Visibility, accessibility and beyond: Next generation Visibility Graph Analysis

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Abstract

Visibility Graph Analysis (Turner et al., 2001) is widely used for the analysis of architectural space and is linked to pedestrian movement distribution or agent based modeling through a number of studies. However, until now spatial relations associated with a visibility graph were simple, very limited and in most cases sub-sampling the affordances of spatial models in question. In this study we use a newly developed analysis methodology, which we call Augmented Visibility Graph Analysis or AVGA, and is based on mixed-directionality graph structures, in order to study a number of hypothetical architectural designs where visibility, accessibility and permeability challenge the existing tools and methodologies.

The paper presents the computational problem of analysing spaces that include 'augmented visibilities', areas with 'inaccessible but visible' locations, and through the case studies it demonstrates how the exclusion of some affordances, of the architectural morphology, from the graph representation can dramatically affect the analysis results. AVGA overcomes the limitations of current visibility graph analysis methodologies and allows the analysis of architectural and urban space that includes visuo-spatial and hybrid configurations past the simple 'wall or opening' restriction. The results show how visuo-morphological relations beyond accessibility can be encoded programmatically and how they can shape our understanding of space through computational models.

Introduction

The concept of visibility graph analysis (VGA) and isovist analysis has a long history in architecture and other disciplines. Space syntax uses VGA primarily in building and in semi-urban scale in order to derive how visibility defines relationships of spatial elements, influences movement and helps to understand the space around us. Turner et al. (2001) presented the computational foundations of visibility graphs as a method of taking away from built environment a permanent record of spatial configurations and relationships. Since then VGA has revealed a series of meaningful characteristics and correlations about architectural space, morphology, movement and space usage. While constructing a graph from simple inter-visible locations in space is widely used in spatial analysis techniques, Turner et al.'s (2001) VGA generated some limitation which researchers tried to overcome by using elaborate tricks or simplifications in order to enable an acceptable analysis.

In this paper, we continue our exploration by challenging these 'troublesome for VGA' situations, such as transparencies, half-height partitions, office furniture and voids where the resulted spatial morphologies include directly visible connections that lack overlapping movement routes. Similarities can be found in visual augmentations produced by ambient projections, displays and other digital elements, where someone can not only create pairs of locations with non-matching visual and movement routes, but also in most cases generate dislocated spatial realities that distort the architectural morphology of the perceived surrounding space that belong to the same 'troublesome' category. A simplified such space was part of a preliminary study (Varoudis, 2014) with encouraging results that led us to present here a number of complex physical environments.

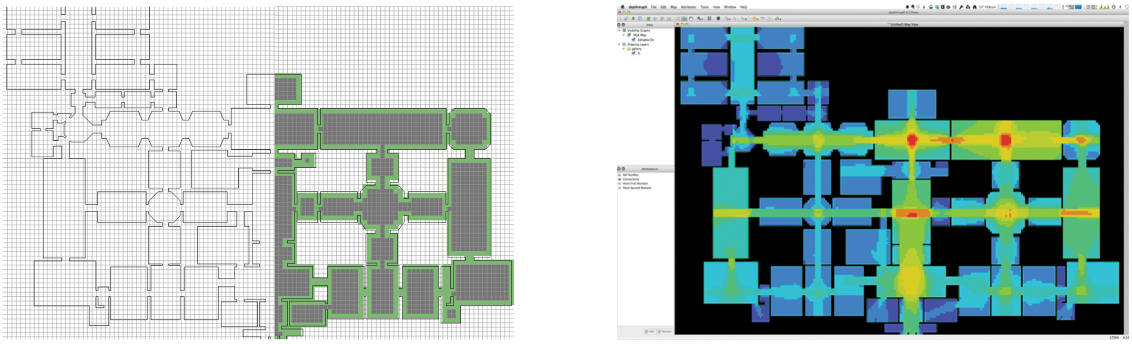
We start by describing a number of situations that challenge the mapping of architectural visuo-spatial relations and morphologies, in some cases described as 'architectural disjunctions' (Koch, 2012), to mathematical graph models and then we present a set of visuo-graph relations that can be represented in a mixed-directionality graph. In Augmented Visibility Graph Analysis (AVGA) methodology the undirected graph used in VGA is replaced by a mixed graph that allows complex origin-destination distinctions to be made. Finally, the AVGA methodological and computational advances are illustrated through hypothetical environments that emulate challenging spatial characteristics typically found in space around us. All analyses were made with a new experimental AVGA software, developed by Tasos Varoudis, called vSpace (version 0.10) and the figures with a combination of R/ggplot2 and Grasshopper.

Background

Visibility graph analysis (VGA) was developed by Turner et al. (2001) based on space syntax theory (Hillier and Hanson, 1984) and early foundation work on visibility fields (Benedikt, 1979; Thiel, 1961). Turner et al. (2001) attempted to record the details of the visual experience through buildings or urban environments by analysing the properties of visibility fields. The concept of 'isovist' (Benedikt, 1979), which has had a long history in various fields of research including architecture, geography and mathematics, is central to visibility analysis. An isovist is "the set of all points visible from a given vantage point in space and with respect to an environment" (Benedikt, 1979, p.47). Turner (2001) argued that isovists are an intuitively attractive way of thinking about a spatial environment because they provide a description of the space 'from inside', from the point of view of users as they perceive, interact with it, and move through it.

