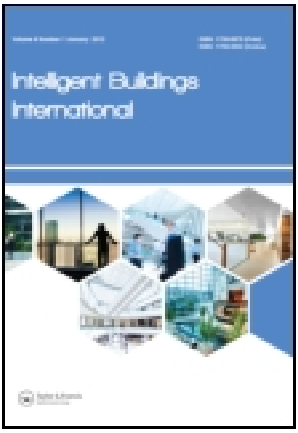

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The influence of visual perception on responses towards real-world environments and application towards design

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Experience of the built-environment is said to be dependent on visual perception and the physical properties of space. Scene and environmental preference research suggests that particular visual features greatly influence one's response to their environment. Typically, environments which are informative and allow an individual to gain further knowledge about their surroundings are preferred. Although such findings could be applied to the design process, it is first necessary to develop a way in which to accurately and objectively describe visual properties within an environment. Recently, it has been proposed that isovist analysis could be employed to describe built-environments. In two experiments, we examine whether or not isovist analysis can capture experience of real-world environments. In experiment 1, we demonstrate that isovist analysis can be employed to describe experience within a controlled, real-world, laboratory environment. In experiment 2, we employed post-occupancy examination of a student centre to examine the robustness of isovist analysis and whether it would capture experience of a complex, real-world environment. The results of experiment 2 suggest that isovist analysis could capture certain experiences, such as spaciousness, but failed to capture other responses. Regression analysis suggests that a large number of variables predicted experience, including previous experience with the building and the presence of other individuals. This suggests that experience of real-world, complex environments cannot be captured by the visual properties alone, instead various factors influence experience. Implications towards the design process are discussed.

Keywords: design process; environmental preference; isovist analysis; visual perception

The vast majority of our day-to-day life is spent within built-environments; thus, it is not surprising that we develop a very intimate relationship with the spaces we occupy. The physical properties and configuration of built-environments have been demonstrated as influencing not only mental health (Evans 2003) but also pleasantness and enjoyment of our daily experiences (Goss 1993). Architects and design professionals have an innate understanding that the design decisions they make will have a profound impact on how an individual will experience and feel within the space. Indeed, such a notion is not novel; the Roman architect, Vitruvius addressed this relationship between the architect and their user base by stating that built-environments should provide 'commodity, firmness and delight'. During the design process architects will often discuss how the building will 'feel' and be experienced by its user base. Yet, rarely do architects get the opportunity to examine whether or not design intent is achieved. What is more, researchers who may be able to enlighten and explain what factors influence how a built-environment will be experienced are not in direct communication with architectural professionals, the

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group which would benefit directly from their research. As behavioural researchers and cognitive neuroscientists, we believe that we have, not only a knowledge base but a very specific toolset, which if applied correctly, could very well be useful to design professionals.

Architectural spaces are said to belong to the visual domain, therefore the research discussed here will focus on visual properties of environments and how they may drive experience. Thus, it may be useful to consider how our visual system functions. When visual input is received by the brain from the retina, the scene or object is parsed for low-level visual features. During this step, known as low-level visual perception, the visual primitives of a stimulus such as edges and colour are extracted (Henderson and Hollingworth 1999). From here, visual perception continues to build a more complex and complete representation of the stimulus, during intermediate-level visual perception. Here, an understanding of the basic shape and relationships between various elements within the stimulus is developed. Finally, during high-level visual perception, the stimulus is identified and semantic representations are activated (Henderson and Hollingworth 1999). At this stage, we move from perception to cognition as we realize what it is we are looking at and unlock the complex web of relationships between this object or scene and various cognitive processes. It should be noted that visual processing is not solely bottom-up. In fact, activation from higher level processes influences visual perception during more subordinate stages. Indeed, some research suggests that the 'gist' of an image or scene is processed first (Rasche and Koch 2002). It also appears that specific brain regions respond preferentially to built, enclosed spaces (Aguirre, Zarahn, and D'Esposito 1998; Epstein and Kanwisher 1998). This region, known as the parahippocampal gyrus, is a part of the ventral visual stream; a series of neural regions which mediate stimulus identity and high-level associative concepts (Milner and Goodale 2006). Interestingly, the parahippocampal gyrus appears to respond specifically to the global properties of space, such as how open or expansive a view is (Park et al. 2011). This notion that it responds preferentially to spaces is supported by findings, which demonstrate that the presence of specific objects and elements within a scene do not mediate activation of the parahippocampal gyrus; it appears to respond to the spatial properties of a scene (Epstein et al. 1999). It also appears to be viewpoint specific, meaning that it treats differing viewpoints of the same space or environment as novel (Park and Chun 2009). Perhaps, of most interest to architectural professionals is the finding that environment preference appears to be, at least to some extent, mediated by the parahippocampal gyrus, so that more preferred environments lead to greater parahippocampal activation than less preferred environments (Biederman and Vessel 2006; Yue, Vessel, and Biederman 2007). Such findings suggest that not only is the parahippocampal gyrus important for perception of the built-environment, but that it may also play an important role in how the environment is experienced. Since the parahippocampal gyrus appears to respond preferentially to the spatial arrangement and properties of an environment, the next step might be to determine what factors predict preference and experience of the built-environment. By examining findings from both scene preference research and also environmental psychology, it may be possible to determine the cognitive factors and psychological influence of response towards the built-environment; and perhaps further explain the activation seen in the parahippocampal gyrus when viewing a built-environment.

There is a long history within behavioural research and within environmental psychology examining how visual properties of a scene or environment may shape experience of environment. One of the most widely cited and disseminated concepts related to environmental preference is Appleton's (1975) duality of prospect and refuge. He argues that aesthetic preferences are derived from perception of the basic physical features of an environment. In particular, environments whose physical features signal benefits to survival are preferred. Appleton argues that the ability to hide from potential predators while at the same time being able to see the environment around oneself is beneficial. These concepts of being able to see around and being provided with shelter, are referred to as ‘prospect’ and ‘refuge’, respectively. The features of an environment which may provide an organism with prospect and/or refuge are numerous, and will shape preference. Studies demonstrate that the concept of openness, which is closely related to prospect, is positively correlated with scene preference (Herzog and Leverich 2003). Although originally discussed from an evolutionary perspective and with regard to natural environments, prospect and refuge have recently been shown to influence animal behaviour (Singh and Ellard 2012) and it is possible that such factors could potentially influence preference of built-environments. Despite the major differences between the environment, which mankind once inhabited and the environment that mankind finds itself in today, issues of safety and ability to easily see one’s surrounding are still relevant. Indeed, feelings of safety and preference in urban environments seem to be driven by the ability to see around oneself along with easy access to refuge (Loewen, Steel, and Suedfeld 1993).

