A NEW FRAMEWORK FOR EVALUATING INDOOR VISUAL CONNECTIVITY IN OPEN PLAN WORKSPACES

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Abstract

An occupant's visual experience within a space plays a key role in his or her feelings of exposure and privacy. Particularly in open workspaces, such as offices and classrooms, creating a comfortable plan with degrees of exposure is critical to occupant well-being and social engagement. In this paper, we present an analysis framework for evaluating internal visual connectivity, i.e., how much one can see from a particular location. Unlike single-point-of-view methods, the analysis proposed evaluates connectivity for a grid of points throughout a space to calculate mutual connections. While an occupant's perception is complex and multifaceted, visual connectivity is a key component of the total view experience. The internal visual connectivity methodology draws the line of sight from each location to the rest of the building's interior. The framework is intended to be used during the design process, providing quick feedback that can inform decisions as a project develops. To test the workflow, we apply the tool to a sample office floor plan with various core configurations. The analysis results reveal hotspots of exposure and privacy in the space that are not readily apparent from looking at the plans with a naked eye. Through the proposed internal visual connectivity analysis framework, we aim to better assess an occupant's visual experience inside a building through quantitative means and further our understanding of a view in architecture.

Introduction

Views have a significant impact on occupant health, well-being, and satisfaction within a building. This has been shown to be true in a variety of building types, from offices and schools to hospitals and residential dwellings (Aries, Veitch, & Newsham, 2010; Chang & Chen, 2005; Farley & Veitch, 2001; J. J. Kim & Wineman, 2005; Li & Sullivan, 2016). The relevance of views in architecture is evident not only in studies of environmental psychology, human health, and workplace productivity, but also in the market value of buildings. Empirical real estate data show that views can increase the value of a property anywhere from three to over 50% depending on property type and location (Baranzini & Schaerer, 2011; Damigos & Anyfantis, 2011; Jim & Chen, 2009; Kaysen, 2017).

A view in the realm of architecture is often reduced to what users see outside a window. In fact, a number of studies of views in design use the presence of a window as a proxy for the view itself (Chang & Chen, 2005; Farley & Veitch, 2001; J. J. Kim & Wineman, 2005; Jeonghwan Kim, Cha, Koo, & Tang, 2018; Tregenza & Loe, 1998). However, a view is not solely linked to the outside. The quality of a view is dependent on two factors: visual connection to the surrounding context, often with preference for the natural environment; and visual interest or variation (Reinhart, 2018). While generally associated with the outdoors, neither property is tied necessarily to elements seen through a window. There is as much potential for visual interest *inside* the walls as *outside* them.

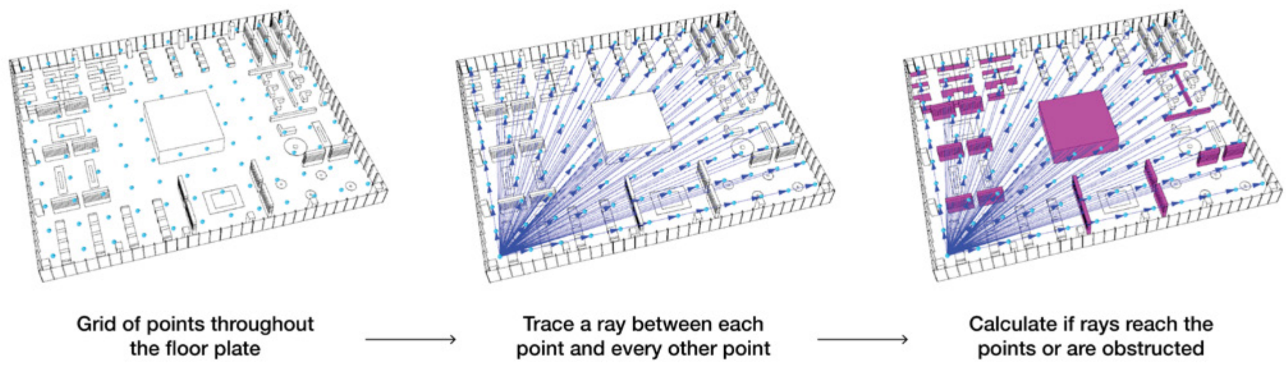

Figure 1: Schematic description of internal visual connectivity analysis workflow.

