Augmented Visibility

A visibility graph analysis for hybrid architectural spaces

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Abstract. *The introduction of digital technologies in architecture formed new relations between space and people that are affected by the redefinitionof the spatial properties. Ambient projections can augment walls creating hybrid spatial configurations without changing the physical morphology of space. Such augmentations allow space to be transformed into a dynamic environment where visual boundaries are dissolved. This paper argues that in order to adapt our understanding of spatial analysis we need to look space as a dual system of physical and virtual properties incorporating human's behavioural and perceptional changes.Extending the idea of visibility graph analysis by using the 'augmented visibility' representation, which includes a joined set of spaces in both physical and virtual domain, the paper presents interesting finding and correlations with data fromexperiment observations.*
Keywords. *Augmented visibility; ambient displays; human navigation; hybrid space; visibility graph analysis.*

INTRODUCTION

The introduction of digital technologies in architecture has allowed the formation of new relations between space and people redefining the spatial properties of the environment. Embedding ambient displays in design requires a new way of thinking of how these systems interweave with architectural space and people's perception. Ambient displays can simply augment walls creating more pleasant environments without changing the physical morphology of space. Such augmentations allow space to be transformed into a dynamic environment in which boundaries are dissolved.

This study's interest lies in extending and adapting our understanding of architectural design by looking at space as a dual system of physical and virtual properties incorporating human's behavioural and perceptional changes. We initially analyse two studies that include real-space experiments augmented by ambient projections. We then use visibility analysis to talk about morphological properties of the architectural space, how people move or interact within the visible space, and argue about the discovery that visual objects placed within space, which augment the visual depth, significantly change visual relations and understanding of space.

Finally, the 'augmented visibility' paradigm is proposed that extends the existing visibility graph analysis (Turner et. al., 2001). The 'augmented visibility' representation includes a joined set of spaces in both physical and virtual domain and generates interesting finding and correlations with the experimental data of previous observations.

BACKGROUND

It is generally accepted in architecture that the structure and configuration of space affect people's navigation and movement. On the one hand, Gibson's research that was primarily developed for visual perception, suggests that our senses provide us with direct awareness of the external world and its properties. People perceive space with their senses and act accordingly, thus there is a tight relation between perception and movement. On the other hand, visibility analysis has a long history (Thiel, 1961) in trying to analyse the visual properties of spatiotemporal paths.

Architect and virtual reality pioneer Benedikt(1979) proposed that space is perceived as a collection of visible surfaces that are not obstructed by physical boundaries and he defined 'isovists' (figure 1) to describe the area in the environment that is directly visible from a location within space. A single isovist is the area of space directly visible from a given location in space, together with the location of that point. For example, in a convex space or a rectangular space with partitions the isovist area of a given point may not include the full area of that space and some parts of the space will not be directly visible from other points in space.Benedikt looked at isovist measures of visible space throughout configurations and the associated visual fields through space that they produce while others have examined the visual properties of real-space routes that people use or have compared visibility analysis with aggregate behaviours.

In addition, an urban and architectural theory that is deeply integrated with the spatial properties and visibility is Space Syntax (Hillier and Hanson, 1984). Space Syntax research among other things shows that the majority of human movement occurs along the longest lines of sight, and that the more open visible space we have in front of us the more we tend to move towards that direction(Hillier et al, 1993).However, the complexity of the spatial elements that are taken into consideration is limited. Space Syntax sees space as a set of solid walls and empty openings and does not examine transparent elements. In addition to the lack of consideration of transparent materials, there is also a lack in understanding the effects of ambient technologies and 'digital' transparencies.

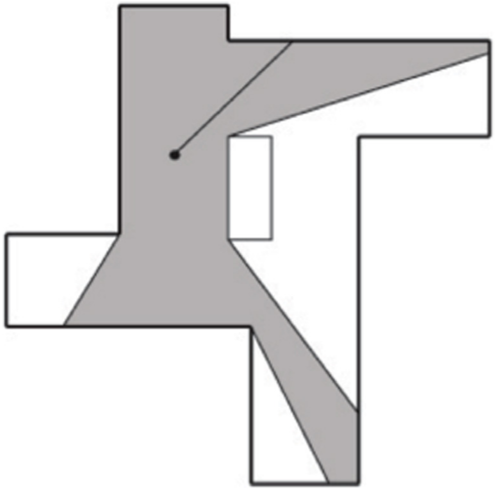

Figure 1
Isovist field from point.