One of the main concepts posited by the prospect and refuge theory is the notion that environments which provide an organism with visual information about their environment will lead to preference. This emphasis on the informative value of an environment was expanded upon by Kaplan and Kaplan (1989) through their informative environment theory. Here, they suggest that several high-level visual properties of an environment drive preference; most interestingly is the suggestion that environments which suggest ‘mystery’ are preferred. An environment is said to posses ‘mystery’ if it suggests to the viewer that further exploration of the environment will lead to the acquisition of additional information about the environment (Kaplan, Kaplan, and Wendt 1972; Kaplan 1987). Thus, an environment which features a path extending into a wooded area might be perceived as possessing ‘mystery’ and would therefore be preferred. Such a concept relates to the notion of ‘prospect’ as they both discuss acquisition of visual information; with the difference that ‘mystery’ deals with the potential of gaining information. ‘Mystery’ might not relate to ‘refuge’ directly, and indeed the relation between them might appear contradictory. Saying this, ‘refuge’ does not necessarily suggest a location from which an organism cannot see their environment; indeed a slightly hidden location might be seen as both being a refuge and being ‘mysterious’. If an organism was to move from a secluded location which provided ‘refuge’, it could be argued that this action would lead to acquisition of information about the organisms surroundings, and thus could potentially be seen as ‘mysterious’. They also suggest that other visual features of an environment are said to play an important role, in particular, it appears that open spaces which are well structured are preferred (Kaplan, Kaplan, and Brown 1989; Herzog 1992).

Berlyne (1970) argues that much of human exploratory behaviour and preferences for certain objects and scenes is dependent on maintaining appropriate levels of arousal, which in turn is influenced by stimulus complexity. As Hebb (1955) argues, medium levels of arousal lead to optimal performance in most situations; thus, to maintain an optimal state of performance, we will seek environments that maintain such intermediate arousal levels. Berlyne and colleagues argued that the process of regulating arousal is linked with visual complexity. Thus, environments of intermediate complexity lead to intermediate levels of arousal (Berlyne et al. 1963; Berlyne, Ogilvie, and Parham, 1968; Berlyne 1970). Visual complexity does not simply influence preference but it also promotes exploratory behaviour (Berlyne 1958), leading to greater information acquisition (Berlyne 1954). More recent studies suggest that the concept of entropy, a measure of diversity, predicts preference in a positive linear manner and not in the u-shaped manner suggested by Berlyne (Stamps 2003, 2006). Once again it appears as if the visual properties of an environment and the ability of such properties to provide information about the environment influence how the environment is experienced. Typically, thought to be driven by the autonomic nervous system and the endocrine system; and increased activation leads to increased sensory vigilance (Coull 1998). Interestingly, high-level cognitive areas also appear to respond to the arousing nature of a stimulus (Coull 1998; Critchley et al. 2000). Activation of the parahippocampal gyrus appears to be moderated by the arousal resulting from viewing pleasant images; although the authors posit that this is due to the role of the parahippocampal gyrus to formation of episodic memories (Nielen et al. 2009). Areas responsible for high-level visual perception, such as the lateral occipital cortex, which is responsible for object perception, appear to be influenced by the arousing quality of stimuli (Mourão-Miranda et al. 2003; Sabatinelli et al. 2011). Such activation due to arousal in visual areas is posited to influence the fluency and efficiency of visual processing (Lane, Chua, and Dolan 1999). Thus, if an environment is complex, arousal levels will potentially increase allowing for more efficient and complete acquisition of the information present within the environment.

In order to apply theory in environmental psychology to the design process, concepts such as openness, mystery, complexity, prospect and refuge need to be clearly defined and objectively measured. Without a relatively simple, yet effective way by which to capture and describe the visual properties of an environment it becomes not only difficult but also nearly impossible to apply empirical research to the design processes. Isovist analysis may provide us with a systematic way to examine and predict ones experience of built-environments.

Originally described by Benedikt (1979), an isovist is the two-dimensional polygon generated by the visible space from a viewpoint (Figure 1). Each isovist is unique to its own particular viewpoint, and as an individual moves through their environment, the isovist will change to reflect their new viewpoint within the environment. From this simple isovist polygon, it is possible to extract some basic, descriptive values, such as isovist area, isovist perimeter and the number of vertices (point where two lines of an isovist polygon meet). A computational method for generated isovist properties was also developed (Davis and Benedikt 1979). Isovist analysis might prove to be useful tool as it is able to accurately describe both small- and large-scale built-environments and it takes into account the presence of a viewer within the environment. Most importantly, it was suggested that isovists capture the visual properties of a space (Benedikt and Burnham 1981).

In order for isovist analysis to serve as a tool understanding experience of built-environments, it is necessary to first examine what perceptual features and properties are captured by isovist analysis

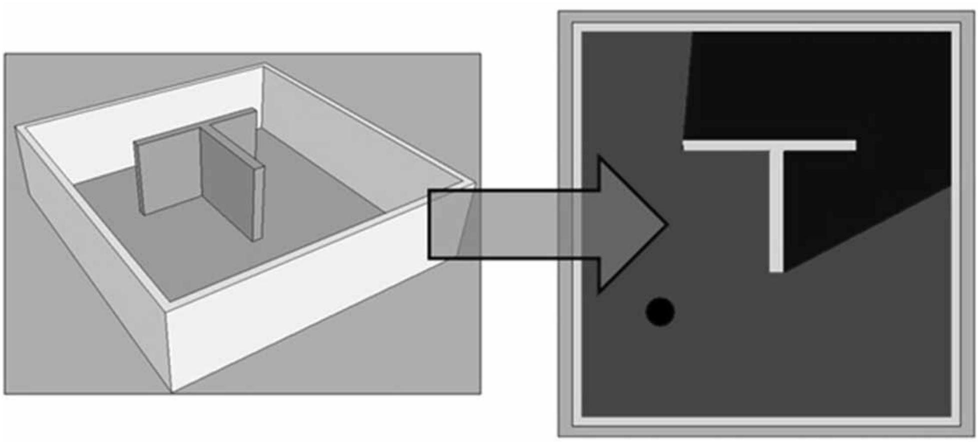

Figure 1. Image on the left shows a sample environment. The image on the right shows this same environment from a top-down view. The black dot represents an individual's location within the environment. The lighter area is the what the individual can see from this particular location; this is the isovist polygon. From this polygon it is possible to calculate the area of the isovist polygon and vertices, locations where two edges of the polygon meet.