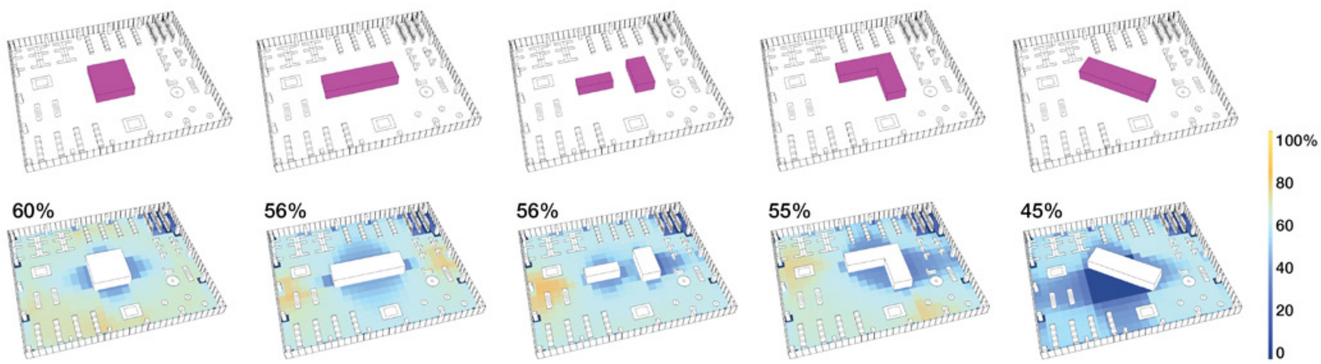

Figure 2: Various Open Plan core configurations and resulting spatial distribution of internal visual connectivity.

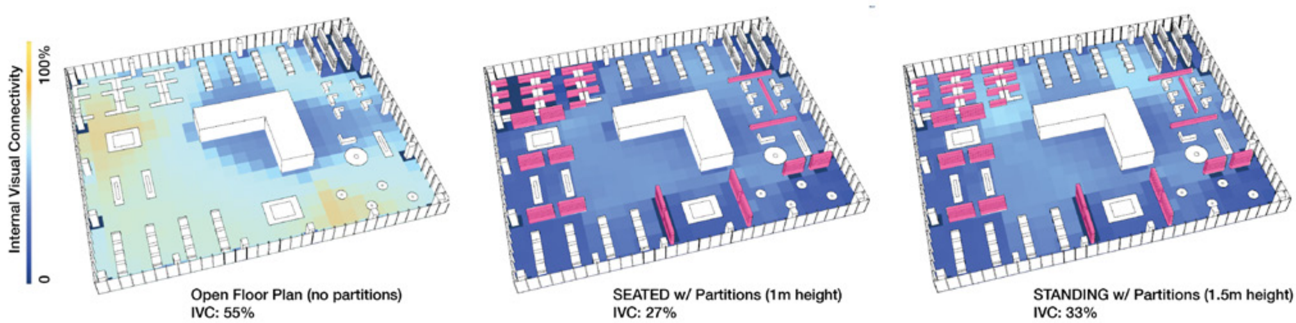

Figure 3: Spatial distribution of internal visual connectivity results in test floor with and without partitions.

Views have long been a topic of study within research in the realms of architecture and urban design. In 1979, Benedikt introduced the concept of an isovist, a horizontally projected polygon capturing the two-dimensional area seen from a particular vantage point (1979). Expanding on the isovist, Turner et al. introduced the visibility graph, a representation of mutually visible locations through a horizontal grid (2001). More recently, the visibility graph has been expanded into three dimensions, categorizing the points in space that are accessible both vertically and horizontally from a particular position (Varoudis & Psarra, 2014). Until now, these concepts have been primarily applied within the urban realm, exploring human interactions in the city and user perception of space.

In this work, we build upon the concept of a three-dimensional visibility graph with the specific goal of showing the visual connections within a space for early design decision-making in architectural practice. We aim to connect concepts of space syntax with applied building performance design methods. Within practice, views are most often evaluated based on what is seen outside of a window, ignoring the internal visual interest. By creating a new metric for internal visual connectivity, we intend to develop a more nuanced understanding of views and the visual experience of occupants in a space.

Internal visual connectivity is not, by any means, a measure of the full quality of an occupant's view. As it measures solely the mutual visual connections, it does not capture aspects of a view that are influenced by sensory and physical factors such as light, material, and composition. However, it does provide insight into one major component of the visual experience: the quantity of elements visible within the view, specifically inside a space. Traditionally, designers have used their intuition and trained perception to subjectively evaluate views. The internal visual connectivity framework is an aid to evaluating views by quantitatively analyzing the field of space, objects, and people that can be seen from a particular location.

Methodology

We present a novel framework for evaluating the internal visual connectivity within a building. The analysis is intended to reveal areas that are more or less visually open to the rest of the space, which can inform the spatial layout to create zones of more exposure (such as social areas, break-rooms, and collaborative working spaces) or privacy (such as individual offices or study spaces). The methodology is built upon the concept of a three-dimensional visibility graph (Varoudis & Psarra, 2014). As part of the framework, we propose a new metric: *internal visual connectivity* (IVC), defined to be the percentage of the interior space that can be seen from a particular position.

The analysis is based on ray tracing between nodes in a three-dimensional grid of points placed throughout an interior zone. The grid of points represents the positions where occupants are located within a space, placed at approximate eye level. Rays are traced from one point in the direction of every other point in the space. The length of the ray, when compared to the total distance between the origin and destination points, reveals whether there is a clear line of sight between the points. The number of connections is tallied for every point to provide a total IVC score.