Moreover and compared to the traditional Space Syntax, Turner et al. (2001) developedVisibility Graph Analysis(VGA) that provides a more fine-grained representation of space and can analyze urban and building spaces. The visibility graph is based on a two-dimensional grid of points, which fills all open space to be considered (physical space in this case). Two nodes are connected if, and only if, the corresponding locations in space are mutually visible and form a visibility graph.Having constructed the visibility graph it is possible to take measures of various features of the graph. So far, having been inspired by Hillier and Hanson's (1984) work, the pioneers of this research technique have concentrated the connectivity of a point in space (node) andthe integration of a point in the graph more than other measures. Connectivity or degree of a node A captures the amount of space directly visible from A, and thus approximates isovist area (Conroy, 2001). The integration is a normalized version of the mean depth

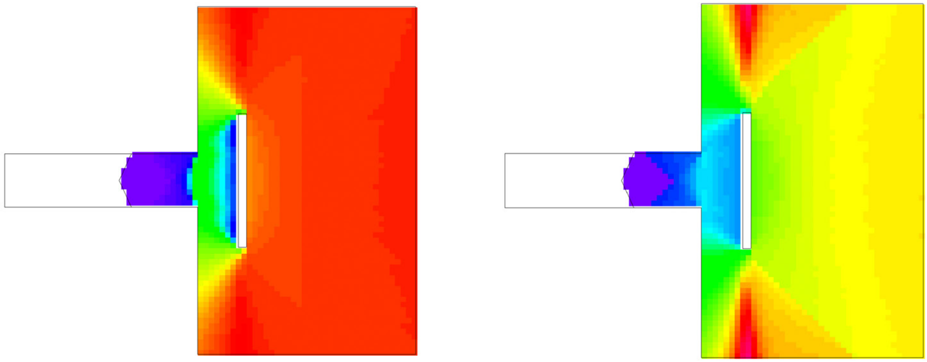

Figure 2
Viability Graph Analysis of the experiment setting (base model). Connectivity and Visual Integration HH: Blue=Low, Red=High.

of a node A to all other nodes in the system. Integrationreflects the centrality of a node with respect to the whole graph (Turner et al, 2001) and along with other VGA graph measures have been suggested for predicting movement rates in space (Desyllas and Duxbury, 2001; Turner and Penn, 1999).

What is clear from all previously presented studies and techniques of spatialanalysis and visibility analysis is the lack of consideration of complex hybrid architectural components such as ambient projections and displays.Placements of such elements in physical space introduce a transparent layer of a dislocated virtual depth. While other studies (Mathew and Taylor 2008) have considered this interface as a digital link of the outside to the inside, the main argument of this paper is that the digital opening is a virtual window that extends both architectural space and the vision of users in a given space. Like a window that connects two physical spaces transferring information between them, an ambient display can be seen as a link between physical and virtual worlds. The emerged movement patterns not only influence the dynamics of the built environment (Varoudis, 2011; Varoudis et al., 2011) but also shape social behaviours and co-presence in space (Wisneski et al, 1998; Mathew et al, 2008; Tomitsch et al, 2008, Röcker et al. 2004).

AIMS AND METHODOLOGY

The first phase of the studystarted with the assumption that the topological and visual relations between physical spaces are two important factors that determine the distribution of people's movement in space.To achieve a credible result for further analyses, a series of experiments (figure 3) were developed in order to observe and analyse how the presence of an ambient display, that augments the visual field, affect people's movement.

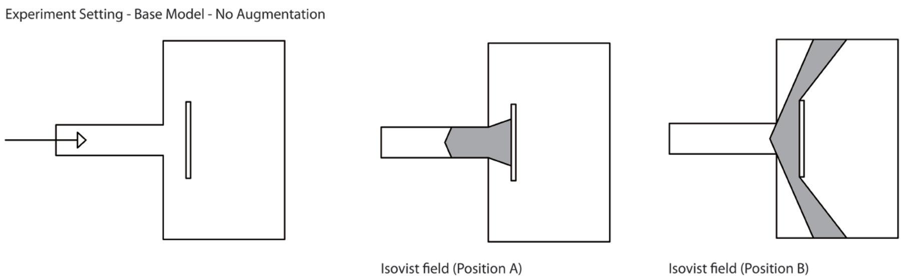

Figure 3
Experiment setting: 'Base Model' with no augmentation, Isovist fields from two positions (A and B).