in the first place. Using small-scale models, Benedikt found that isovist area and isovist variance significantly affected experience of the perceptual property of spaciousness, so that viewpoints with larger isovist area and greater isovist variance were perceived as being more spacious (Benedikt and Burnham 1981). Such a finding serves as proof of concept that isovist properties are perceptually relevant and could potentially influence experience of not only spaciousness, but perhaps other responses. More recently, studies employing virtual-reality suggest that several properties, including spaciousness are influenced by isovist properties (Stamps 2009).

A prominent examination on isovist analysis and their possible influence on the experience of environment was conducted by Wiener et al. (2007). Employing virtual-reality, Wiener et al. (2007) immersed participants in 16 art-gallery environments. For each environment, participants were instructed to navigate to the location within the environment which would provide them with the 'best hiding-spot' and the 'best-overview spot'; essentially the locations which would generate the smallest and largest isovist areas. Once each of these locations was reached, participants completed an experience rating task, asking them to rate on a 7-point Likert scale, the location on the properties of spaciousness, pleasantness, beauty, interestingness, complexity and clarity. The Likert scale is a commonly used method by which attitudes towards a stimulus are examined by employing increasing numerical values, where both high and low values represent extreme response towards a stimulus (Likert 1932). For each location, they generated a number of isovist properties which were correlated with responses on the experience rating task. Performance on the tasks was quite good; isovist areas from the selected locations closely matched the absolute largest and smallest areas within the environment, suggesting that isovist area was perceptually relevant. Several significant correlations were noted between isovist properties and ratings for several of the categories. Thus, the authors suggest that isovist analysis captures certain properties of an environment associated with affective response and experience of built-environments.

Such results are encouraging and isovist analysis has been suggested as a possible tool in predicting how a building might be experienced or perceived (Derix, Gamlesæter, and Miranda 2008), and in predicting navigation in work environments (van Bilsen and Poelman 2009). Although isovists might predict experience of built-environments, the fact that the studies to date have been conducted employing virtual-reality, brings into question the applicability of such findings. Indeed, differences between virtual and real-world distance estimation have been noted (Lampton et al. 1995), as well as differences based on the type of virtual-reality apparatus used (Plumert et al. 2005). Although current virtual-reality technology is sophisticated, it only approximates the real-world and the applicability of virtual-reality research examining isovists to the real-world needs to be explored. Thus, the first step would be to take isovist analysis and see whether it is able to predict experience within a controlled real-world environment. If isovist analysis is to be applied by design professionals and if it does capture properties relevant for experience of space, we should see some direct relationships between isovist properties and experience of space. Experiment 1 attempts to replicate the findings of Wiener et al. while employing a real-world environment. This would be the first step in suggesting whether or not isovist analysis could be applied as a tool in the design process.

Experiment #1

Participants

A total of 14 individuals participated in this study (8 female, 6 male) between the ages of 18 and 24. Participants were contacted through *PsychPool,* a participant directory. Upon participation in the experiment, participants received $12.00. All participants were students at the University of Waterloo, in Waterloo, Canada.

Materials and isovist analysis

The study was conducted within a room measuring 9 × 12 metres. Positioning eight room dividers within the room 12 unique environments were created. The room dividers measured 1.2 metres in width and 2 metres in height. The 12 environments were created to match the environments employed by Wiener et al. (2007), although it was not possible to recreate the exact environments due to constraints in the size of the room and the width of the room dividers.

A semantic differential task was employed in an effort to capture experience towards the environments. The task required the participants to rate the environments on six properties including pleasantness, interestingness, beauty, complexity, clarity and spaciousness. Responses were made on a 7-point Likert scale, where one represented the low/negative end of the scale and seven the high/positive end. The semantic differential task was conducted by presenting the rating category in the form of the question, such as: 'How pleasant is the current stimulus?' Following this, the scale was identified and the participant positioned their response verbally on the 7-point scale.

Since we are attempting to examine whether or not isovist properties can capture properties, which shape how a built-environment is experienced, it was necessary for us to generate a number of isovist properties for each of our environments. We employed the program *Depthmap* to conduct isovist analysis of our environments.[1]

Procedure

Participants were led into the environment and asked to perform two tasks adapted from Wiener et al. (2007). During task one, participants were asked to find the location within the environment which would provide them with the largest overview of the space. This task would require them to find the location within the environment which possessed the largest isovist area. They were also instructed to find another location within the environment, which would provide them with the smallest overview or the best 'hiding-spot'. This location would correspond to the location within the environment which had the smallest isovist area. Participants would complete both of these tasks for each of the 12 environments. Upon reaching and selecting each of the two locations (largest and smallest overview), participants completed the semantic differential task as described above. Upon performing the semantic differential task within each location, participants were lead out of the room and the room dividers were rearranged to create the next environment. The ordering of environments was randomized between participants.

Results

In order to determine how successful participants were in locating both the largest and smallest overviews/isovist areas, we employed the equation presented in Wiener et al. (2007, 1073):

$$P_{\max(r)} = \frac{I_{\text{sub}(r)} - I_{\min(r)}}{I_{\max(r)} - I_{\min(r)}}$$

$$P_{\min(r)} = 1 - \frac{I_{\text{sub}(r)} - I_{\min(r)}}{I_{\max(r)} - I_{\min(r)}}$$

$P_{\max}$ is performance in finding the largest overview location or the maximum isovist within the environment. $P_{\min}$ is performance in finding the smallest overview location or minimum isovist within the environment. r is the identity of the environment; this value would range from 1 to 12, since a total of 12 unique environments were used. I_{sub} is the isovist area generated from the chosen location for each task within the specific environment (r). I_{min} would be the absolute minimum isovist area for the given environment, while I_{max} is the absolute maximum isovist area within the environment. Thus, performance for each of the tasks is scored on a range of 0–1. A score of 1 would represent perfect performance, so the chosen location ($I_{sub(r)}$) would match perfectly either the absolute maximum isovist ($I_{max(r)}$) or the absolute minimum isovist ($I_{min(r)}$) within the environment, depending on task.