Benedikt starts by considering the volume visible from a location and then simplifies this representation by taking a horizontal slice (two dimensional) through the 'isovist polyhedron'. The resulting 'isovist' is a single polygon without holes. The geometric properties, such as area and perimeter, are then considered and through this process the qualities of space, and its potential, are quantified. Earlier than Benedikt a similar concept was called 'viewshed'. Tandy (1967) used that earlier concept for the analysis of landscape but it was Benedikt (1979) who developed the method for the consideration of architectural space. Tandy used 'viewshed' to "[take] away from the architectural space a permanent record of what would otherwise be dependent on either memory or upon an unwieldy number of annotated photographs" (Tandy, 1967, p.9). Similar ideas were used in the field of landscape architecture and planning (Amidon and Elsner, 1968; Lynch, 1976) and computer generated 'inter-visibility' topographic models (Gallagher, 1972).

First formal analysis of isovists was performed by Benedikt who believed that analysis of multiple isovists is required in order to quantify a spatial configuration and suggested that the way through which we experience and use space is related to the interplay of isovists. This complex interplay is also our main driving force for this paper. Benedikt developed methods to calculate isovist fields which record the individual properties for all locations by using contours to plot the way those features vary through space. For example, the closeness of the contours showed how quickly the isovist properties are changing and, according to Benedikt, this relates to Gibson's (1979) conception of ecological visual perception with textured gradients.



A) VGA steps: buidling the grid (left) - Filled space (right)

B) Typical VGA result - depthmapX

Figure 1 - VGA with depthmapX

Space Syntax primarily seeks for answers through the analysis of the configuration of space. This can be simply defined as the relation between two spaces taking into account a third, and at most, as the relations among spaces in a complex configuration taking into account all other spaces in that environment (Hillier et al., 1987, p.363). Turner et al. (2001) developed the Visibility Graph Analysis (VGA) methodology in order to overcome the limitations of Benedikt's theory. The first limitation was identified in the geometric formulation of isovist measures, meaning that isovist records only local properties of space, and the visual relationship between the current location and the spatial environment as a whole is missed, including the isovist's internal visual relationships. The second is that Benedikt did not develop any guidelines on how to usefully interpret the results of the analysis, meaning that there is no framework to show how isovists relate to social or aesthetic factors. The VGA method draws from space syntax theory (Hillier and Hanson, 1984) and small worlds analysis (Watts and Strogatz, 1998) and produces a graph of mutually visible locations in a spatial layout termed visibility graph. VGA (Figure 1) is implemented and widely used by both academics and practitioners through the open source and multi-platform 'depthmapX' spatial network analysis software (Varoudis, 2012; Turner, 2001). Turner et al. (2001) suggested a number of local and global measures of spatial properties that are likely to relate to perception of the built environment. The measures can be extracted from the graph and compared with real life data of usage to “shed light on the effects of spatial structure on social function in architectural spaces” (p.104). Other studies have also demonstrated a significant correlation between visibility analysis measures and the way people move (Desyllas and Duxbury, 2001; Turner and Penn, 1999).

Interestingly though, while space around us is full of complex and interesting visuo-spatial phenomena, such as trans-spatiality in office spaces (Sailer, 2009), transparencies or reflection elements (Psarra, 2009), depth augmenting hybrid configurations (Varoudis, 2011; Varoudis et al., 2011), digitally linked office environments (Schnadelbach, 2007, 2010) and urban displays (Fatah gen. Schieck, 2005), the systematic analysis of settings that include these elements is not possible with VGA. While VGA overcame limitations of older studies of isovists, it is restricted to analyse spaces that only include fully obstructive walls or simple openings. In the past, researchers tried to go outside the traditional VGA method ether by re-inventing measures based on the same graph representation and software (Depthmap at the time) or use axial layered-graphs (Doxa, 2001;

Dalton and Dalton, 2009), but none proposed a unified model that incorporates spatial, trans-spatial and a-spatial elements and relations. In practice, researchers and practitioners in most cases have to remove some elements from the input drawings or extend and block other elements before performing an analysis. We believe that by doing so, in most cases they lack an understanding that considers the architects' intention associated with morphology, accessibility, visibility and design.

Visibility, accessibility and beyond: Augmented Visibility Graph Analysis

Permeability, visibility and accessibility from a morphological and spatial analysis point of view can be seen as the problem of different relations formed in complex spatial and trans-spatial settings. In extent it is a problem of multi-dimensionality of information, both spatial and visual, in the visibility analysis techniques. Before describing the Augmented Visibility Graph Analysis (AVGA) we first need to describe some basic concepts, which form the foundation of this exploration, and how to perform a typical VGA.

Graph Based Analyses and Mixed-directionality Graphs

Describing visibility relations in space with VGA requires the use of a graph based structure (Trudeau, 1993) were nodes (vertices) represent locations in space and links (edges) denote some form of direct relationship. Similar to axial and segment graph analysis, dominant in space syntax theory (Hillier and Hanson, 1984; Turner, 2007), the edge formed in VGA can only be an undirected link that represents a symmetrical relation between the two locations. For any given pair of linked locations it is required that both ends of the link can be origins and destinations of movement and visual rays. In addition the movement vector *from* and *to* the two locations must coincide with the visual ray that connects the two. In essence, you cannot form a link with a location if you can see that location directly but cannot approach it using the same route as the visual ray connecting you to that location.

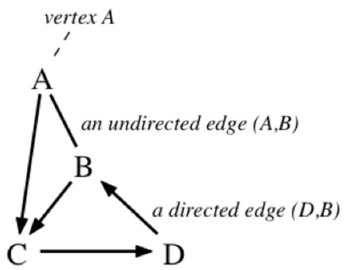


Figure 2 - Mixed directionality graph

In order to overcome the limitation of not being able to encode asymmetrical spatial or visual relations we use a mixed graph (Figure 2). A mixed graph allows a set of un-directed and directed relations along with sets of associated locations to be encoded into a graph. The mixed graph combined with additional data (description tags) that can be encoded into the graph structure via spatial categorisation techniques is able to describe a large set of architectural and urban settings, if not all. In this case, additional tags are used to identify locations where movement could occur, furniture or materialities.

