As stated in the section above, typically isovists and the accompanying visibility graph analyses (VGA) are calculated on a grid of varying resolution. This grid is known as a square orthogonal grid. Considering first principles, what is a grid? And does the definition of a grid aid us in determining other possible ways in which an array of isovists might be laid out?

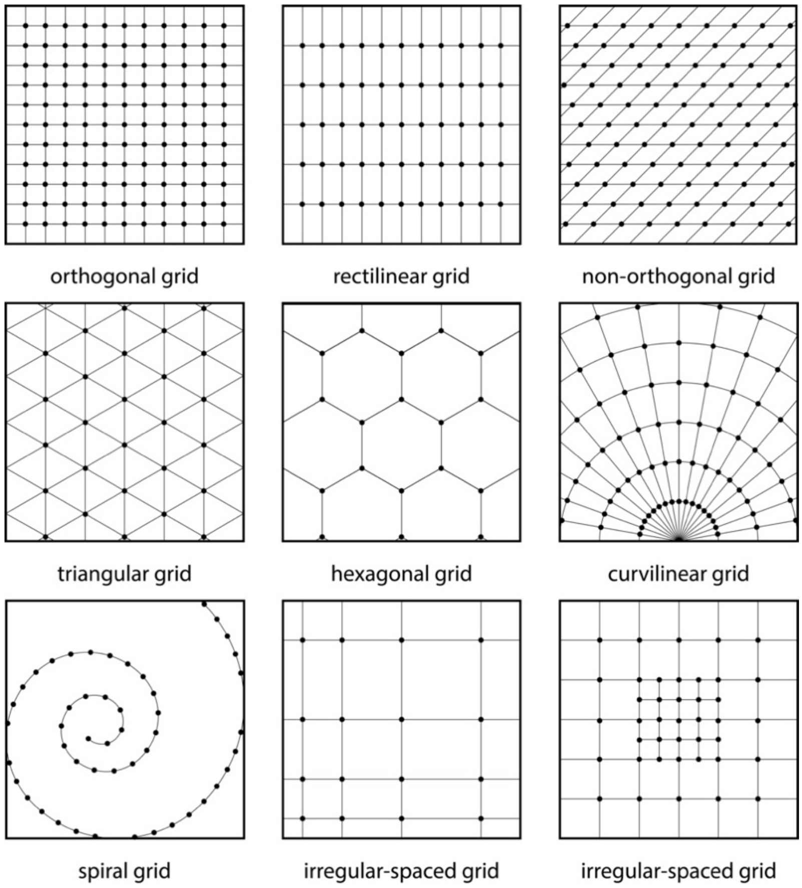

Figure 2 Different types of grids

According to Uznanski's definition, *"A grid usually refers to two or more infinite sets of evenly-spaced parallel lines at particular angles to each other in a plane, or the intersections of such lines."* (Uznanski, n.d.). The first thing to note about this definition is that it can apply equally to a set of intersecting lines, forming a grid, or to the points of intersection of those lines. In this section we will be referring to both these senses of the word 'grid' but it should be noted that for isovist grids, the generating points of the isovists are typically placed at the intersections of any implicit grid-lines. The first type of grid, we will discuss, is the most common type, and the type most familiar to users of Turner's Depthmap software (Turner, 2001b) this being the orthogonal grid (and which could equally be described as a Cartesian grid or a raster grid). For the orthogonal grid, two sets of lines, equally spaced apart, are arranged perpendicular to each other on a flat plane. Assuming that the spacing of the lines in either direction are the same, the resultant grid will always be a square grid. If, however, the spacing of one set of lines differs to the other, the resultant grid may be a rectangular, or rectilinear grid (see figure 2).

Varying the angle at which the sets of lines intersect with each other, can result in different kinds of grids, such as a non-orthogonal gird and, a special case, the isometric grid, which consists of three sets of lines, each of which are intersecting the other sets of lines at 60-degree angles. This produces a characteristic triangular grid. It is worth noting that this grid also represents the optimal packing of circles, if placed with their centres at the intersections of a triangular grid (also true of a hexagonal grid). It is therefore somewhat surprising that it was the square grid and not, perhaps, the triangular grid, that was adopted as the *de facto* standard for VGA analysis. If the angles between lines vary, at a consistent rate of variation, this can result in a curvilinear grid. A polar-coordinate grid is just one example of such a curvilinear grid and varying both a line's angle and interval-spacing will result in a spiral grid. Neither curvilinear nor spiral grids are likely to be of much value for general isovist analysis with the exception of the special case when analysing a circular plan building; see Steadman's paper on the topic of circular plan buildings (Steadman, 2015).

