Evaluating Spatially-Distributed Views in Open Plan Work Spaces

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Abstract

We present a framework for evaluating views in open plan work spaces, such as offices and classrooms. Previously proposed analysis methods have evaluated views from a few select positions on a building's perimeter, looking outward to specific objects of interest. Our approach evaluates views in a spatially distributed grid, considering the occupant visual experience to be fluid and dynamic within a space. The framework does not (nor can it ever) measure the quality of a view. Instead, it analyzes compositional elements that one sees within a particular field of vision, such as proportion of sky to ground, diversity of visual elements, and depth-of-field. The method employs standard architectural modeling software, and is meant to be a tool that can be used iteratively and easily throughout a design's development. The framework is applied to a concept-level office project to illustrate the potential for view analysis in early design. The case study depicts how the view analysis framework can reveal visual opportunities throughout a floor plate that may not be intuitively apparent by looking at an architectural model alone.

Introduction

Vision is the means by which we perceive and connect to our environment. It plays a significant role in one's experience moving through a building and one's sense of place within the surrounding context. As it informs our spatial experience, seeing also impacts our comfort and well-being in a building. Given that people spend up to 21 hours a day inside (Environmental Protection Agency, 1989), visual experience and the associated quality of indoor environment become evermore important.

The impacts of views on human well-being is widely documented in a large body of environmental psychology literature. Across building types, from offices and schools to hospitals and residential dwellings, views have a positive impact on occupants: they improve workplace satisfaction, productivity, focus, employee retention, life satisfaction, stress modulation, and patient recovery time in hospitals (Aries, Veitch, & Newsham, 2010; Chang & Chen, 2005; Farley & Veitch, 2001; Gladwell et al., 2012; J. J. Kim & Wineman, 2005; Li & Sullivan, 2016). The desirability of views, whether it be a result of the human health impacts, associated prestige of a space, or pure visual delight, reflects in buyers' and renters' real estate choices. The preference for desirable 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).

Given the benefits and preference for views, there is a longstanding interest in understanding, defining, and evaluating them. Yet, there is no standard method or set of metrics to evaluate views. Views are often grouped together with daylight, a quality for which there are well established assessment methods that measure different human impacts such as intensity (illuminance), temporal dynamics, contrast (glare), spectrum (circadian response), etc (Andersen, 2015). There is a positive correlation between the two phenomena, however, they are distinct experiences. It is possible to have good daylight with a bad view and bad daylight with a good view. Therefore, it is critical that views are evaluated independently from daylight, by its own measures.

Efforts in practice and research have been made to standardize view quality, both to inform building design and to enable comparison between buildings. Design firms have devised their own methods of evaluating views from a building façade. For example, Doraiswamy et al. developed a parametric framework to shape a Kohn Petersen Fox Associates (KPF) tower concept in New York City (2015). Similarly, Studio Gang used both digital and physical modeling methods to analyze views from the balconies of the Aqua Tower in Chicago (2016). Green building certifications and design standards consider views to be a core component of indoor environmental quality and comfort, and have thus included their own methods of evaluation. The Leadership in Energy and Environmental Design (LEED) certification system credits buildings that have a minimum amount of floor area with a direct line of sight to the outdoors (U.S. Green Building Council, 2013). In Europe, the new standard *EN-17037 Daylight in Buildings* (coming into effect in 2019) recommends a minimum horizontal angle of view, depth-of-field and layering of view objects (European Committee for Standardization Technical Committee CEN/TC 169, 2018).

In this work, we deconstruct a view into its elemental components, account for the *types* of visible objects, the *diversity* of visible objects, and *depth-of-field*. We acknowledge that it is impossible to quantify the quality of a view given the complexity of the human spatial

experience. Perception is more complicated than simply the objects in view, and the phenomenology of visual perception evades computational simulation. (Pepperell, 2012). Fully aware of the limitations of quantitative methods to understand visual experience, we do not claim to quantify a view in full. Instead, we analyze select formal components of the view. Human visual perception is based on relational observations, and thus is not just about *what* is seen (whether it be buildings, sky, landmarks, and open space), but also *where* and *how* each of the points of interest relate to one another. As Rudolf Arnheim writes in his seminal book *Art and Visual Perception*, “no object is perceived as unique or isolated. Seeing something involves assigning it a place in the whole: a location in space, a score on the scale of size or brightness or distance” (1974). Considering relational observation as a core principle of visual perception, we propose a method that begins to capture and characterize a comprehensive picture of the occupant’s view. By understanding a view’s parts, we may begin to better conceptualize its whole.