Using Undirected and Directed Links

Constructing a visibility graph is a two-step procedure. Firstly, we select an appropriate set of location in space to generate the isovists locations. These locations form potential nodes of the graph. The most obvious approach to construct the isovists is to generate them at some regularly spaced intervals (Figure 1). This implies that the generating locations will be at points defined by some sort of grid. In practice we try to select a set of generatedlocations that provides an acceptable 'near-full' description of the space. Turner et al. (2001) argues that in order for the analysis to relate to human perception of an environment, then the resolution of this grid must be fine enough to capture meaningful features of the environment in human movement scale. In Turner et al.'s VGA, we then select the physical or walkable space to be analysed. This continuous set of grid-cells depicted in Figure 3 represents the nodes (vertices) of the resulting visibility graph. Secondly, given the set of final nodes, we determine the direct visibility relations between them and form links (edges) in the graph. In order to add an edge between two locations at the graph, the two locations must be directly inter-visible.

The two simple scenarios shown in Figure 3 aim to a elementary introduction to the concept of AVGA, one of them describing an office with desks and the other one depicting a space partially divided by a glass wall. Indeed a number of layouts like these can occur that cannot satisfy the origin-destination or directionality restrictions of Turner et al.'s VGA. The first part (Figure 3) of the series of illustrations depicts the undirected visibility relational graph between locations in space. A typical graph representation in Turner et al.'s VGA.

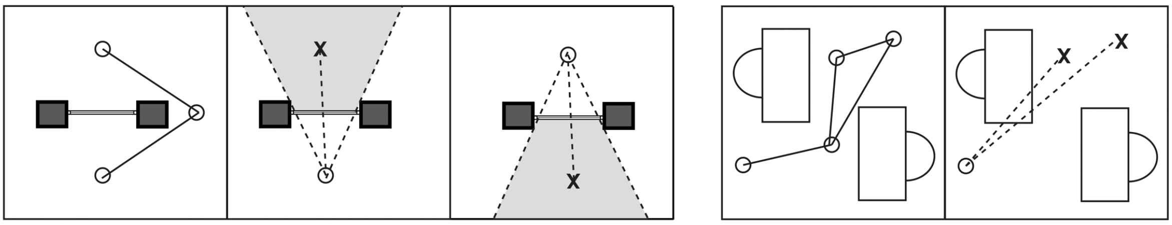


Figure 3 - Complex visuo-spatial layouts, transparencies and obstacles.
('accessible' = O, 'augmented' = X)

However, the environment's affordances are more complex. Dourish (2004) described affordances as "a property of the space that affords action to appropriately equipped organisms". While we move in space through a set of 'unrestricted' areas, we constantly scan space for potential destinations over furniture, through transparent elements and across multi floor atria. Every time our visual field passes over one of these we subliminally know that there is more 'space' or 'visual information' towards the destination of that ray but in order to go there we still need to follow the 'walkable path'. Further illustrations in Figure 3 demonstrate the additional visual clues. That extra bit of visual information forms a multi layered visuo-spatial model. The number of dimensions of visual information for each location of space varies based on the number of augmented visibility fields that are produced through the affordances of a particular space. Multi-dimensional overlaps (grey regions in Figures 3 and 4) are generated when movement is obstructed (or not possible) but a visual clue is given, in essence, multiple layers of information and relationally connections are fused into one physical location. Moreover, in spatio-temporal scenarios a new dimension could be part of the location-based data associated with a physical location. Similarly, the left side of Figure 3 describes the added dimension of visual information that exists past a glass partition.

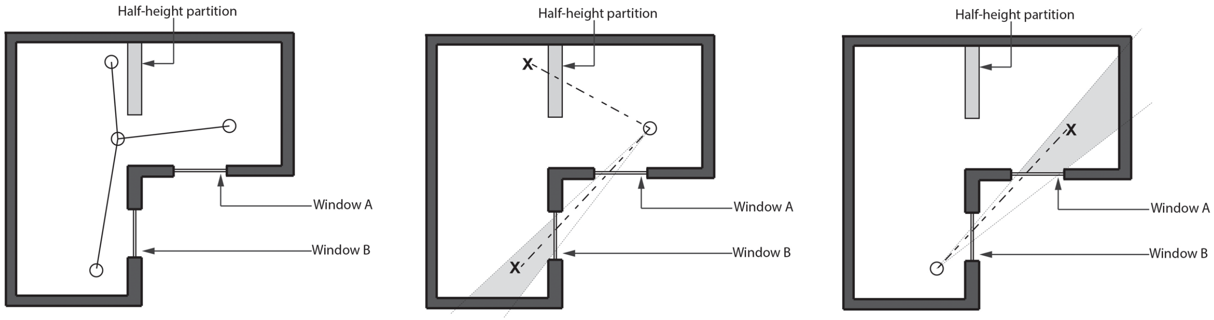


Figure 4 - Complex visuo-spatial layout ('accessible' = O, 'augmented' = X)

Figure 4 illustrate another common spatial configuration that includes windows and a half-height partition (not much different from furniture). The left illustration is the un-directed origin-destination model, which usually forms the graph in VGA, and the next two illustrations demonstrate the multi-dimensional information omitted in traditional analyses. Starting with the half-height partition, which easily relates to spatial arrangements seen in all kinds of commercial and residential buildings, it produces a direct-inaccessibility but gives a visual hint about the open-plan arrangement of the destination. The space feels partially unrestricted and as such it should be analysed as one. Furthermore, the two windows generate an augmented overlapping space for each of the opposite locations. Windows in similar architectural settings, that give hints of space around the corner, amplify the experience of visual and spatial discontinuity and trigger further movement (Peponis, 1997), thus play a significant role in any form of analysis. The same can be said for the open space beyond the building (through the windows, outside space) but it is omitted in this example.