As well as varying the angles between the intersection lines and the number of sets of lines, the spacing between the lines can be varied. This can result in our first example of an irregular grid, resulting in there being more intersections in some parts of the grid, and fewer intersections in others. Although this might seem rather arbitrary at first, this type of grid could be useful for situations where more granularity is needed in some areas of a plan/map and less granularity required in other locations. We would term this an irregularly-spaced grid.

Uznanski's points out that grids can be generalized into n-dimensional space by using the centres of packed n-spheres or n-cubes as the points (ibid). Once we start to consider non-standard grids, we eventually arrive at the most non-standard grid, which is the entirely random grid, see figure 3. The use of such a random grid for isovist analyses was first proposed by Dalton in his doctoral thesis (Dalton, 2011). However, it is worth stating that there is a different between fully random grids and a stochastic distribution of grid points. Pure random, irregular grids, (or at least, uneven distributions) are problematic because of the fact that the density of nodes in some areas relative to others might be quite different (i.e., clumps of points can form), which would result in a distortion of integration values, and integration would tend to favour these 'clumps'. We will return to this concept of purely randomised versus stochastic or restricted randomised grids later in this paper. In the next section we aim to provide a detailed account of the shortcomings and limitations of a square, orthogonal grid as typically used in current VGA analysis.

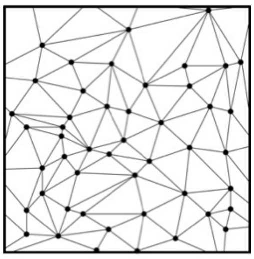

Figure 3 An example non-standard, randomised grid

3 DATASETS AND METHODS

In this section we will first demonstrate the kinds of situations where grids can produce inaccuracies accompanied by a few worked examples. Next, we will present our new software programme, illustrating how we produced a new type of restricted randomised visibility graph grid analysis. In particular, we will explain the algorithm in such a way that it can be reproduced easily. Then we will go on to provide some worked examples of this new random isovist method applied to a selected number of case examples. Finally, in the conclusions section, we will show how this new form of VGA analysis might be considered as belonging to an entire family of visibility graph analyses and present a proposed taxonomic structure for such an expanded set of analytic methods.

3.1 The Limitations of VGA Orthogonal Grids

Empirical work with grid-based isovist analyses reveals that such calculations are intrinsically unstable and can produce divergent results depending on how the researcher initially sets up their analysis grid. There are four main problems that can arise from the use of an orthogonal grid, these are: the starting point or orientation of the grid; the grid's alignment (or mis-alignment) with major boundaries of the site or building; clashes between the grid and any curved surfaces and the presence of narrow apertures in the building and the relationship between the width of such apertures and the grid scale or spacing. We will briefly explain how each of these can cause problems with a regular isovist analysis.

The problem with the location of the starting point of the grid is a particular problem in Depthmap, since it is a feature of the grid placement with which the user has no control: it is optimised by the software programme. Problems can arise where the grid spacing is such that narrow spaces, such as corridors, can contain a noticeably different number of isovists, depending on the exact placement of the origin of the grid. Moving the grid-origin just slightly can cause a new row/column of isovists to be generated. Although the overall effect on the resultant, calculated space syntax values are relatively minor, it is noticeable that this can cause variation.

The orientation of the grid can have a much more profound effect on the analysis. If an orthogonal grid is aligned with the underlying grid of the building, this will produce a different effect to a mis-aligned grid. We can demonstrate this effect using the plan of Aldo van Eyck's Sculpture Pavilion in Sonsbeek Park & the Kroller Muller Museum. This is an excellent plan for showing how and where orthogonal grids have difficulties precisely because it contains many of the problematic features: a strong building-grid (which may clash with the VGA grid), narrow corridor-like spaces, curved walls and narrow apertures. In figure 4 we show the plan of the Sonsbeek Pavilion first analysed in Depthmap using an orthogonal grid aligned with the grid of the pavilion (top left) and then the same plan but rotated through five degrees (top right), causing a mis-match between the pavilion's grid and the isovist grid. The bottom image superimposes the two resultant analyses (in this case, representing isovist integration values) on top of each other and highlights the areas of most disagreement between the two analyses. It should be noted that in this example, below, we used a very fine grid scale, and so the distortions for typical would be even more exaggerated for a coarser-scaled grid (as is typically used in VGA analysis).