On the first study (Varoudis, 2011) the hypothesis was that, placing ambient displays so that they virtually link and extend one physical space towards another real or virtual space and thus augmenting the visual depth, will influence the topological and visual relations between spaces and as a result will affect the distribution of people's movement (figure 4). Namely, the location of the ambient projection will change people's perception and direction of movement.

The second study (Varoudis et al., 2011) tested whether an ambient display, when placed in order to extend the visual field through a skewed perspective projection towards another space, will influence the topological and visual relations because a skewed projection changes the subliminal geometric representation of space and lengthens the line of sight towards the side of the vanishing point. In that study a single location for the ambient display was used with varying perspective projections as depicted below (figure 5). Included in the two studies were specific null-tests in order to be sure that any results will only be significant because of the augmentation of the visual depth.

The fundamental form of space (figure 3) in which it was simple to examine the flow and direction of people between discrete routes was a corridor-like setting. Based in this setting, two distinguished and symmetrical routes used to access a target space (at the right end of each diagram). 'Target space' is considered as a space with common interest for the participants of the experiment such as a coffee area.

Intuition and a simplistic interpretation of 'Space Syntax' and VGA analysis suggest that the presence of an ambient display in a corridor should not influence the route decision-making choices of occupants going down this corridor. In the condition when both routes are equidistant from the objective, one might well expect a 50/50 left-right split of occupants.Something that the results of the first phase proved wrong.

During the second phase, analysed in this paper, visibility graph analysis (Turner, 2001) introduced in order to detect potential correlations or limitations and propose a broader methodology for visibility graph analysis, which embraces how the visual characteristics of hybrid spaces are related to people's perception and movement. Existing visibility graph

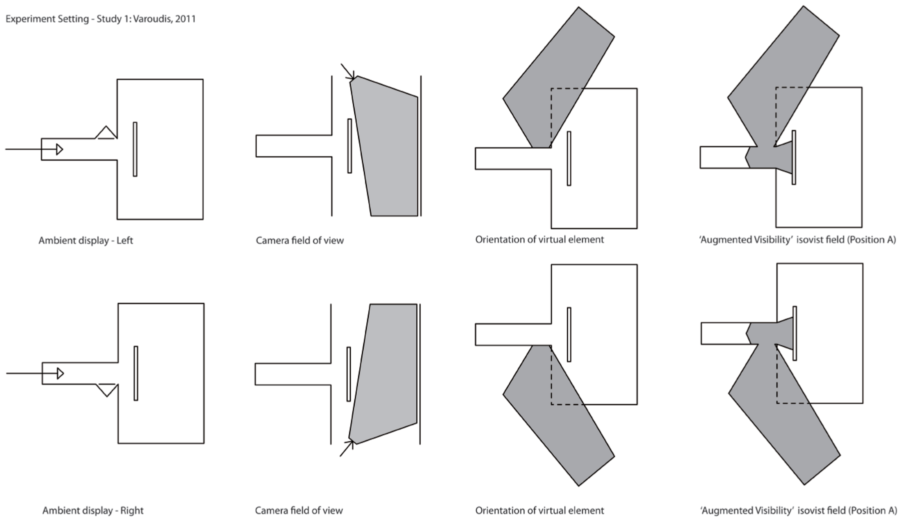

Figure 4
Study 1: Ambient display location, Camera field of view, Orientation of virtual element, 'Augmented visibility' isovist field (Position A).