In terms of spatio-visual information, for any space we can form a relational model merging the accessible and augmented layers (dimensions) by following a simple set of procedures. The model can then be encoded into a mixed graph structure. In AVGA the accessible space can act both as origin and destination of a visibility relation. While both these locations can be populated by users that are looking to go somewhere, the augmented or multi-dimensional location can only be a destination of visibility or information. The relation or link always originates from some accessible location. Locations in the augmented space, marked with 'X' in Figure 4, are restricted from forming outgoing links with any other node in the systems. Such augmented links are encoded as directional graph edges in the AVGA graph and relations between 'accessible locations' are encoded as undirected (or bi-directional) edges.

The foundation of AVGA is a multi-dimensional definition of space and associated information with asymmetrical relations. As illustrated in Figures 3 and 4, a location can exist in both accessible (marked as 'O') and augmented (marked as 'X') space, layered on top of each other. The process of generating the nodes and the spatial categorisation is done through a series of ray-casting analyses and algorithms in order to find all possible augmented isovist locations in space and their relations to others (i.e a location is only visible through glass and not accessible etc). Materiality, object location in space and dimensions (especially height) play an important role here.

Layered Information - Spatiotemporal

While this study limits the examples presented to a number of real space spatial configurations, we have designed AVGA's mixed directionality graph structure so it can hold a number of complimentary information about locations (vertices) and links (edges). A typical AVGA graph has nodes that can be identified by their 'location tag', like 'accessible' or 'augmented' and special tags like 'hybrid', 'virtual', 'reflected' or other. Also location data fields can store any data type, reflecting to both space and time. The edges apart from the directionality information can have added information like 'edge description' tags, coordinate system translations (euclidian or other) and typical spatio-temporal conversions. With AVGA developement we are not only aiming to create a 'more complete' description of space, as it is presented here, but outside the scope of this paper, our work has expanded to spatial representations that focus on the analysis of multi-model spatio-temporal data.

Processing the graph

The analysis and discussion will mainly focus on three computed measures, two of them are mostly considered as the foundation of VGA and a new measure based on the mixed graph representation.

Turner et al. (2001) systematically defined visual connectivity and integration following Hillier and Hanson's (1984) earlier work. Visual connectivity, in both VGA and AVGA, is equivalent to the degree of the node, as discussed in graph theory, thus represents the number of connections (undirected links in Turner et al.'s case) that the node has with other nodes in space. As space in both analyses is quantised based on a grid, connectivity can only approximate the isovist size but the relation between the connectivity value and the isovist size is linear. Visual integration is directly linked with 'mean shortest path' of a node. Turner et al. (2001) describe the mean shortest path in their implementation of visibility graph analysis and its connection to Hillier and Hanson's 'integration'. Hillier and Hanson (1984) link visual accessibility of spaces with the number of changes in direction, whereas in a visibility graph we can describe the visual accessibility of every location in the spatial system through the number of steps. Visual mean shortest path is a representation that quantifies the visual accessibility of every location in a spatial system and it has a significant advantage over other analyses of spatial configuration. As the mean shortest path length measures configuration by considering all locations with respect to each other in the system, global relationships between locations in the system can be explored. This is a noteworthy difference to the measure of connectivity. Users of spatial analysis techniques extensively use this significant feature of the visibility graph to obtain an alternative spatial and morphological description of the build environment that departs from the previously available technics of partitioning in terms of local geometric properties of visual fields as Benedikt does.

In AVGA definitions don't change significantly but due to the increase of the informational dimensions we can extract different layers independently. Connectivity, for example, is specified as the total number of graph edges a node has. This number includes links formed as both directed and undirected. Connectivity represents the total visual information relations presented to the user at a location but due to the more complex nature of the graph representation connectivity is a complex measure. While an undirected link denotes that movement can be as important as vision for a particular location, a directed link works in a parallel dimension by giving subliminal hints of visual information. In order to describe the added spatial or trans-spatial information in a location we also use the measure of hybrid connectivity. Hybrid connectivity accounts for the number of directed links formed with particular nodes and essentially is a subset of AVGA's connectivity.

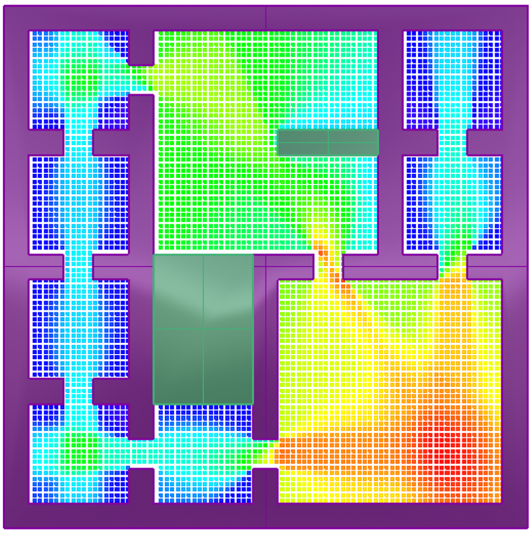
The analysis process starts by building the augmented visibility relational model. With all visibility and directionality information assigned to each vertex of the graph, we can now determine all possible paths. The shortest paths analysis is not as straight forward as VGA's, here we perform spatial categorisations when building the visibility data, as well as later on in the process when we need to build an origin list. While in Turner et al.'s analysis, all possible pairs of locations are used as origins and destinations of a shortest-path search, AVGA uses only a subset of the locations as an origin while the full set of locations remain as destinations. It should be noted here that a number of nodes in an AVGA graph has no outgoing links, thus acting as network dead ends. Indeed locations that present augmented visual information are only useful for the location linked with (the origin) and they don't present a possible 'through vision' or 'through movement' opportunity between locations. Graph shortest paths always terminate when reaching these nodes as no exit is permitted.