The framework is developed within the Rhinoceros 3D modeling environment and its visual scripting plug-in Grasshopper (Robert McNeel & Associates, 2016a, 2016b). The analysis employs the Radiance-based ray-tracing program *rtrace* (Ward, 2016), initiated through a Python script in Grasshopper. The Radiance model is set up using components of the DIVA-for-Rhino daylighting analysis plug-in (Solemma, 2018a). The workflow for the analysis, as illustrated in Figure 1, proceeds as follows:

- Establish a grid of points throughout the model at locations of interest. The points may be on the same x-y plane or at varying heights within in the space
- Build the Rhino scene for analysis in Radiance by initiating DIVA-for-Rhino (set a location and assign materials to components of the model) and use the DIVA octree component in Grasshopper to write the scene to a file.
- Run the internal visual connectivity Python script in Grasshopper. The script proceeds as follows: reads the input points; creates a list of rays between each point in the grid; initiates the Radiance rtrace program using the ray list and radiance scene as inputs; then, using the rtrace output of ray length results, calculates whether each ray reached from the origin point to the destination point; and finally, tallies the total number of connections for each point in the grid.

The component outputs both the average IVC for all points in the grid as a single score, and a list of the total IVC for each point. The list of point IVC values can then be piped into Grasshopper visualization components to create colored representation of IVC throughout the space.

To test the framework, we apply it to a 39x48-meter sample open office floor plan (Solemma, 2018b), with five different core configurations. The sample model and various spatial layouts are illustrated in Figure 2. We established a two meter by two meter grid of points throughout the space at a height of one meter above the floor, roughly at a person's eye level while sitting. Most of the furniture in the space is designed for an office environment and therefore lies below eye-level; only a group of library bookshelves (seen in the top right corner of the model) are above the one meter height.

We additionally applied the framework to the same five models with additional partitions placed throughout the room, as shown in Figure 3, to see how more localized obstructions to views would impact the visual connectivity in particular areas. These partitions do go above one meter and would obstruct the line of sight for an occupant in a seated position.

Results

Applying the IVC framework to the open plan model with five different core configurations, we obtain an average IVC score for each model and spatial distribution of visual connectivity throughout the floorplate, as presented in Figure 2.

The floor-wide average IVC score ranges from 45% to 60%. The variation in IVC score illustrates how the massing of the core can impact visual connections throughout an entire floorplate: the greater the perimeter length of the core, the less visual connectivity there is; additionally, when the core is positioned at an angle to the grid (i.e., not aligned with the orthogonal axes), the average IVC score drops as the angles of core massing do not follow the lines of the sensor grid.

The IVC spatial distribution (i.e., IVC at each point in the grid) reveals visual connectivity hotspots within the floorplate. This is valuable because these zones of high or low IVC are not always readily apparent from looking at the plan alone. For example, in the model with the L-shaped core (Figure 3), there are two areas with IVC over 80% near the perimeter of the space. This high score indicates that these two locations have a direct visual connection to over 80% of the rest of the occupiable space floor-wide. In other words, they are spots where occupants can see and be seen. Knowing this to be the case, a designer may choose to locate more social programmatic elements such as lounging or break spaces in these locations.

In addition to testing the core configurations, we applied the framework to the one of the office space configurations with added partitions to divide up the perimeter zone of the floorplate. We applied the framework to derive the IVC at both a seated (1 meter) and standing height (1.5 meter). The floor-wide average IVC with no partitions in the space is 55%. With the addition of partitions, the seated height average IVC is 27% and the standing height average IVC is 33%. The results of this analysis is illustrated in Figure 3. The results illustrate how the partitions can effectively create localized privacy zones within the floorplate. While the partitions obstruct views at eye-level from a seated position, they may not necessarily obstruct views of a standing person. By conducting the analysis at various heights, one can see a strata of visual connectivity throughout a space. By considering the floorplate at different heights, a designer can create various visual experiences for the occupants in different positions.

Discussion

In its current set up, the IVC framework does not consider view direction, rather it considers potential views in all directions, i.e., 360 degrees in the x-y plane and at any height. In most cases, an occupant will face one primary direction (e.g., sitting at a desk), and the view from that position will dominate their perception. Therefore, a future step in this work is to develop a method for weighting certain occupant positions and view directions over others in the IVC analysis.

Finally, when considering the occupant's visual comfort, neither internal nor external views should be assessed alone. An occupant's visual experience is dependent on what she or he sees both inside and outside the space at once. It is critical that the internal connectivity metric is connected with an analysis of external views. The next step of this work is to incorporate a method for evaluating outdoor views in parallel with the IVC framework.

Conclusion

In this paper, we present a novel method for evaluating the visual connectivity throughout the interior of a building. As part of the proposed method, we introduce a new metric: *internal visual connectivity* (IVC), defined to be the percentage of the interior space that can be seen from a particular position. The framework provides a quantitative measure of a spatial quality that has, up to this point, been largely addressed subjectively by designers. We test the proposed framework in various configurations of an example open plan office space. The analysis reveals both changes in layout and height of visual experience do impact the IVC performance in the space. By measuring the IVC at each point and at differing heights, we can uncover hotspots of exposure in the plan as well as strata of visual connectivity. While the presented framework is still in its early stages and requires further development, it serves as a first step towards a comprehensive view analysis tool. As the work continues, we intend to develop the method to be a tool that is easily applicable in architectural practice, serving as an aid to designers as they consider the visual experience within a space.

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