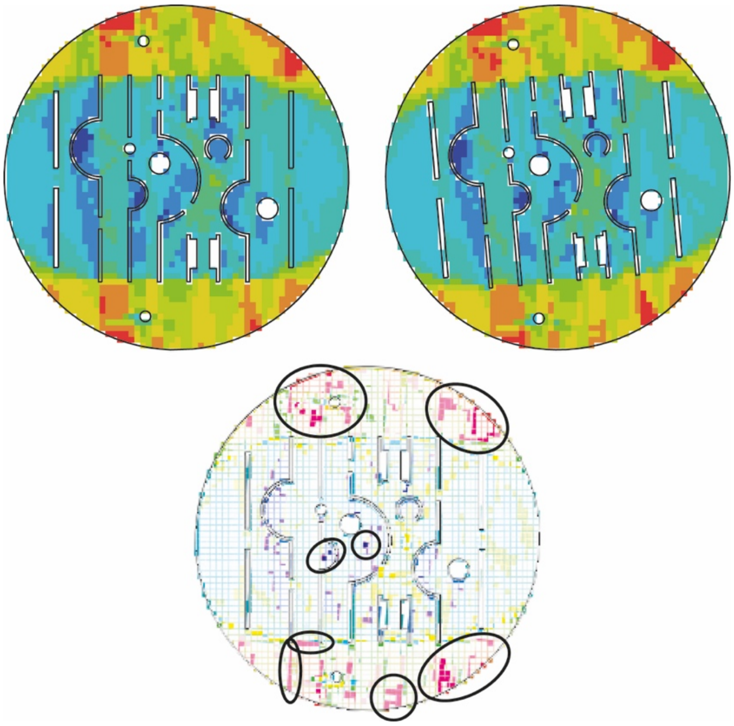

Figure 4 Graph comparisons. Top left, the Sculpture Pavilion in Sonsbeek with a vertical aligned grid; Top right, the Sculpture Pavilion in Sonsbeek with its grid rotated through 5-degrees; A comparison of the two analyses (corrected for rotational angles), showing the areas of maximal divergence between the two analyses.

We can also demonstrate the effect of rotating the isovist grid numerically. Continuing to use Aldo van Eyck's Sculpture Pavilion in Sonsbeek Park we gradually rotated the plan/grid through 2° increments, 180 times (i.e., sweeping through the full 360°) and plotted the total number of isovist locations, the maximum isovist integration value, the minimum integration value and the average integration value. The results are shown in figure 5, with the degrees through which the plan has been cumulatively rotated shown along the x-axis. It can be seen that there is considerably more variation for the most integrated locations (the top line) than for the most segregated locations (the bottom line). Also note the repetition of the pattern, which repeats every 90°, i.e. as the grid placement moves into, and moves out of, alignment with the underlying grid of the building.

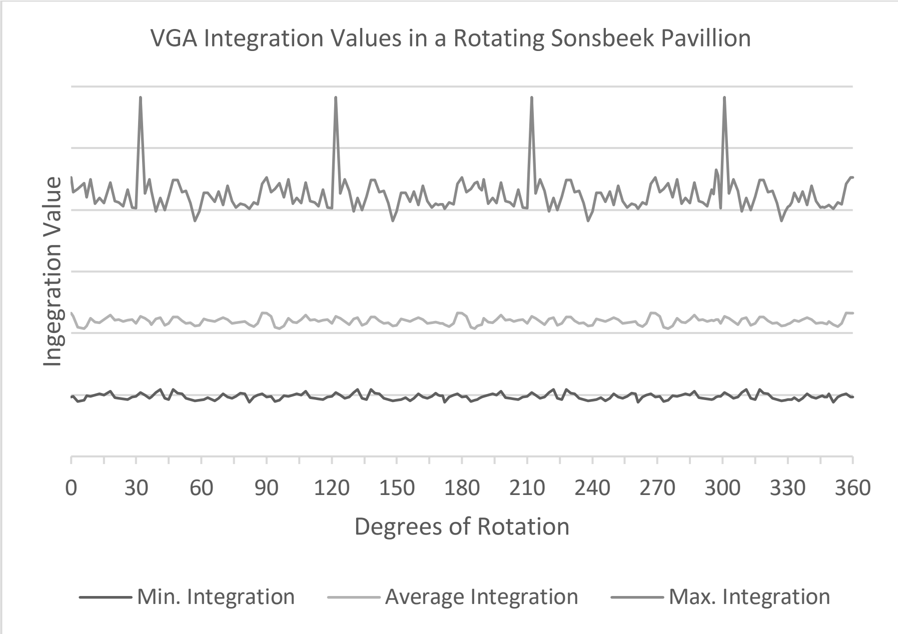

Figure 5 The resultant integration values for a rotating grid orientation, rotating through 2-degree increments