Performance approached 1 for both the largest overview task ($P_{max} = 0.87$, SD = 0.157) and for the smallest overview task ($P_{min} = 0.84$, SD = 0.177). Participants were equally good at locating both the largest overview and the smallest overview, ($t_{13} = 1.348$, $p = 0.18$).

Partial correlation analysis was conducted controlling for individual differences in order to see whether a relationship existed between isovist properties and ratings on the semantic differential task. Several significant correlations were found between isovist area and a number of rating categories. Isovist area was significantly positively correlated with pleasantness ($r = .25$, $p < .01$), beauty ($r = .26$, $p < .01$), clarity ($r = .34$, $p < .01$) and spaciousness ($r = .51$, $p < .01$). The number of vertices was significantly positively correlated with interestingness ($r = .16$, $p < .01$) and complexity ($r = .3$, $p < .01$).

Experiment #1 discussion

It appears that isovist analysis could be relevant for experience of real-world environments. As isovist area increases so do ratings of pleasantness, beauty, clarity and spaciousness. Although it is correlated with fewer of the rating categories, the number of vertices is significantly positively correlated with ratings of complexity; so that as the number of vertices within the isovist increase so do ratings of complexity.

The relation between isovist area and spaciousness is to be expected; isovist area can be seen as a direct measure of visible space from a viewpoint. The property of spaciousness is practically definitional within the term isovist area. A similar point can be made with the concept of clarity. As the total amount of visible space increases the environment should be seen as being less obstructed and more clear. In this way, isovist area appears to accurately capture and describe the physical experience of an environment. Indeed, such a connection between isovist area and the experience of spaciousness corresponds, not only with recent studies conducted within virtual environments (Wiener et al. 2007; Stamps 2009), but also with early work examining isovist analysis within small-scale model environments (Benedikt and Burnham 1981).

Perhaps the more interesting relationships are those between isovist area and more subjective experiences of space, such as pleasantness and beauty. It is possible that such relationships could be explained by some of the theories mentioned earlier. Appleton's (1975) prospect and refugee theory place importance on the environment's ability to provide the individuals with the ability to see the environment around them, so that those environments which provide a larger and more expansive overview are preferred. In this way, as isovist area increases, an individual can see a greater amount of their environment and thus might find such a location pleasant and perhaps beautiful. It also appears that Kaplan and Kaplan's (1989) informative environment theory might apply when examining the relationships between isovist area and pleasantness and beauty. As the overview within an environment increases, as captured by isovist area, the viewer is provided with more information regarding the environment. In this way, positive aesthetic judgements should also increase, and this is indeed what is suggested by the correlation analysis.

Our data suggests that the number of vertices, the total number of locations within the isovist polygon where two edges meet, capture properties within an environment which relate to subjective experience of complexity. The relationship between estimated complexity and the number of vertices held when we controlled for isovist area, so vertices could be conceived as possible metric for complexity. According to previous research conducted on stimulus complexity, we would expect either a linear (Herzog and Shier 2000; Stamps 2006) or u-shaped (Berlyne 1970) relationship between complexity and aesthetic experience of preference. Interestingly, neither of these two relationships was found here, as the number of vertices did not correlate with ratings of pleasantness nor beauty in any meaningful manner.

The results of this small-scale real-world isovist analysis suggest that, to a certain extent, isovist analysis might capture properties relevant for experience of real-world environments. It serves as a first step in possibly applying isovist analysis within the design process. The findings here replicate many of the findings of the virtual-reality study conducted by Wiener et al. (2007). Participants were able to successfully locate locations corresponding to the largest and smallest overviews within the environments. These locations correspond to positions within the environment which possess the largest and smallest isovist areas within the environment. Such findings provide support that isovist properties (isovist area in particular) are perceptually relevant and perceptible by individuals within real-world environments. The relationships between isovist area and the semantic differential task, in particular, match the findings of Wiener et al. (2007) quite well. Specifically, positive correlations found here between isovist area and the categories of pleasantness, beauty and spaciousness all match the previous virtual-reality study. On the other hand, the number of vertices does not seem capture nearly as much experience within the small-scale controlled real-world environments used here, as compared with results in virtual-reality. Such findings suggest that application of isovist analysis within the design process may be fruitful. Indeed, isovist area and the number of vertices, both appear to describe visual properties which may shape and contribute to how an environment is experienced. Although the correlations seen here were not overly strong, they still suggest that a relationship between isovist properties and experience of the built-environment is present. In addition, the relationship is present despite the fact that other factors which may influence responses, such as lighting levels and the materials used within the environment were not accounted for.

The next step in our research was to examine whether or not such relationships can be observed within complex, real-world environments. As researchers, we often strive to create controlled environments in which we manipulate small aspects of the environment in order to answer specific questions. Although such an approach is vital to the scientific process, for the findings above to be applicable within architectural design, we need to be aware that built-environments are not laboratory settings. Built-environments are incredibly complex; the next study attempts to examine whether isovist analysis is robust enough to describe experience within such complex real-world environments.

Experiment #2

The goal of this study was to examine the relationship between isovist properties and experience within a complex real-world environment. In collaboration with *Stantec Architecture Ltd.*, we decided to explore experience of student centre designed by the firm for *The University of Toronto at Scarborough*. Such a space would provide us with a number of distinct spaces which would having naturally varying degrees of isovist properties. In addition to this, the multipurpose nature of the building would allow us to examine the robustness of the findings of experiment 1. Would isovist properties predict experience despite difference in building usage and programming of the various spaces within the building? Finally, by working in conjunction with the architects responsible with the designing the building, we would have direct access to design intent and could address directly whether or not the building is being experienced in the manner intended.