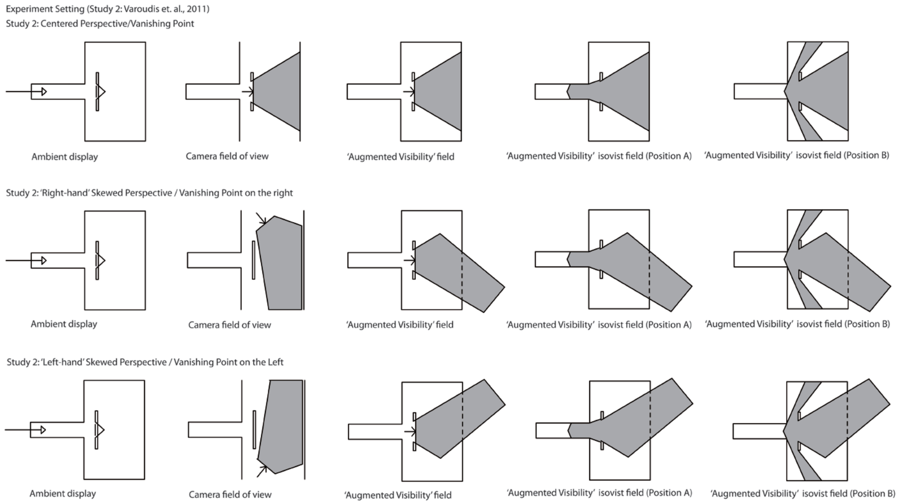

Figure 5
Study 2: Ambient display location, Camera field of view, Orientation of virtual element, 'Augmented visibility' isovist fields (Position A and B).

analysis draws on graph-based representations used in social theories of networks, primarily the Space Syntax theory and the small worlds analysis and uses isovists to derive a visibility graph of the real space graph of mutually visible locations in a spatial layout.

The 'augmented visibility' paradigm extends the existing, limited to physical space, visibility graph analysis by using the observations, the analysis and the results of our studies and detects potential correlations with the analysed measures in the hybrid space. The 'augmented visibility' representation includes a joined set of spaces in both physical and virtual domain. Through this representation we can obtain a number of measures of spatial properties that seem likely to relate to our perception of hybrid space.

Focusing on the VGA as a way for analyzing visual relations, this paper will demonstrate the absence of a correlation between movement and traditional VGA in a hybrid architectural space tested with real experiments above; and will use the notion of an 'augmented visibility'in VGA to demonstrate a visual correlation with the experimental data.

RESULTS

The first phase's data were categorized according to the experimental phase and route choice. These categories were analysed using a chi-squared test and logistic regression analysis. The p-value of the chi-squared tests was less than 0.001 in all cases. Additionally, several null-test experiments were tested and were in all cases not statistically significant. An extensive analysis of the results of the two studies can be found in Varoudis (2011) and Varoudis et. al. (2011). Below are two figures depicting the significant 'shifts' in movement patterns when the ambient projection is present at ether side or the projection is skewed left or right. More than 1500 people took part.

In the 'base model' used for all experiments (no display/augmentation), the findings revealed that combining groups and individuals, 55% of the people turned left in the specific setting and 45% turned right (figure 6). In the phase where the display was on the right side the shift towards the right side was 13.9%. In the phase with the display positioned on the left side the shift towards the left side was 18.4% combining all test subjects together (figure 6) compared to 'base model'.

In the phase where the display was positioned in front and produced a centred projection of the 'target area' the results showed no significant 'shift', as expected, in people's distribution along the two alternative directions in view of the fact that there was no distortion of the visual field or the hybrid spatial topology(figure 7).In the phase where the display produced an off-centred projection with a skewed perspective to the right, the shift towards the right side was 17.9%.Finally, in the phase where the display produced an off-centred projection with a skewed perspective to the left, the shift towards the left side was 10.3% combining all test subjects together (figure 7).

The significant results in multiple experimental conditions combined with the null-tests (Varoudis, 2011; Varoudis et. al., 2011) confirmed our hypothesis that the virtual extension of visual depth changes the perception of space influencing the human movement.In short, when an ambient projection shows typical two-dimensional information there is no change on pedestrian route choice behaviour. When the display shows a projection of another space, the presence of the augmented visual depth influences route choice behaviour. Another factor is the importance of the projected vanishing point. A non-cantered perspective projection of a space influences route choice behaviour towards the side of the projected vanishing point. Moreover, a skewed projection changes the geometric representation of space and lengthens the line of sight towards the side of the vanishing point. Therefore, a subliminal direction is imposed towards this augmented longest line of sight.