The next way in which the use of an orthogonal grid can cause problems is if there are curved surfaces in the plan/map to be analysed. Clearly where a curved surface meets an orthogonal grid, the grid must be forced to approximate the curved surface and the larger the grid, the coarser is this approximation (and hence the more space left over without a grid square/isovist point). As the grid interval becomes smaller (between 0.5m and 1.0m tends to be the unit typically used in VGA analyses) and smaller the approximation to the curve becomes ever more accurate. Incidentally, this is exactly the same problem as *anti-aliasing* in computer graphics (how to ensure that a pixelated representation adequately displays curves and arcs). See figure 6, where we have used a small section of the Sonsbeek sculpture pavilion to show the effect of grid size on the approximation of the grid to a curved wall. The inevitable result of this process is that where researchers are analysing buildings containing curved walls, using current VGA analyses, they are often forced to use a much smaller grid and hence a larger number of isovist locations and consequent longer processing times, just to ensure that the curved surfaces are adequately addressed.

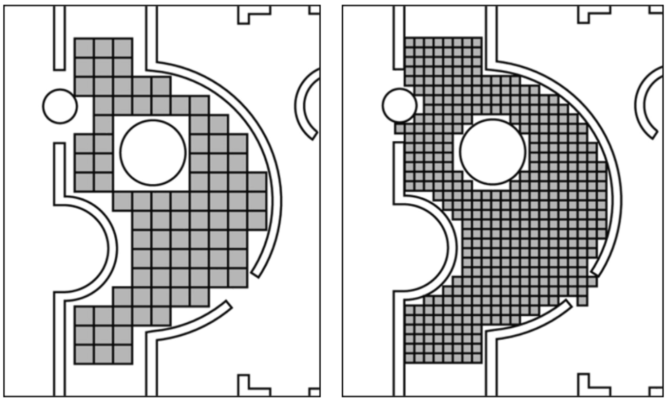

Figure 6 A part of the plan of the Sculpture Pavilion in Sonsbeek showing the effect of an orthogonal grid meeting a curved wall; larger grid on left and smaller grid on right.

The final way in which a standard, orthogonal, square grid can cause problems is where the building being analysed contains narrow apertures or openings. What becomes crucial in this situation is the relationship between the width of any such apertures and the grid spacing interval. A good example of this is figure 1 of Dalton et al.'s paper on VGA intelligibility (Dalton et al., 2022). Again, in a manner very similar to the example of the grid and the curved wall above, if the grid spacing is too large, relative to the size of the opening, either the opening can be missed entirely or its effect on the result VGA space syntax measures are artificially reduced.

We hypothesise that a new method, which we are terming the Restricted Randomised Visibility Graph Analysis, or R-VGA, is a more robust method of producing isovist 'grids' with less invariance in resultant space syntax measures in the situations shown above compared to the original orthogonal grid. We will present this in the next section.

3.2 Introducing the Restricted Randomised Visibility Graph Analysis, or R-VGA

In this section we will clarify how we programmed a new piece of software (as yet without a name). This was a new software programme intended only for producing randomised visibility graph analyses. The new software was written in the Java language using the Processing IDE and library (Arnold et al., 2005). For reference, figure 3 showed, in principle, what is a random grid and how this varies from a standard, square-based grid (figure 2). However, as also discussed in Section 2, purely random grids are also not without problems, due to the chance of 'clumps' of points clustering in specific locations; our method aims to avoid this problem.