The building

The University of Toronto at Scarborough Student Centre designed in close collaboration and paid for by the *University of Toronto Student Union* (Figure 2). In this way, the design was intended to have a 'students first' approach and to meet the specific needs of the student body. The building was completed in 2004, features three levels connected via a central staircase and has an overall area of 50,700 square feet. The building design features three multipurpose stacked areas from which elongated axes of programmed space extend.

Participants

A total of 61 participants participated in the study (male = 18, female = 43); average age was 20.91 years. Participants received a coffee shop gift-card, valued at $5.00, for their participation in the study, which lasted approximately 30 minutes.

Materials, isovist analysis and data collection

A questionnaire consisting of numerous questions with regard to demographic information, previous usage of the building and general opinions of the building was administered to each participant. A semantic differential task, such as the one described in experiment 1 was also administered to each participant. Here, the rating categories included the original six presented in experiment 1 with the inclusion of one additional category: sociability.

A three-dimensional model of the building was created using *Google SketchUp*, guided by architectural drawing of the building provided by *Stantec Architecture Ltd*. Once again, *Depthmap* was used to generate isovist analysis of our model. Isovist analysis was conducted for a total of eight areas of interest within the building. These areas of interest were determined by natural subdivisions within the building. This included areas such as the TV lounge, cafeteria, the second floor lounge and several of the hallways within the building. All isovists were produced as if in an individual was looking into these areas of interest (Figure 3).

Figure 2. Images of the University of Toronto at Scarborough Student Centre designed by Stantec Architecture Ltd. Image on the left shows the main entrance into the building. Central image shows the lounge located on the second level. The image on the right shows one of the main corridors found on the main level.

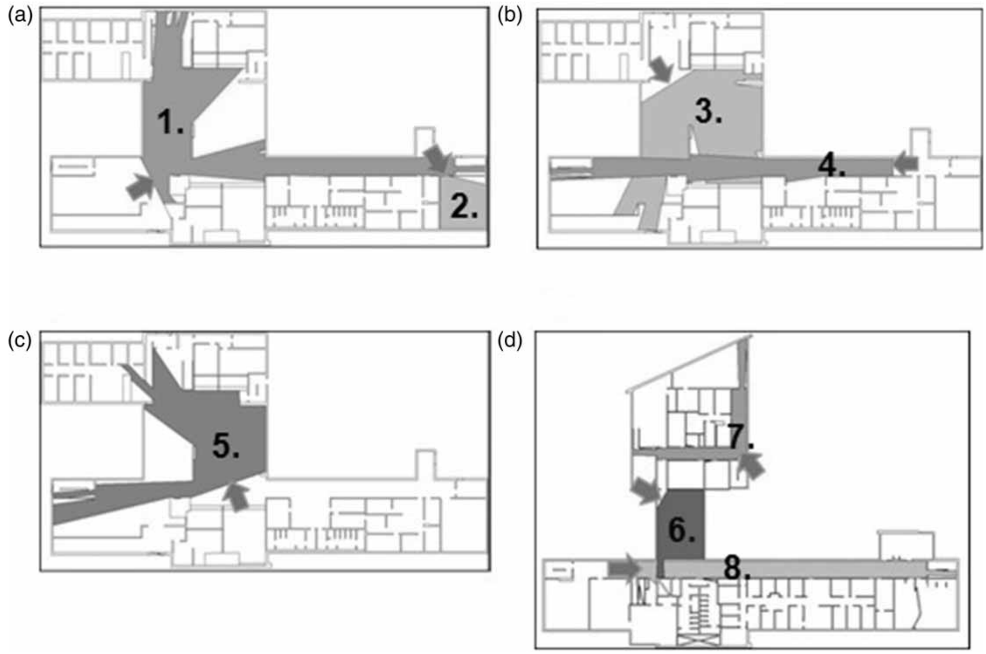

Figure 3. Above are shown isovist polygons from each viewpoint into our eight areas of interest. The arrows represent the approximate position of each participant as they looked into each area of interest and completed the semantic differential task. (a) The main level is shown with areas of interest: (1) The *Campus Express* hallway and (2) the TV lounge. (b) The main level is shown with areas of interest: (3) cafeteria and (4) long hallway on the main level. (c) The main floor is shown with area of interest: (5) cafeteria. Finally, (d) the second level is shown with areas of interest: (6) upstairs lounge, (7) the radio hall and (8) long hallway on the second level. Note that two isovist polygons were generated for the cafeteria (3 and 5), due to the fact that the polygon's generated varied by the viewpoint location looking into the cafeteria.

Since the questionnaires were administered during regular work and class hours, the building was populated with students. The presence of other individuals could potentially influence how the space will be perceived. In order to examine such a possibility, we measured frequency of behaviours within each of the area of interest in the building. This was done by research assistants, who entered each area of interest approximately every 15 minutes and recorded the frequency of behaviours occurring at that time. Initially, over 30 different types of behaviours were recorded, but this was later collapsed into three categories based on the nature of behaviour: social, independent and transitory behaviours.

Procedure

Participants approached the experimenters, who were seated at a table with a sign explaining the purpose and goal of the study. Upon signing the information and consent form, the questionnaire examining demographics and previous usage and experiences with the student centre was administered. Following this, participants were led to each of the eight areas of interest within the building. Once the area of interest was reached, participants were asked to stand in a particular location and face a particular direction; looking into the area of interest. In this way it was hoped that all participants would be positioned in the same location and would have the same viewpoint in each area of interest. These particular viewpoint locations matched those locations, which were used to generate the isovist analysis for each of the areas of interest. Once the correct location and viewpoint was achieved, participants were instructed to remain stationary. At this point, the semantic differential task was administered in the same manner as describe in experiment 1.

Results

Partial correlation analysis was performed, examining the relationship between isovist properties and the ratings on the semantic differential task for our areas of interest in a manner similar to experiment #1. Partial correlations were done in an effort to control for differences between previous experience presence of other individuals and individual differences. We controlled for a number of factors including the number of years the participant has been used the building, how often a week the participant walks and passes through the building and how familiar with the building the participant rated themselves. We also controlled for the presence of other individuals within the areas of interest, while the semantic differential task was being administered by partialling-out both the number of individuals engaged in social and independent tasks during the task. Isovist area was significantly positively correlated with ratings of complexity ($r = .12$, $p < .05$), clarity ($r = .13$, $p < .05$), spaciousness ($r = .28$, $p < .01$), and sociability ($r = .17$, $p = 0.024$). The number of vertices was significantly negatively correlated with ratings of clarity ($r = -.12$, $p < .01$), spaciousness ($r = -.14$, $p < .05$) and sociability ($r = -.18$, $p < .01$).