The elements of a desirable view are context dependent and subjective. A good view in a dense urban setting is different from a good view in a rural environment. Despite the variability, most views share the same visual components, albeit in different proportions: sky, landscape, ground, and objects of interest. In combination, these elements provide a connection to the natural world; provide a sense of place in the surrounding context; and create intrigue and delight. Alongside the compositional elements, formal qualities such as view angle and depth-of-field contribute to the conceptualization of a view. Moreover, a view changes as one moves within a room, therefore it is critical that an architectural analysis of views accounts for an occupant in different positions in space.

Defining and Measuring a View

Much of the development of computational view analysis in architecture is built upon early work done within landscape geography and urban planning. Tandy first proposed the idea of a isovist or viewshed, a 2D field of space visible at eye height, for landscape surveying (1967). This concept was adopted by Benedikt to create the isovist field, measuring the volume of space visible in architectural form (1979). The idea has been further expanded in space syntax research to assess mutual connections between two points through a visibility graph, and in three dimensions as a 3D visibility graph (Turner, Doxa, O’Sullivan, & Penn, 2001; Varoudis & Psarra, 2014). At the urban scale, Morello and Ratti proposed a method to count urban visual elements (paths, nodes, districts, edges, landmarks) that are visible through a 3D isovist in order to understand the city’s form as a system (2009). At the building scale, various proposed architectural view analysis methods have adopted the isovist and 3D visibility graph concepts. The Ladybug Grasshopper plug-in uses this method to determine if pre-specified visual features are viewable from designated positions (Sadeghipour Roudsari, 2016). Similarly, Doraiswamy et al. used raytracing to analyse lines of sight

that are unobstructed, varied, and those that see either landmarks or landscape in Manhattan (2015).

In this work, like in previous methods, we employ vector raytracing in a 3D model and calculate the types of objects reached by the projected rays. Contrary to earlier methods, however, we analyse the frame of view as a whole picture rather than a compilation of individual objects. Moreover, we propose a method that assesses views distributed throughout a space, rather than at a few distinct points. A view within a building is fluid and dynamic; one experiences it not just at discrete points but as one moves through a space. Therefore, to understand views as an element of architecture, it is critical that we evaluate the view throughout a space.

Methodology

We propose a method for analysing the formal components of a view at spatially distributed points throughout a full floorplate. The method is built upon the idea that a view depends not just on what one sees outside a window, but how the interior space frames the view. The method does not evaluate the quality of a view. Instead, it analyses the visibility of pre-specified visual elements that the user considers to be part of the view, both individually and as a whole. In this way, the tool aids the designer in the process of shaping and understanding visual accessibility from within a building.

The framework builds upon previously proposed methods that quantified select elements of views, described in the previous section. The precedents use raytracing to evaluate three-dimensional spatial views, however the methods limit the analysis to select objects of visual interest (Doraiswamy et al., 2015; Sadeghipour Roudsari & Pak, 2013). In this work, we assert that a view is more than just the select physical elements that one can see. The quality of a view is a product of the entire composition within one’s frame of view. Furthermore, within a building, the visual experience changes from one position to another, and therefore views must be evaluated not just at the façade, but throughout a floorplate.

Figure 1: Rays cast from position of occupant eye within the 120-degree cone of vision.

The framework is developed in the Rhinoceros 3D modelling environment and its visual scripting plug-in Grasshopper, using Radiance and DIVA-for-Rhino (Robert McNeel & Associates, 2016b, 2016a; Solemma, 2018; Ward, 2016). We employ DIVA-for-Rhino to tag the exterior objects and build the Radiance model, and use the Radiance program *rtrace* to trace the rays. A Python script initiates the Radiance simulation and post-processes the output to return the view results.

The view analysis sends out an array of rays from the position of a person's eye within a 120-degree cone of vision, as depicted in Figure 1. All orientations are weighted equally, assuming that the person may change direction and angle of their head; however, this may be modified depending on the project.

For each ray cast, the simulation returns the type of object, the object identification name, and the distance of the object that the ray first intersects. This output is processed to return the following view metrics for each grid node within the floor plate, as illustrated in Figure 2:

1. Type: Total number of rays that hit each type of outdoor view element: sky, landmarks, buildings, landscape, and ground. The object types are easily editable and may be revised to suite a particular project site and context.
2. Diversity: The total count of unique exterior objects (excluding sky and ground) that are intersected by rays from one point. This is an indicator of diversity of the view, assuming that seeing more objects at once leads to a more interesting perspective.
3. Depth-of-Field: The difference between the nearest exterior object and farthest exterior object (excluding sky) that is intersected by rays from a single origin.

This is an indicator of whether the eye can see both near and far objects from the same position.