The way in which we are producing a random grid for isovists analysis is quite simple. The first step is to initially 'seed' a plan or map with N (in our test cases N=125) entirely random points, from which isovists can be generated (from this point onwards, isovists generating locations are simply referred to as points). During the creation of these initial points, each point is checked to ensure that it is inside the spatial system's 'navigable space' and not located within, for example, as wall (or inside a building if it is being used for urban-level analysis). This initial 'seeding' of the R-VGA process will produce a type of skeleton analysis which needs to be further refined. The next stage is not fully random, hence the name *'restricted randomised'* VGA. In this stage, additional points are added incrementally, one at a time, to the analysis. Each time a new point is added, ten candidate points are initially generated and checked to ensure they are in open space (and not in a solid wall or inside a building). For each of these candidate, new points, the distance from this point to the nearest existing point (initially one of the 125 points) is calculated and the point with the largest distance from any other point is selected and the other nine candidate points are rejected and discarded. This new point is then added to the set of points resulting, this first time, in a total of 126 points. Since it is possible to create R-VGA analysis at different densities, this process is continued until the required number, N, is achieved, for example, N=500 points (or isovists locations). See figure 7 for a simplified (fewer initial points, N) illustration of this process.

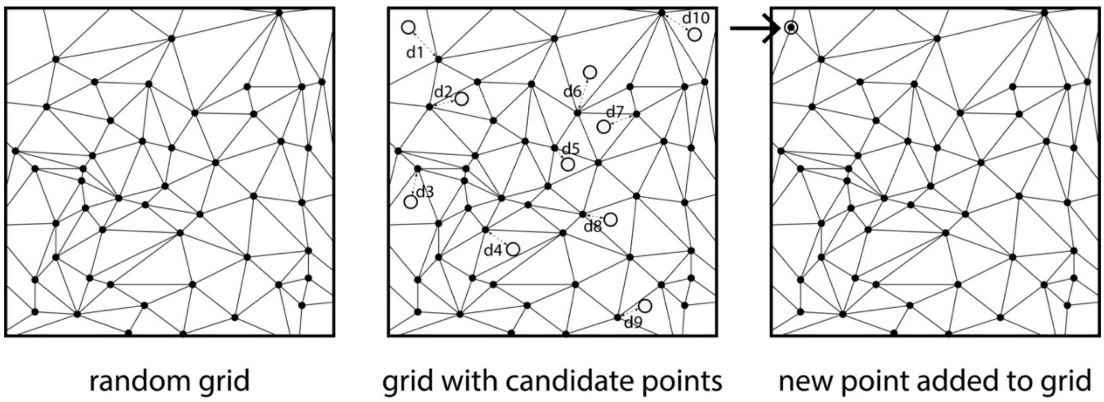

Figure 7 The process of adding a new point to a random grid. Left: the starting grid. Middle: adding ten candidate points and measuring the distances, d1 to d10. Right: the point with the greatest distance, d1, is added to the grid.

In this next section we will show an R-VGA analysis of number of selected building plans.

3.3 Using the Restricted Randomised Visibility Graph Analysis, or R-VGA, to analyse selected sample buildings

The test environments that we have used to analyse are Aldo van Eyck's Sculpture Pavilion in Sonsbeek Park, used already in this paper because it exemplifies the very situations in which orthogonal grid-based VGA performs less well, and Hillier's 'intelligible world' from Space is the Machine (Hiller, 1994).

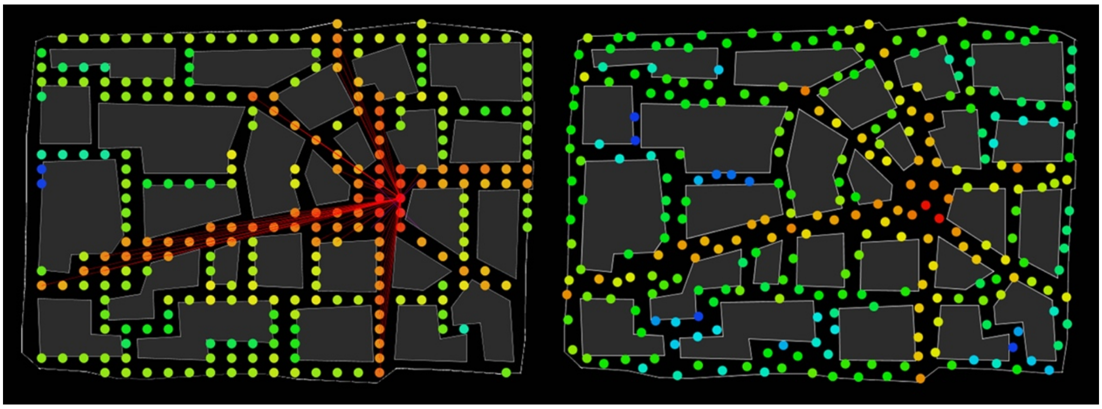

Figure 8 Hillier's intelligible worlds compared, each with exactly 270 isovist generating points, in an orthogonal grid (left) and a restricted random grid (right) showing the pattern of global integration.