Linear regression analysis was performed in an effort to understand what role, if any, the properties other than the visual features of the environment (as captured by isovist properties) may play in shaping ratings on the semantic differential task. Linear regression was done so that each semantic differential category served as a dependent variable in turn. Three blocks of independent variables were added. Block 1 featured individuals previous experience with the building as captured by the number of years the participant has been used the building, how often a week the participant walks and passes through the building and how familiar with the building the participant rated themselves. Block 2 featured the presence of other people within the area of interest, while the semantic differential task was administered as captured by frequency of social, independent and transitory behaviours. Finally, block 3 featured our isovist properties of isovist area and the number of vertices. Results are summarized in Table 1. Although the model significantly explained the variance in each of the dependent variables, generally the R^2 values were quite small. Out of all the dependent variables, sociability was most strongly predicted by the model ($R^2 = 0.261$, $F(9,374) = 14.692$, $p < 0.01$), with weekly passage through the building ($\beta = -0.128$, $p < 0.01$), the total amount of people present in the space ($\beta = 2.957$, $p < 0.01$), social behaviour observed in the space ($\beta = -1.551$, $p = 0.033$), independent behaviour observed in the space ($\beta = -1.598$, $p < 0.01$), isovist area ($\beta = 0.215$, $p = 0.037$) and the number of vertices ($\beta = -0.236$, $p = 0.012$) all significantly describing rated sociability. On the other hand, while still significant, pleasantness was least strongly predicted by the model ($R^2 = 0.052$, $F(9,365) = 2.265$, $p = 0.018$) with only usage per week significantly describing ratings ($\beta = -0.166$, $p < 0.01$). When we consider two of our more interesting variables spaciousness and complexity, we see that the model significantly captures ratings of both. For spaciousness ($R^2 = 0.094$, $F(9,372) = 4.290$, $p < 0.01$) both isovist area ($\beta = 0.583$, $p < 0.01$) and the number of vertices ($\beta = -0.557$, $p < 0.01$) all predictive ratings. While for complexity ($R^2 = 0.098$, $F(9,374) = 4.514$, $p < 0.01$), both weekly usage ($\beta = -0.122$, $p = 0.019$) and isovist area ($\beta = 0.226$, $p = 0.048$) predicted ratings.

Table 1. Linear regression demonstrates that a number of variables predicted various rating categories.

	Pleasant		Beauty		Interest		Complex		Clear		Spacious		Sociable	
	β	t	β	t	β	t	β	t	β	t	β	t	β	t
Years[a]			0.187	3.34*	0.113	2.04*								
Usage[b]	−0.166	−3.13*	−0.128	−2.48			−0.122	−2.36	−0.108	−2.09	−0.136	−2.63*		
Passage[c]													−0.128	−2.87*
Familiar[d]			−0.179	−3.11*	−0.142	−2.49*								
Total #[e]			2.681	2.27									2.957	2.76*
Social[f]			−1.694	−2.12									−1.551	−2.14
Indepen[g]			−1.519	−2.31									−1.598	−2.68*
Iso area[h]							0.226	1.99	0.231	2.04	0.583	5.12*	0.215	2.09
N. Ver[i]									−0.291	2.82	−0.557	−5.38*	−0.236	−2.52*
Model F	2.265*		4.64*		5.51*		4.514*		4.77*		4.29*		14.69*	
Model R^2	0.052		0.100		0.117		0.098		0.103		0.094		0.261	

Although the isovist properties of isovist area and the number of vertices did predict ratings on several of the categories, they alone do not tell us the whole story. Overall, the nine factor model predicts a small amount of variance in ratings with the highest R^2 value being 0.261 for ratings of sociability.

Notes: All t values are significant at $p < 0.05$, values marked with * are significant at $p < 0.01$. Standardized β values and t values are only given to those variables which were significant within the model.

[a]Years that the participant has used the building.

[b]Number of times per week that the building is used.

[c]Number of times per week that the building is passed through.

[d]How familiar they are with the building on a 1–10 scale, 10 being very familiar.

[e]Total number of individuals present in the space while semantic task was administered.

[f]Number of individuals engaged in social types of behaviour while semantic differential task was being administered.

[g]Number of individuals engaged in independent types of behaviour while semantic differential task was being administered.

[h]Isovist area generated from given observation point.

[i]Number of vertices within the isovist generated from given observation point.

Overall, this suggested that 26.1% of the variance in ratings of sociability was explained by the model. At the same time, only 5.2% of the variance in ratings of pleasantness was explained by the model. For spaciousness and complexity, 9.4% and 9.8% of the ratings were described by our model, respectively.

Experiment #2 discussion

Here, we examined if isovist analysis could capture experience of a complex real-world environment. Some of the results match what was observed in experiment 1, while other findings are surprising and difficult to reconcile with previous research. Isovist area does appear to be related to both clarity and spaciousness, so that as isovist area increases so do experiences of clarity and spaciousness. Surprisingly, a positive relation was also found between complexity and isovist area, such a finding was not expected and does not appear in experiment 1 nor in previous experiments conducted in virtual-reality. The reason for such a relation could be due to the fact that, although we attempted to control for much of the differences between the areas of interest, locations with larger isovist area might have featured an overall greater degree of perceptual complexity in the form of furniture and decorations. In this way as area increased so did these other variables, which in turn could have lead the area as being perceived as more complex.

In addition, isovist area did not seem to have a positive influence on rating of pleasantness, beauty nor interestingness; relationships which were expected to occur. Both Kaplan and Kaplan, along with Appleton suggest that the larger overviews and vistas will be preferred and seen as positive as they allow for acquisition of information with regard to ones environment. Clearly, isovist area captures the visible space from a given observation point, yet in this study, this property does not shape subjective, positive experiences of a real-world environment.

Within the *University of Toronto at Scarborough Student Centre* it appears as if the correlations found between the number of vertices and experience of the space diverged from what was expected. The number of vertices was not related to ratings of complexity. In addition, if number of vertices is intended to capture complexity, then the negative relationships should also be present between the number of vertices and ratings of clarity and spaciousness. Neither of these two relationships was found. These results bring into question whether number of vertices can truly capture the experience of complexity within a real-world environment.