The three category of results – *types* of objects, *diversity* of unique objects, and *distance* of objects – touch upon the qualities that may contribute to an intriguing view. The metrics are intended to give the user insight into what one may see from each position within the space, but stop short of placing a qualitative value on the frame of view. The determination of view quality is still in the hands of the user. This is deliberately left open as the definition of a good view is highly dependent on both context and content. For example, a good view in a dense urban environment may be the bustling street under the city skyline, while a good view in the countryside is a panorama of a single mountain range. In the former, one would see many object types, with a large number of unique objects (i.e. diversity) and at different distances (i.e. depth-of-field). In the latter, there would be few unique objects; they would all be of similar type and far from the viewer. Both views may be considered good, but for different and perhaps even contradictory reasons.

Because the objects of interest are defined by the user, internal elements can be assigned in the same way that external elements are assigned. This way, one may evaluate indoor and outdoor views simultaneously. This is particularly important given that the user's visual experience is dependent on not just the visual content in the surrounding environment, but the architectural framing of the view.

Similarly, internal partitions, external shading devices, and façade elements may be added to the 3D model to quantify how much of a visual obstruction is created by counting the number of rays hitting the façade element.

Figure 2: Elements of the human view captured by the view analysis framework: exterior object types (sky, landmark, buildings, landscape, ground); the diversity of objects seen; the depth-of-field, i.e. range between the closest and farthest object seen (excluding the sky). Graphic icon credits: the Noun Project (sky: Madeleine Bennett, landmark: Alvaro Cabrera, buildings: Made x Made, landscape: ani, ground: Peter van Driel).

Figure 4: Set up of the 3D model for the case study office project. Sensor grid represents potential occupant positions throughout the space (2-m x 2-m); and the site model shows the types of exterior objects included in the simulation.

Figure 3: Floor plans and cumulative view analysis result for second floor of test case office building. The colour gradient diagram illustrates a cumulation of both the object count for each object type and the depth-of-field calculation for all of the rays. The analysis results are annotated to explain the variation in the coloration, creating areas of more open or closed views.

Different glazing types would not impact the analysis as it is assumed that, while glazings may have different light transmittance and thermal properties, so long as the glazing is translucent the user's line of sight is not impacted. The light penetrating a window does impact the visibility of the view, however it would not impede the compositional elements in view. As long as the glazing is translucent, we assume that the occupants can see the view.

Currently, the method considers objects visible in all directions from the node. In future work, we intend to allow the user to specify a primary view orientation, to prioritize views in that direction.

Test Case: Concept-Level Open Office

The view analysis framework is applied to a proposed architectural design for a five-storey office building. The project, developed to the concept-level, is for a company headquarters building in a small town near Munich, Germany. The project is situated in a context with a variety of objects of visual interest in all orientations. It is part of a master plan development directly north of the historic town centre. The office building is on a proposed main pedestrian artery, which is envisioned to be a vibrant and busy streetscape. Figure 3 shows the building and surrounding environment, as well as the simulation set up for a sample floor, in which the simulation grid is applied with a 2-m by 2-m spacing. There are three atriums that penetrate through all five floors of the building. The floor is primarily open office spaces and meeting rooms. Clear glazed partitions run parallel to the façade around the office areas, allowing a line of sight across the full floor. Opaque partitions are used to create areas of privacy, meeting rooms, and utility spaces.

The main visual points of interest outside the building are the central pedestrian artery, historic town centre, green spaces, and more generally, the neighbouring buildings (which are less notable but contribute to the sense of place in the site). We tag these four visual object types in the model. For all rays cast from each grid point, the simulation records what type of object is intersected (either one of the four types of objects of interest or sky or ground) and its distance from the origin point. Using the results of the ray tracing, for each grid point we calculate how many rays reach each object type, how many unique objects are seen from the point, and the

depth-of-field (i.e. the distance of the closest and farthest object reached). The total count of objects and the depth-of-field results are cumulative metrics that consider all object types, and are indicators of the relationship of the exterior objects of visual interest as a whole, rather than as individual parts.

Results

We present the view analysis results for one floor within the test case office building, the second floor. The second floor is an open plan office space. The exterior envelope and the walls facing the atriums are glazed. Inside the

Figure 5: Results for sample floor in the example office project.

space, transparent glazed partitions organize the internal plan, with opaque partitions used where there is a need for privacy, acoustic isolation, or utility spaces. The site plan of the building, the second-floor plan and the 2-m by 2-m analysis grid are illustrated in Figure 3.