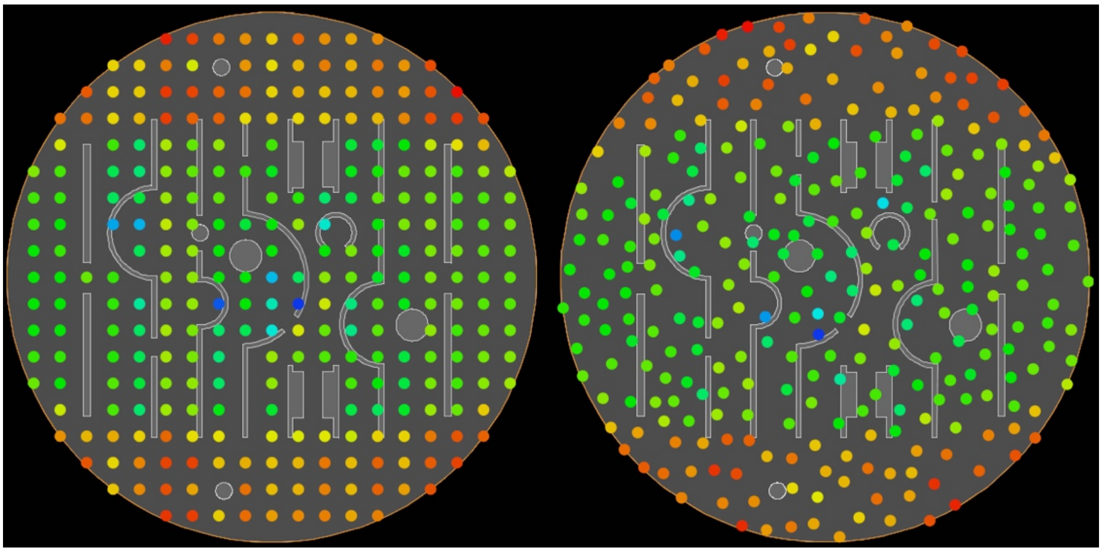

Figure 9 The Sonsbeek Pavillion compared, each with exactly 281 isovist generating points, in an orthogonal grid (left) and a restricted random grid (right) showing the pattern of global integration.

First, considering Hillier's intelligible world, as shown in Figure 8. We used a relative sparse orthogonal grid, so that it was easier to identify and to explain the differences between the two, however we ensured that the restricted randomised grid contained the same number of grid-points (N=270). Then for the Sonsbeek Pavilion (figure 9) we repeated this exercise, but this required a different number of grid-points, namely 281 (this is because we could not control the number of grid points in Depthmap and so had to set the upper limit of N in our software to match the resultant value of N produced in Depthmap). There are differences evident in both figures. In figure 8, the first thing to notice, is that there are whole sections of the plan which are without any grid points (or isovist generating locations) at all, namely a large extent of the far-left side, a narrow vertical street in the top left corner and a large proportion of the bottom right corner. Conversely, in the R-VGA analysis, there are no convex spaces without at least one isovist inside it, despite the fact that the R-VGA analysis contains no additional points compare to the VGA analysis. The other striking aspect in the differences between the two plans in figure 8, is evident in the differences in the colours of the point (in figure 8). What is noticeable is that the orthogonal grid, on the left, has a far stronger, red integration core, and fewer blue, segregated points. The reason for this, we believe, is that in the orthogonal grid analysis, it is possible for a row or column of points to fortuitously align, forming a strong clique, and hence pulling the distribution of integration towards it. This kind of alignment often tends to be the case for streets or street/corridor-like spaces: and if this does happen the distortion is, in effect, 'baked-in' to the analysis. This is evident in the vertical column of twenty points (in figure 9), that pass through the central, open space. This alignment of points means that the section of this column, below the central open space, is consistently dark orange reaching almost to the edge of the world. In contrast, this same space is more yellow, in the restricted random grid analysis. Many of the very narrow side streets are green in the orthogonal grid world, but are blue in the restricted random world. As we increase the numbers of grid points, using either method (orthogonal or restricted random) it is clear that the R-VGA analysis more closely represents the 'correct' values than does the orthogonal VGA analysis (see the top left image of figure 4 to see a higher resolution analysis of the Sonsbeek Pavillion and figure 1b of our other paper (Dalton et al., 2022) for a higher resolution analysis of Hillier's intelligible world).