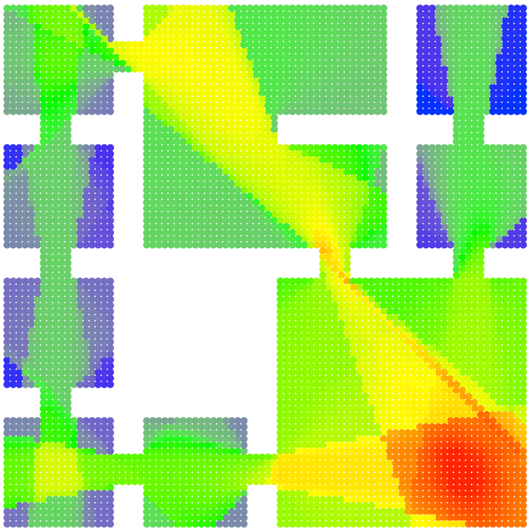
Test Scenarios

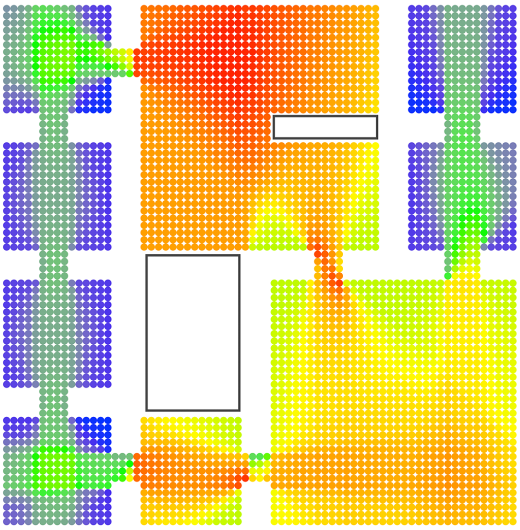
The novel scenarios presented below try to emulate a number of real architectural settings. In total four layouts are used, ranging from the interior of buildings with partitions and voids to larger corridor based labyrinths. All of them keep some symmetrical characteristics in their design in order to focus the discussion in the core differences of the analyses. Figures 5, 6, 7 and 8 depict an overview of the layouts as well as the added materiality or visibility-permeability restriction in certain locations; Figure 5-A shows the traditional VGA connectivity values.

Figure 5, describes a floor plan with a void between two spaces and a half height partition similar to Figure 4 above. It has a series of segregated spaces but also a small transitional space near the void that even though in reality might generate sufficient visual clues of the large space beyond the void, it is not seen as one by VGA. Figure 5-B depicts the VGA Visual Integration, while Figures 5-C and 5-D give the AVGA connectivity (visual augmentation areas are highlighted with black boarder) and visual integration respectively.

In this layout we clearly see the difference between not taking into account accessibility and permeability affordances of space and AVGA that encapsulates both the void and the half-height partition. Both visual integration and connectivity shift significantly from the bottom right space. The void boosts connectivity on both of its sides, for the segregated transient space at the lower part of the layout it potentially represents the added visual clues of space across, while for the large space across boosts the openness close to the void's edge. In contrast to the rather unified boost of connectivity values, AVGA visual integration, while heavily skewed, it clearly separates the contributed 'visual only' or augmented information from the primary accessible space. The half-height partition and the void don't block vision but they do block movement and 'through movement' when performing shortest paths thus restrict the high values near and behind the half-height partition.


A) Void and halfheight partition in green - Connectivity


B) Visual Integration HH


C) AVGA Connectivity

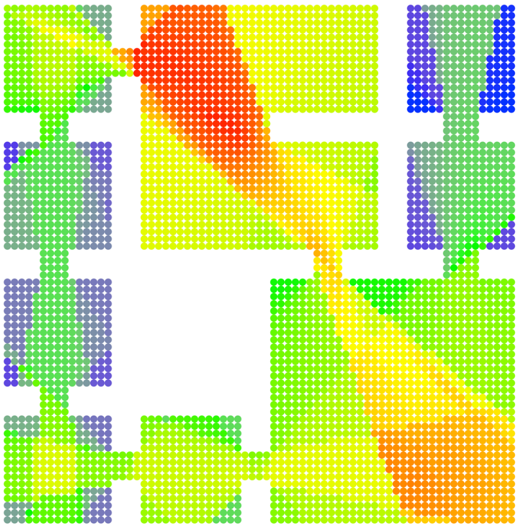
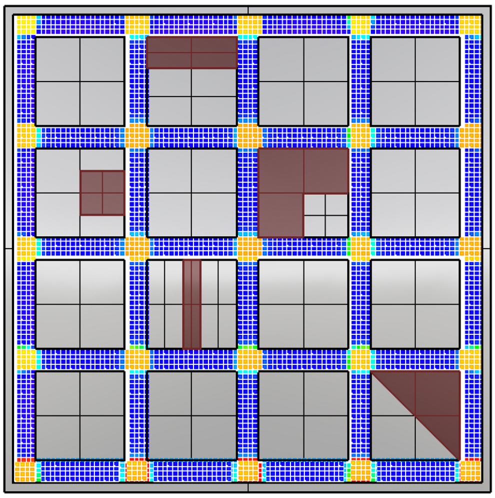
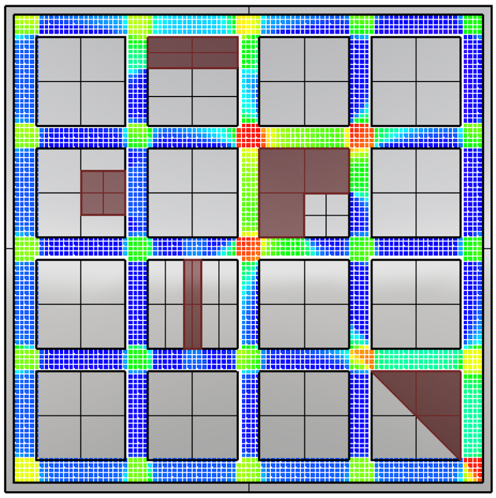