With this in mind the research continued with the traditional VGA analysis of the experimental setting in key phases of the experiments. As the traditional VGA analysis only accounts for physical space, even in experimental phases with some digital augmentation the results of the analyses were exactly the same with the analysis of the 'base model'. The Connectivity and Visual Integration HH (HH is integration as specified in Hillier and Hanson, 1984) of the basic space, the 'base model', without ambient projections can be found in figure 2. Connectivity and Visual Integration is used across this paper because it has been suggested that has significant correlations with movement rates in space (Desyllas and Duxbury, 2001; Turner and Penn, 1999).

Moreover, in order to generate an accurate 'augmented visibility' field for further VGA analysis, the virtual part of the setting was correctly oriented and aligned with the location of the ambient display as depicted in figure 4 and 5. The hybrid layouts of space depict the a) physical setting, b) the visual link's view of the target space (camera view), c) the 'augmented visibility' field of view and d) the augmented isovist field for a point just before the 'decision making point'. All settings (left/right symmetrical results omitted) then analyzed with VGA analysis using the 'augmented visibility' space paradigm (figures 8 and 9).

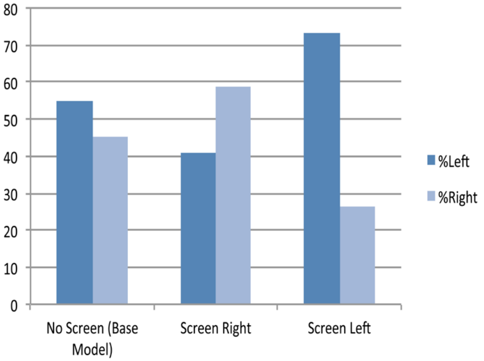

Figure 6
Study 1: Percentage of movement with: No screen, Screen located right, Screen located left.

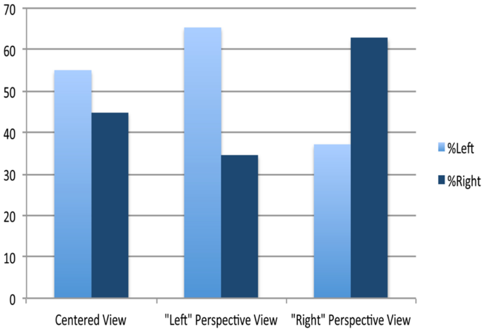

Figure 7
Study 2: Percentage of movement with: Centred view, 'Left' perspective view, 'Right' perspective view.

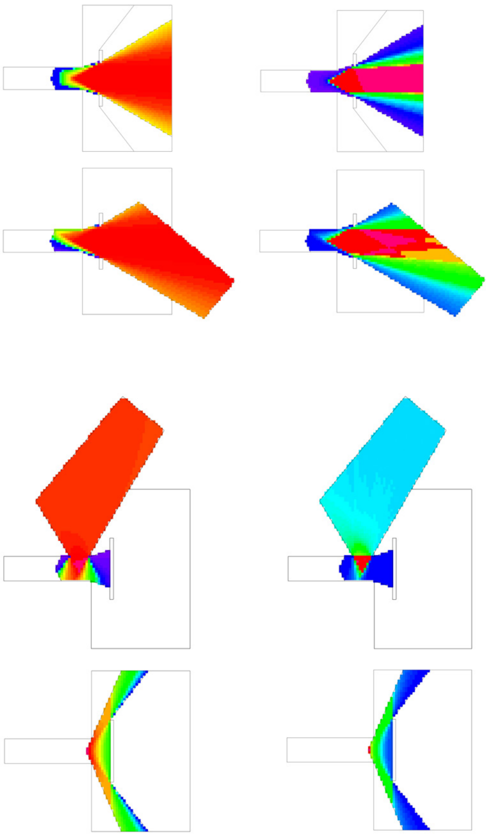

Figure 8
'Augmented Visibility' VGA analysis. Left part of each layout is Connectivity while Right part is Visual Integration HH. Red = High, Blue = Low.