Turning to the two analyses of the Sonsbeek Pavilion, the first thing to notice is that for the orthogonal grid analysis, on the left, is that there are, again, some narrow spaces without isovists grids. Another interesting feature of the pavilion is that there are a number of corridor-like spaces that are the same width, but because of the difference between the grid spacing of the analysis and the underlying grid of the building, some of these 'corridors' contain two columns of points and some only one column of points (this can also arise from the placement of the grid's origin). Naturally, the 'corridor' with an extra column, i.e. extra grid points, is more integrated than the space with fewer columns. In other words, the misalignment of the grid squares, causes more 'weight' to be placed on those long, narrow, spaces that just happen to benefit from accommodating more columns of points. Again, there are subtle differences in the colours of more integrated, open spaces towards the top and bottom of the two figures. Once again, the R-VGA, despite having the same number of isovists generating points (N-281) more accurately represents the pattern of integration for an analysis using a much denser grid.

Finally, although not shown here as a figure, we reproduced the experiment with rotating the Sonsbeek Pavilion through two-degree angles of rotation and filling it with a restricted random visibility graph analysis, R-VGA, and then measured the value of the most integrated point, the most segregated point and the average integration value for each rotation. This was an exact replica of the process used to generate the graph in figure 5. Whereas figure 5 showed considerable variation in the most integrated locations, and less in the average integration values and least of all in the most segregated value, for the R-VGA calculations there was almost no variation at all, the graph consisted of three, straight, horizontal lines. In other words, the R-VGA calculations remained invariant under any orientation of the plan, as would be expected.

4 RESULTS

The results analysis consists of three stages. We first demonstrated how the traditional, orthogonal, VGA analysis struggles to perform well in the presence of certain building conditions, namely buildings with the potential to have an underlying grid that does not align with the VGA-grid, either because of its origin, orientation, or grid-spacing, a building with a-typically narrow spaces or narrow openings, or a building with a large number of curved surfaces. Figure 5 showed how the integration values of the isovist grid points can change depending on the relationship between the orientation of the building and the orientation of the isovist grid meaning that researchers would need to give thoughtful consideration to the orientation of their building prior to conducting any isovist analysis.

Second, the substitution of R-VGA (restricted random visibility graph analysis) was shown to have some clear advantages: it is possible to achieve better isovist integration results with a much sparser grid, by ‘better’ we mean that the integration values of a sparse R-VGA grid are more similar to the integration values of a denser VGA grid. This has considerable advantages for the researcher. Since VGA can be quite a time-consuming form of analysis (the processing time increases in proportion to the square of the number of points, i.e., double the number of isovist points will results in a quadrupling of the process time) then being able to produce more accurate results with fewer points means that processing times can be made more efficient.

Third, other comparisons between traditional VGA analysis and this new, R-VGA analysis revealed other advantages of the R-VGA analysis. Namely that artificial artifacts of the orthogonal grid, such as a fortuitous alignment of a row or column of points that exaggeratedly ‘pulls’ the weight of integration towards it can be entirely avoided. Equally, the problematic features identified, such as narrow spaces or apertures or curved walls also cease to be a problem.

5 CONCLUSIONS

The aim of this study was to extend the investigation of the fundamentals of isovists grids to encompass a wider range of possible grids and hence determine whether there is an optimal grid type and, if so, what would it be. Through the course of this paper, we incrementally demonstrated the intrinsic limitations of traditional isovist grids and the advantages of a new method of performing VGA analysis, namely R-VGA or restricted random visibility graph analysis. Via worked examples, we showed how R-VGA overcomes the limitations of traditional orthogonal isovist grids, whilst, at the same time, having the advantage of being a more accurate representation of isovist integration at lower grid densities and therefore reducing processing times (an unanticipated advantage).

We propose, therefore, that R-VGA becomes recognised and established as a new standard of VGA analysis in the space syntax ‘family’ of measures. We also call for it to be recognised that the current orthogonal isovist grid-based analysis is only one form of VGA analysis and that there are many other possible forms of alternative grid visibility analyses. Indeed, we conclude this paper by suggesting that there may be value in considering VGA analyses as an entire family of different forms of analysis, forming a taxonomy, as shown in figure 10.