D) AVGA Visual Integration HH

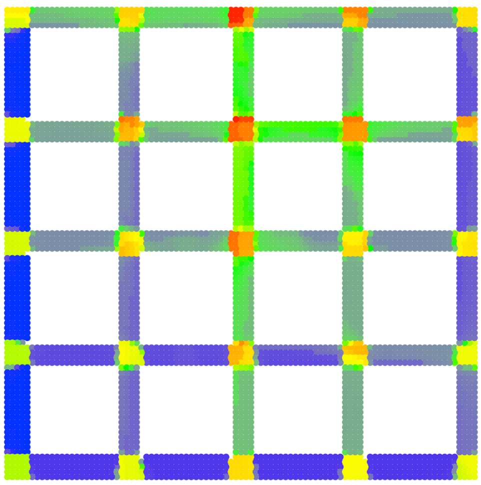
Figure 5 - Test Layout 01



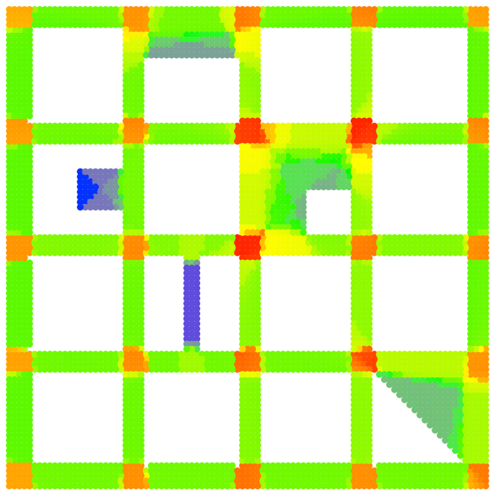
A) Transparent materials in dark brown - Connectivity



B) AVGA Connectivity



C) AVGA Visual Integration HH

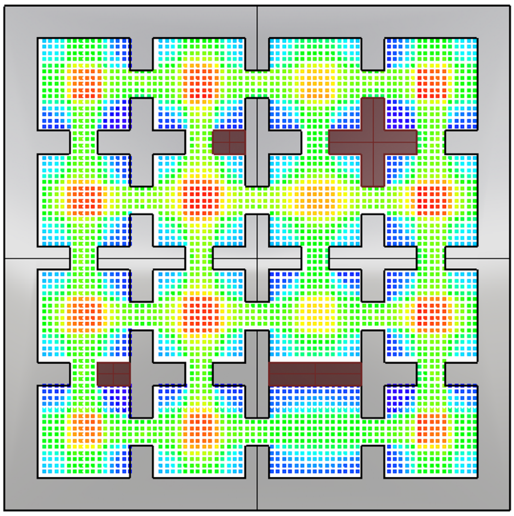


D) VGA Integration without augmented elements

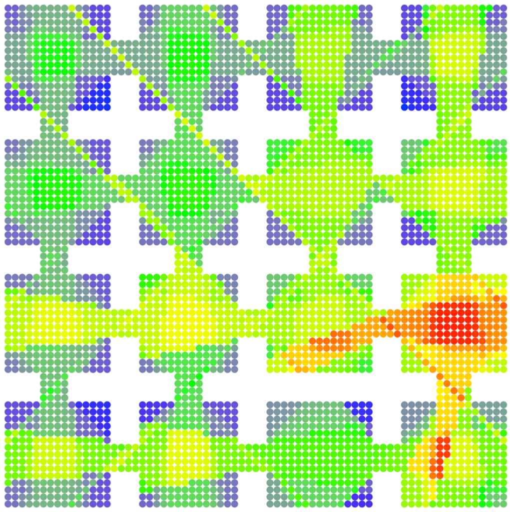
Figure 6 - Test Layout 02

The next layout that we analyse with AVGA is depicted in Figure 6. As a traditional VGA analysis would be virtually meaningless because of the symmetry, only Figure 6-A shows the VGA connectivity. This layout was designed to emulate a semi-urban setting with Manhattan style street network and a number of augmentations. We envisioned closed yards, small restricted access alleys and parts of building covered with glass that even though they form a barrier for the pedestrian, they also generate a subliminal visual openness. If we use depthmapX (Varoudis, 2012) to perform a VGA analysis, the values of connectivity and visual integration will be symmetrically distributed, with no information (or visual clues) about the visuo-morphological differences between the physical and the augmented multi layered topologies. In Figure 6-B we see the AVGA connectivity values that correspond better to the feeling of openness. While movement is restricted in the Manhattan style grid the visual integration of some locations is elevated as depicted in Figure 6-C that show AVGA visual integration. Another interesting point is that the narrow passage (restricted movement) pushes the connectivity values up, through its directed component, but because the passage is blocked from movement, shortest routes don't favour the nearby areas as much. In caparison to the hybrid morphology that AVGA analysis, Figure 6-D depicts the same spatial setting but removes all movement restriction and treats the space as open. The resulting output is based on depthmapX's VGA integration HH analysis. While researchers and practitioners use tricks in order to perform meaningful analysis in complex environments, we believe that doing so produces slightly inaccurate results as for instance to give equivalent 'power' to both restricted and unrestricted relations.