The *University of Toronto at Scarborough Student Centre* is a large and dynamic building, and although we attempted to control for a number factors such as previous experience with the building and the presence and behaviour of other individuals, our ability to measure such complexities within the building is limited. The regression analysis does support the notion that a wide number of properties other than isovist analysis, influence experience of the building. Indeed, both previous experience and the presence of other individuals seem to predict ratings on the semantic differential task. Interestingly, pleasantness, beauty and interestingness were not significantly predicted by isovist analysis. Other categories, such as sociability are influenced by all three groups of factors: previous experience, presence of other individuals and isovist properties. Although these regression models are insightful, they only explain a small amount of variance within the dependent variables, as demonstrated by the relatively low R^2 values. This suggests that other confounds and variables which were present are further driving experience of this real-world environment.

General discussion

The goal of this research is to bridge the gap between architectural professionals and empirical research on scene and environmental preference. In order to accomplish, this it is necessary to develop a way in which to describe the visual features of a built-environment. Isovist analysis was suggested as a possible method to do exactly this. From studies conducted in virtual-reality (Wiener et al. 2007; Stamps 2009) and in a small-scale real-world environment presented in experiment 1, the results seem encouraging. Experiment 2 explores the robustness of such findings by examining a large-scale, complex real-world environment, where the results become more difficult to interpret but suggest several important avenues for future examination.

Overall the results of the two experiments presented here are quite complex with some very unique findings. Perhaps the most robust finding was that isovist analysis did seem to consistently explain experience of spaciousness and clarity. In both experiments 1 and 2, isovist area correlated with both ratings of clarity and spaciousness. So that as isovist area increased so did perceived clarity and spaciousness of the environment. Isovist area also predicted the experience of pleasantness, beauty and interestingness in accordance with virtual-reality research (Wiener et al. 2007), predictions based on both prospect and refuge theory (Appleton 1975) and other environmental preference research (Kaplan and Kaplan 1989). The argument here suggests that environments with larger viewpoints, vistas or visible space would be associated with positive experiences and evaluations (such as pleasantness and beauty) as they provide the viewer with a greater degree of information about their environment, which in turn could be used to gain knowledge about the environment and improve chances of survival. Isovist area is seen as a possible analogue of visible space from an observation point, one which can be applied to describe a wide range of built-environments. Although the results of experiment 1 were somewhat encouraging, experiment 2 does not seem to support such a hypothesis as isovist area was not correlated with rating of pleasantness, beauty nor interestingness.

Number of vertices was intended to measure the complexity of an environment. The visual complexity of a stimulus is often said to be captured by the amount or density of features present within the stimulus (Berlyne 1954; Willis and Dornbush 1968). Indeed previous research does suggest that as the amount of visual features within an object increases, so does perceived complexity (Berlyne 1970). The number of vertices is employed as a possible way to describe the complexity of the built-environment, as any point where two points of an isovist polygon meet can be theorized as being a visual feature within the environment. Where isovist area simply measure the amount of visible space, the number of vertices describes the amount of unique visual features within the space. In this way, as the number of vertices increases within an environment it seems likely that the perceived complexity should also increase. Similarly to isovist area, experiment 1 matched our hypothesis regarding the relation between the number of vertices and complexity, while experiment 2 failed to do so.

Closely examining the findings above, it appears that isovist analysis could potentially capture a very specific experience of the built-environment. Specifically, isovist analysis appears to describe and reliably predict experience of the physical properties and features of the space, such as its perceived spaciousness and clarity. On the other hand aesthetic judgements, such as pleasantness and beauty were not consistently predicted by isovist analysis, instead they may not be so easily captured by the spatial properties of an environment and may vary between individuals, as has been shown previously (O'Hare 1976; Sevenant and Antrop 2010). Thus, it appears that isovist analysis may tap into the spatial properties of a space.

Interestingly, spatial properties have previously been shown to influence categorization and high-level processing of visual scenes (Oliva and Torralba 2001). Here, neuropsychological research pinpoints the parahippocampal gyrus as being crucially important as it is posited as respond preferentially to enclosed spaces (Aguire, Zarahn, and D'Esposito 1998; Epstein and Kanwisher 1998). Specifically, the parahippocampal gyrus is said to respond preferentially to the spatial properties of the space and ignore the presence of objects and other individual elements in the space (Epstein et al. 1999; Park et al. 2011). The parahippocampal gyrus appears to be responsible for the encoding of the visual elements of the scene, as opposed to recognition of the environment or navigation behaviour (Epstein et al. 1999), and such encoding of visual elements has been suggested as influencing high-level spatial judgements (Kravitz, Peng, and Baker 2011) along with scene categorization (Greene and Oliva 2009). From here, it appears possible that the responses as described by isovist analysis are mediated by the parahippocampal gyrus. Isovist analysis describes the visual elements and spatial properties of a scene and this is then able to influence judgements regarding the physical properties of the environment, such as spaciousness and clarity. This processes seems to mirror the literature on the parahippocampal gyrus mentioned above. Finally, it is important to note that such perceptions and judgements with regard to the environment are not formed arbitrarily, instead they are part of the perception–action cycle (Fuster 2004). Connections between perceptual regions and motor regions are plentiful and allow an organism to perceive and then act upon their environment. This directly relates to literature discussed previously (Berlyne 1970; Appleton 1975; Kaplan and Kaplan 1989), as they argue that perceptual elements of an environment will drive and influence motor behaviour within the environment.

Although it is suggested here that the parahippocampal gyrus is responsible for the processing of the global properties of enclosed spaces, it has also previously been suggested as serving an important role in formation of memories (Epstein et al. 1999). Perhaps the parahippocampal gyrus might not directly encode new memories, but it is likely that it has connections and feeds information forward to other neural regions subserving formation of both semantic and episodic memory (Powell et al. 2004). Interestingly, regression analysis in experiment 2 did show that memories and previous experience with the environment did influence evaluations of the environment; perhaps due to the high concentration of μ-opioid receptors found in association areas, involved in memory (Biederman and Vessel 2006; Yue, Vessel, and Biederman 2007).