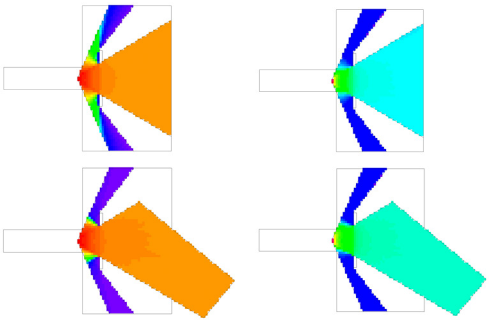

Figure 9
'Augmented Visibility' VGA analysis. Left part of each layout is Connectivity while Right part is Visual Integration HH. Red = High, Blue = Low.

All VGA analyses in this paper where generated with 'depthmapX 0.16' [1] spatial analysis software which is a multi-platform and open source software developed by the author as a continuation of the excellent work by, deeply missed, Alasdair Turner.

In detail, the base model depicted in figure 3 analysed with VGA from both *A* - *B* isovist locations that,as described in figures 4 and 5, represent locations right before the decision point of the corridor. One set of the results is in figure 2 displaying the global analysis of the experimental setting (beyond *A*) and on the lower left corner of figure 8 location *B* is presented analysing the actual visible field at the location. Figure 8 also includes the analyses of the 'augmented visibility' field for the experiment setting with a) the display on the left side, b) the display in front without skewed perspective and c) the display in front with 'right' skewed perspective. All from location *A*. Finally, figure 9 presents the front display setting with centred and 'right' skewed perspective for location *B*.

What is easily observable from the visibility analysis of the base model, that also represents the traditional VGA analysis of any hybrid configurationexamined, is that the use of only solid wall and opening in the analyses doesn't correlate with any of the observed movements in figures 6 and 7. Each experimental phase presented a significant change in distribution even though the traditional VGA analysis is symmetrical.

In the 'augmented visibility' part of the analysis, there are several observable correlations between the charts presenting the percentage of movement distribution and figures of the corresponding 'augmented visibility' VGA analysis base on the experiment phase. Specifically, if we imagine someone walking down the corridor setting in different phases, we can observe that the 'augmented visibility' values of Connectivity and Visual Integration HH are ether higher towards the side of the augmentation at the decision area or, in the case of the ambient display being in front, they tend to be higher following the longest line of side of the skewed perspective. In the case of the display being on the sides, the virtual opening subliminally nudges people to turn towards the side of the display and the better visual connectivity. In the case where the display is in the front, left and right views are similar but with the addition of the skewed perspective the side of the vanishing point the shift of values seem to correlate with the observed behaviours and the vanishing point's location.

Overall, these observations correlate with the hypothesis that people subliminally 'recalculate'the spatial setting as they walk including the visual augmentation produced by the ambient displays. So, the 'augmented visibility' representation proposed in this paper overcomes the limitation of the traditional VGA analysis with the inclusionof a union of both the physical and virtual visible space in the analysis.

CONCLUSION

This paper presented a new approach for the application of visibility graph analysis in hybrid spatial systems. Rather than investigating the properties of a space that is only surrounded by physical boundaries, as has been considered in the literature, it is essential to construct a visibility graph that include virtual hyperlinks between dislocated elements of space. This introduction of new transparencies, through the use of ambient projections that extend physical space into virtual worlds, creates a dual system with new spatial configurations that challenges human's perception of space.

In the 'augmented visibility' graph analysis, emerged spatial configurations include properties and relations of the physical space but also all these relations rising from the presence of the virtual projections.By re-interpreting the set of visibility analysis properties a connections is made between the observed experimental data and the proposed 'augmented visibility' analysis providing a new set of analytic interpretations while preserving a link back to the original visibility analysis interpretation. The new interpretations and the 'augmented visibility' analysis re-enable the use of Space Syntax ideas and VGA analysis in hybrid architectural settings

Further research is needed, however, to produce more insights that might help with the use of 'augmented visibility' analysis in more complex environments.The belief is that the impact in human navigation and perception of space will be more intense in hybrid environments where the augmented virtual depth makes the visibility and angular relations fluid as we increase the complexity. This makes 'augmented visibility' analyses a very important asset with applications innavigation in hybrid spaces, subliminal nudging for accessibility of remote or 'hidden' spaces as well as alternative and more efficient methods to assisting way-finding.

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[1] https://github.com/SpaceGroupUCL/depthmapX