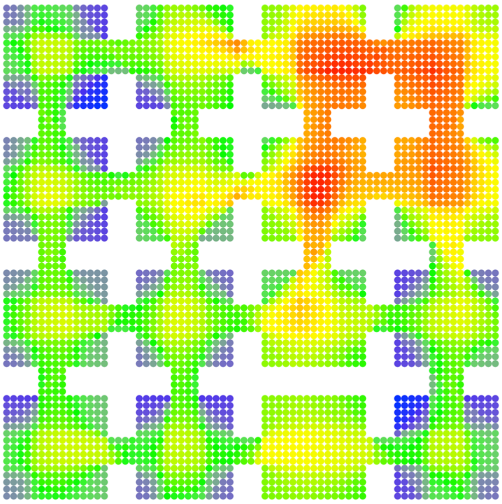
The third and forth test cases share similarities with the 16-room grid based layouts used by Alasdair Turner in the past but evolved and expanded in order to demonstrate augmented architectural morphologies and more fluid visuo-spatial relations. Figures 7-A and 8-A depict the VGA connectivity while parts 7-B and 8-B show the VGA visual integration. The AVGA connectivity and AVGA visual integration respectively are depicted in 7-C/8-C and 7-D/8-D. As layouts 3 and 4 are more complex and sometimes differences can seem subtle, Figure 7-E and 8-E displays the directed component of the connectivity value, the AVGA hybrid connectivity. High hybrid connectivity values means that the added 'augmented' information (in graph terms, directed information) has a significant effect on that particular location. This effect is not only evident adjacent to critical permeability and visibility location but it propagates through space producing diverse effects. Finally in Figure 7-F we give the plot of the difference between the VGA and AVGA visual integration that shows a drastic change in values, both increase and decrease.
Overall, from the four cases we clearly see the shift between the models representing the traditional analysis mechanism, which accounts only for a subset of the spatial affordances, and AVGA, where every visible, accessible or permeable element within architectural space is encoded and contributes to the overall analysis. Even though some 'augmented' elements in our studies are very subtle, they seem to cause significant changes and their effect in most cases propagates further than expected through the complex form of the given spatial affordances.



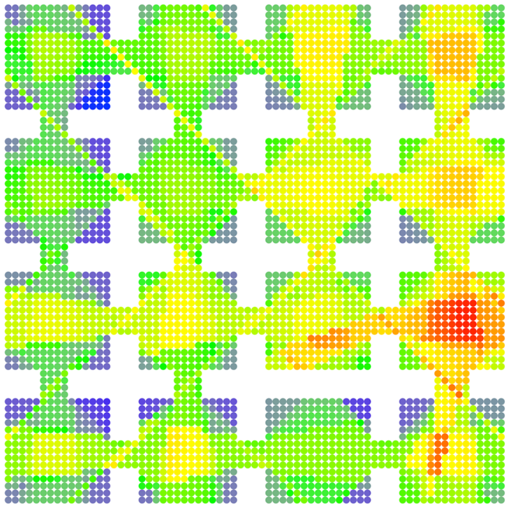
A) Transparent materials in dark brown - Connectivity