Such possible activation of the parahippocampal gyrus to both the spatial and geometric properties of space along with its connection to memory are both posited as leading to preference for certain environments over others (Biederman and Vessel 2006). Due to the high concentration of μ-opioid receptors, which are involved in the experience of pleasure, present in the parahippocampal gyrus, it is suggested that higher activation in this region would lead to experiencing a stimulus positively. The above findings suggest that both the ability of the environment to provide the viewer with information, in the form of spatial properties of the scene (such as spaciousness and clarity) and possible associative connections to previous experiences and memories both mediate activation of the parahippocampal gyrus and thus lead environments which lead to more activation to be seen as more enjoyable. Unfortunately, the findings of experiment 2 do not necessarily corroborate such a hypothesis, which could potentially be explained in several ways.

It is important to note that isovist analysis does have limitations, which could have potentially adversely affected our findings. Isovist analysis, as described here, employs two-dimensional polygons, ignoring height. Architects often employ variations in ceiling height and changes in volume of a space as tools by which to shape experience. In this way, isovist analysis might be missing an important factor which shapes experience of the built-environment. Beyond such spatial property considerations, isovist analysis is also naive to other design features which play an important role in the design process such as the placement and quality of lighting, materials and textures and presence of windows. Indeed lighting and colour have both been shown to influence responses towards ones environment (Caballero-Arce, Vigil-de Insausti, and Benlloch-Marco 2012). Although many of the relationships between our isovist properties and rating categories were significant, it is very likely that the relatively weak strength between them was in part due to the variables which are not captured by isovist analysis as described here.

In addition to the limitations present in isovist analysis, it is important to be aware of the inherent differences between virtual/laboratory and real-world environments. Laboratory environments and virtual-reality environments allows researchers to create very specific and controlled spaces. Such stimuli can be used to pinpoint and elucidate the basic visual properties, which may be relevant to experience of space. At the same time it is important to remember that laboratory and virtual-reality differ in several ways from the real-world. Firstly, laboratory and virtual-reality studies examining the visual properties of the space are devoid of other individuals, the environments are empty. Very rarely would we enter an empty environment, and previous work does suggest that presence of other individuals does shape how the space is experienced (Nagar and Pandey 1987; Machleit, Eroglu, and Powell Mantel 2000). Secondly, laboratory and virtual-reality environments employ spaces which are typically novel to the participant; they have not interacted with the space previously. In the real-world you will only enter a new environment once, all future interactions with the building will be grounded in these previous experiences and memories, whether they be negative or positive. Finally, lab studies typically employ environments which are devoid of true function, they are blank empty spaces which do not serve a purpose or function. This is very different from the real-world, where spaces are typically programmed and serve a particular role. These factors could be responsible for the discrepancy between experiments 1 and 2 and also the lack of agreement with previous research and theories. Indeed, the regression analysis conducted in experiment 2 clearly demonstrates that there is a significant influence of previous experience and the presence of other individuals, on experience of the building.

Future research could potentially explore the arguments mentioned above; the variables not captured by isovist analysis, while remaining aware of the factors which laboratory controlled environments often ignore. The experiments here suggest that visual properties as captured by isovist analysis explain at least how spatial judgements or evaluations are formed. Although it is clear that the parahippocampal gyrus processes such spatial properties of built-environments, it is also necessary to be aware that a large number of high-level visual areas shape scene perception (Park et al. 2011). The lateral occipital cortex, an area responsible for object perception is often stated as also being relevant to scene perception (Park et al. 2011). Thus, it is necessary to examine the contribution of non-spatial properties of an environment on responses towards an environment. As mentioned earlier, many design decisions, beyond the spatial and visual properties as potentially described by isovist analysis, are involved when designing a built-environment. Indeed factors such as materials used, lighting quality and placement and building usage and navigation patterns need to be addressed in turn. Additionally, isovist analysis described here employs two-dimensional polygons; we are currently working on developing a three-dimensional isovist analysis tool. This would allow us to more accurately examine experience of space by capturing the illusive third dimension of height and calculating the volume of built-environments.

In reality would we expect the visual properties and physical features alone to predict experience? Although visual perception does play an important role and there is something unique about perception of built-environments (Epstein and Kanwisher 1998), it cannot tell us the whole story. Indeed, experience of built-environments is complex and is probably shaped by an interplay of various interacting variables. For example, perhaps the visual and spatial properties of a space as described by isovist analysis do directly influence experience of spaces, but they may also influence how the space is used and thus dictate the presence and behaviour of other individuals. This presence of other individuals may then influence how the environment is experienced. In addition, previous experiences may directly influence how an individual uses and experiences the space. As we move forward and collaboration between design professionals and researchers continues, we need to be aware that such interactions between a large number of variables may be present.

Behavioural and neuroscientific research has the potential to be applied to and to assist in the architectural design process. Responses towards a built-environment are bound to be complex and intricate; shaped by various features and properties. The experiments presented here demonstrate how it may be possible to research and elucidate the manner in which such factors influence experience. Although complex, it is possible to examine these individual properties within both laboratory and real-world environments, as presented here. Beyond this, examination of neuroscientific research leads to the development of research questions with regard to the way the built-environment is experienced. In this article, we focus on isovist analysis as a way in which to capture visual and spatial properties, at the same time it is possible for us to measure and examine many other factors. Future work should look to examine some of the factors discussed above, and by employing controlled laboratory experiments, examine the relative contributions of each factor on experience. Laboratory studies and methods found within allow researchers to examine the relative contributions of a wide number of properties on experience; ranging from spatial properties to more subtle properties such as the materials used. What is important is the fact that each of these properties can be examined in turn and then potentially examined in conjunction with one another to build up a holistic explanation of how the built-environment is experienced. Built-environments are indeed dynamic and complex, and it is such complexity that makes the built-environment so captivating. By asking insightful questions and through continued collaboration between architects and researchers, perhaps we can begin to unravel the dynamic relationship between us and the built-environment.

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Note

1. *Depthmap* was created by Alistair Turner and colleagues at *University College London*. The program is free upon registration and can be downloaded from: http://www.vr.ucl.ac.uk/depthmap/. The program allows models of environment to be analysed using isovist analysis, and outputs several isovist properties including isovist area, perimeter and neighbourhood size.

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