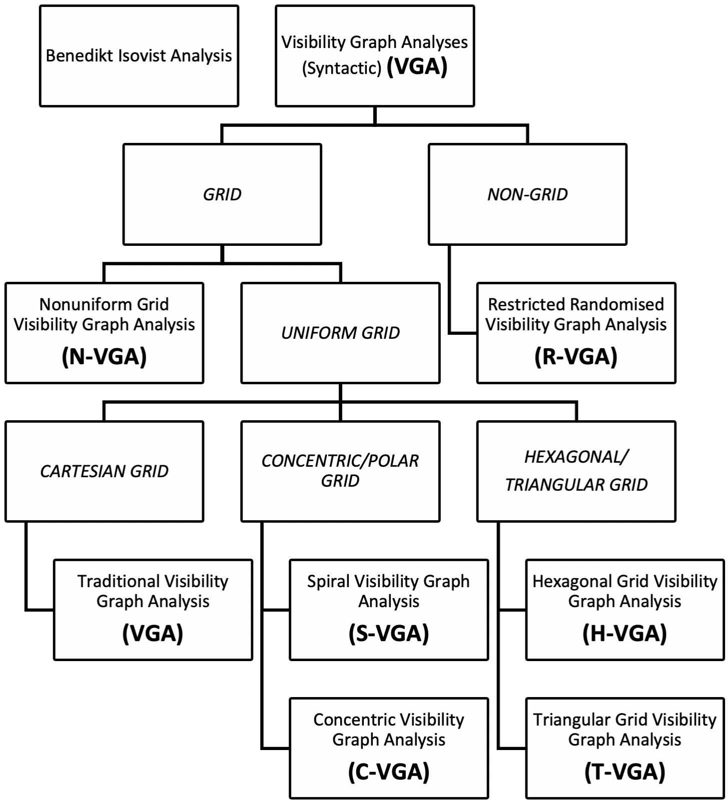

Figure 10 New, proposed taxonomy for a whole family of VGA-analyses, of which R-VGA is just one type

Figure 10 is intriguing as it opens up a potential for significant future work. A limitation of this paper is that we have only been able to focus on only *one alternative* form of a VGA grid, namely the R-VGA grid, but from our proposed taxonomy above it is clear that there may be many other possible forms of VGA-grids. One rich area of future work will be to investigate these other possible forms of VGA grid and to determine which have potential for space syntax analysis and whether some forms of grid may be more suitable for different building/urban typologies and which these are. For example, in the special case of circular-plan buildings (Steadman, 2015) concentric or polar grids may produce optimal, analytic results. For buildings or urban neighbourhoods where there are abrupt 'changes' in the scale of spaces (larger open squares/rooms compared to smaller alleys/corridors) a non-uniform grid, with fewer grid-lines in the larger spaces may warrant being investigated. In this way, more granularity can be provided in some areas of a plan/map and less granularity in other locations. Equally, such changes in granularity might prove useful by providing more detail in the central, area of focus (of an urban neighbourhood, for example) and less detail for its embedded context. This may, however, be problematic because of the fact that the density of nodes in some areas relative to others would themselves distort values of e.g., integration (and/or, such examples might need a varying form of relativisation to be applied). Hence there is also a need for future research in this area to determine the effect of changing granularity using non-uniform grids. All of these possible applications are conjecture, but it is clear to us that, having opened the door to alternative VGA grids, this may be a rich vein for future space syntax investigations. Future studies will have to continue to explore the potential of this taxonomy and assess the extent to which its proposed sub-categories may have utility for space syntax research.

For this paper's authors, specifically, another future area of endeavour is either to release our R-VGA software programme (as yet unnamed) as a stand-alone piece of software available for the space syntax community or to integrate it into McElhinney's, already available, Isovist_App software (McElhinney, 2017).

Finally, there is one significant additional feature of the R-VGA grid which entirely eclipses all of these other advantages listed here in this paper. We have chosen not to discuss it in this paper, since we judge it to be sufficiently important to merit its own paper. This is the fact that when using R-VGA, a researcher is able to precisely control for the value of N, or the numbers of points that are randomly distributed throughout a plan or map (as discussed in the preceding sections). Being able to control for the value of N means that comparisons between different spatial systems becomes easier to achieve. For example, it is possible to directly compare two buildings, of different sizes, but by controlling for the value of N, the isovist integration values can be directly compared without any need for normalisation or relativisation. A corollary of this is that a robust and consistent VGA intelligibility measure becomes an achievable goal. Please refer to our accompanying paper on both these topics (Dalton et al., 2022).

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