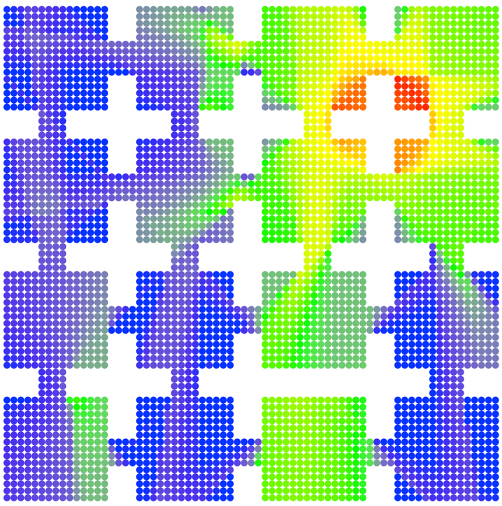
B) Visual Integration HH



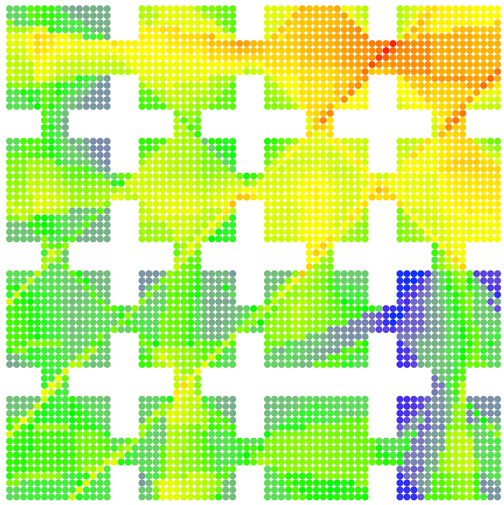
C) AVGA Connectivity



D) AVGA Visual Integration HH

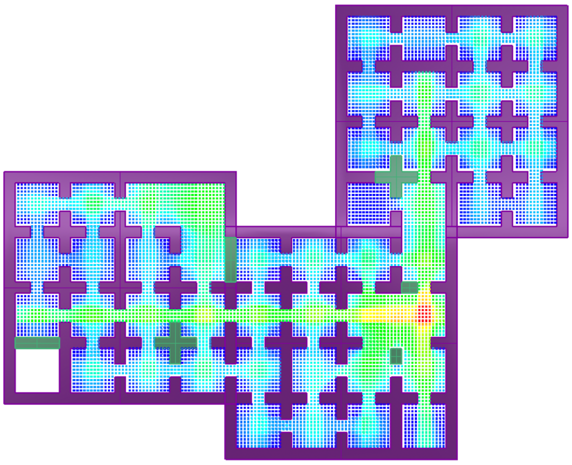


E) AVGA Hybrid Connectivity

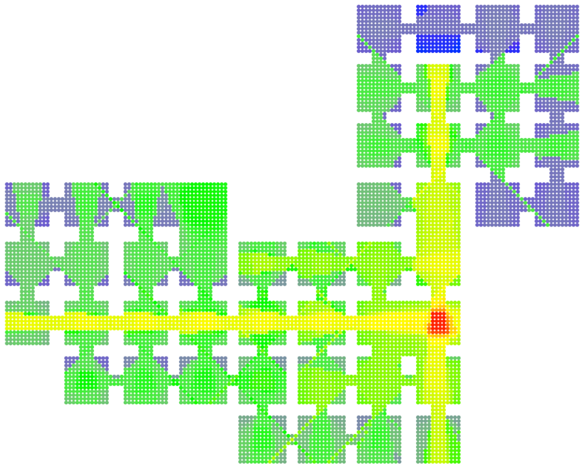


E) VGA and AVGA Visual Integration Difference

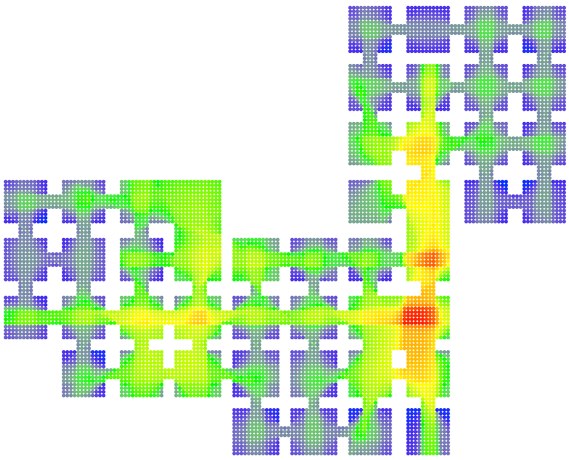
Figure 7 - Test Layout 03



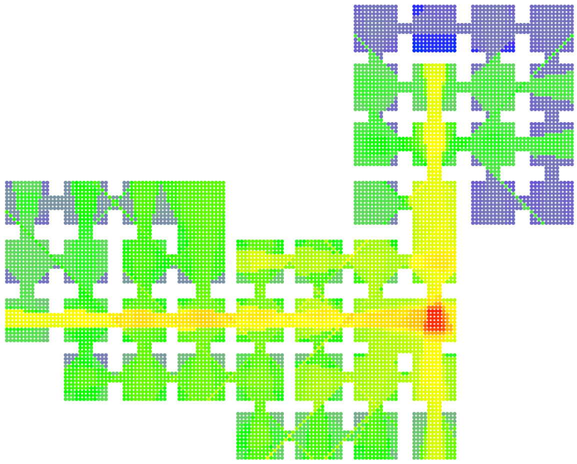
A) Transparent materials in green - Connectivity



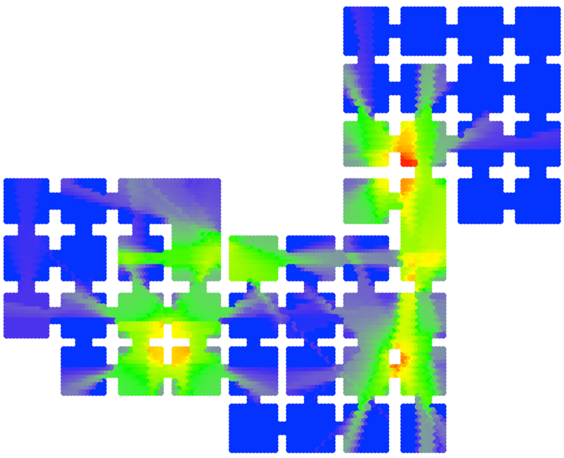
B) Visual Integration HH



C) AVGA Connectivity



D) AVGA Visual Integration HH



E) AVGA Hybrid Connectivity

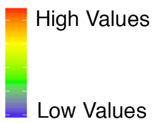


Figure 8 - Test Layout 04

Conclusion

Our work explores the methodology and application of visibility analysis for building and urban architectural space by merging the visio-spatial properties with the asymmetric relations in visibility, permeability and accessibility of architectural morphology, instead of only accounting for solid boundaries, as has been the case so far. To do so we use Augmented Visibility Graph Analysis, first presented in Varoudis (2014), that addresses space as an infinite dimensionality domain of spatial affordances. The morphological and visuo-spatial relations are encoded as a series of directed and undirected (or bi-directional) graph links as well as subsets based on spatial categorisation.

Being able to encode accessibility, visibility and permeability of architectural space in a model able to be systematically analysed gives us the opportunity to advance our understanding of space through spatial analysis techniques. With the case studies presented here together with previous work on 3dVGA (Varoudis and Psarra, 2014) and hybrid morphologies (Varoudis, 2014) we believe that Augmented Visibility Graph Analysis enables the visibility analysis of virtually any spatial configuration or dimensionality of space.

Considering the future directions for work, it is important to emphasise that the paper shows the significance of the fusion of multi-dimensional properties and data inside the graph models that generates new and encompassing ways of capturing architectural complexity, and places graph analysis at the centre of critique and understanding of architectural design. AVGA can better enable us to understand the interplay between spaces, material, objects and forms, with their associated multi-dimensional graph typologies.

Concluding, our work continues and aims to use AVGA and its underlying complex dimensionality in order to better understand hybrid spatio-temporal models and new agent based analyses. A number of new complex multi-model measures are currently being developed that further the studies detailed here and can contribute to areas associated with subliminal visual nudges, accessibility of hidden (segregated) spaces as well as alternative and more efficient methods to assist way-finding.

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