Figure 4 depicts the cumulative view analysis result for the sample floor. Figure 5 depicts each of the view components analysed individually to illustrate how each element contributes to the overall view. In each case, the colour gradient from red to yellow to blue indicates more level of openness, i.e. areas that are blue have either more exposure or see more objects. For each point in the sensor grid, 291 rays are traced. The number of rays that reach exterior objects varies significantly, from zero to 63%. On average 13% of the rays reach exterior objects from a single point. The rays that do not reach exterior objects are intersected within the building. Rays that are internal are not necessarily undesirable, as visual connectivity inside the building may significantly contribute to one's visual experience in the space. In addition to showing the results for the individual object types, Figure 5 presents the results of the diversity and depth-of-field calculations. The diversity metric indicates how many unique exterior objects are intersected by the 291 rays cast from a single point. The depth-of-field metric indicates the distance range of exterior objects that are seen from a single point (excluding the sky), i.e. the difference between the distance of the farthest and nearest exterior objects intersected. The depth-of-field results range from zero to 425 meters, with an average of 16 meters. While the depth-of-field measure is limited by the extent of the 3D model, it does provide a sense of whether one can see objects that are both close and far from a particular location.

Combining the individual visual analysis results (shown all together in Figure 5), we create a holistic metric of the total view potential at each point in the grid. The resulting cumulative metric is depicted for each analysis point in Figure 4, with annotations explaining why the results vary in particular areas of the floor plan. To derive the cumulative results, we normalized the constituent metrics on a scale of zero to 100, and directly added them together at each analysis point. Though the weighting is up to the user, one could weigh the different sub-metrics to emphasize a particular view property over the others. For example, the historic district may be more valuable to see than the neighbouring buildings, and thus may be counted twice as much. The weighting of the metrics is dependent on the user of the tool.

Discussion

In this work, we present a nuanced, multi-dimensional view evaluation methodology, developed to inform the design of new buildings. We consider the occupant visual experience to be dynamic, one that changes as a person moves through the space. It requires an approach that can be equally fluid and adaptable. We acknowledge the limitations in the methodology. Most significantly, the calculated view metric must be validated by a user study. We plan to conduct a human subject survey to better

understand the qualities of views that people do and do not prefer. Evaluating the preferred views, we may better understand the compositional components of a view that users like. Determining human preferences through empirical testing will inform what aspects of a view are prioritized within the framework. It will also help to hone the methodological and technical approach to the work.

Given the importance of considering the full visual experience, both *inside* and *outside* the space, it is critical to account for internal views in the analysis framework. Internal visual connections are an important aspect of how one perceives a space, arguably even more than outdoor views because the objects in sight are in close proximity to the occupant. Inside the building, visual engagement can encourage socializing and human interaction. Particularly in open work spaces, visual exposure impacts occupant satisfaction, collaboration, productivity, and perseverance (Bernstein & Turban, 2018; Haapakangas, Hongisto, Varjo, & Lahtinen, 2018; J. Kim & de Dear, 2013; Kong, Utzinger, Freihoefer, & Steege, 2018; Roberts et al., 2019; Zerella, von Treuer, & Albrecht, 2017). Moreover, internal visual elements may take the place of external views when they are not available. For example, views to vegetation inside the building may substitute a view to the natural environment where it does not exist. Studies show that these internal views to a representation of nature, either indoor vegetation or digital projections of natural scenes, are valued (Gray, 2017; Zhao, Azaria, & Paradiso, 2017).

By evaluating both indoor and outdoor views at once, we can better address the overall visual comfort and well-being of occupants. To this end, we are exploring a method for mapping the internal visual connectivity at each sensor point to overlay with the external view results (Turan & Reinhart, 2018). The methodology presented in this paper can be applied to indoor objects, just as it is to external objects. Thus, it is suited for a comprehensive analysis of internal and external visual experience. In the next steps of this work, we will explore this opportunity further.

Conclusion

We present a framework for evaluating spatially-distributed views in open plan work spaces. We propose not to calculate the quality of a view, but rather to quantify its compositional elements that contribute to the overall visual experience. Previous analysis methods have evaluated views from a few select positions on a building's perimeter, looking outward to specific objects of interest. We evaluate views that occupants see as they move through a floor plate, accounting for dynamic visuals as they change position. The framework is conceived to be iteratively employed by architects, with rapid results to inform a project's design as it develops. We test the framework on an open plan office building in the concept phase of design development. The results illustrate the multitude of possible outcomes of the view analysis, depending on how the view elements are weighted. The example shows the way in which the framework may inform one's interpretation of views,

while still leaving the qualitative valuation in the hands of the tool user. There are limitations to the approach, however, this work is the first step of a more robust view evaluation method for use within architectural practice. To this end, the view analysis framework is a comprehensive computational methodology for evaluating view performance in architectural, spatially-distributed terms, using a flexible quantitative metrics that describe the occupants' visual experience in architectural space.

Acknowledgement

This work was generously supported by Behnisch Architekten.

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