Isovist Analysis as a Tool for Capturing Responses Towards the Built Environment

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Some of the research described in this thesis has been submitted by invitation and conditionally accepted to the journal Intelligent Buildings International.

Abstract

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 the visual properties within an environment. Recently it has been proposed that isovist analysis could be employed to describe built-environments. In two experiments we examined whether or not isovist analysis can capture experience of real-world environments. In Experiment one we demonstrated that isovist analysis can be employed to describe experience of environment within a controlled, laboratory environment. In Experiment two we employed some of the methods of post-occupancy analysis to examine the robustness of the isovist approach and whether it would capture experience of a complex, real-world environment. The results of Experiment two 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. These findings suggest that experience of real-world, complex environments cannot be captured by the visual properties alone, but also highlight some of the other factors, such as presence of others and previous experiences may influence experience of built settings. Implications for the design processes are described.

Acknowledgements

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Dedication

For my family and girlfriend. Would not have been possible without you.

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1.1 Introduction

Most of our time is spent within built-environments, so it is not surprising that we develop an intimate relationship with the spaces we occupy. Much of our behaviour and attitudes towards built environments is influenced by the physical properties of these built- environments which have been shown to influence behaviour in the form of navigation and path selection (Hillier & Hanson 1984, Conroy-Dalton, 2003). Beyond navigation behaviour, the form of built-environments also influences pleasantness of our daily experiences (Goss, 1993) and even our mental health (Evans, 2003). Architects and design professionals understand that the design decisions they make will have a profound impact on how an individual will experience and feel within the space. Indeed, the Roman architect, Vitruvius Pollio addressed the relationship between the architect and the user base by stating that built-environments should provide "commodity, firmness and delight", a statement which he expressed many years ago (Pollio, 1999). During the design process architects will often discuss how a building will "feel" and be experienced by its user base. Yet despite such an understanding, many design decisions are made intuitively and are not necessarily supported by empirical research (Lawson, 2006; Zeisel 2006). As behavioural researchers and cognitive neuroscientists it is our hope that an examination of the built-environment and how it may influence behaviour and experience may not only allow us to inform the design process but will also provide us with knowledge regarding the factors and mechanisms by which behaviour and experience are shaped.

The design process involves complex relationships between the architects, the individuals who commission the building and the building's potential users, who may or may not be members of the group who commissioned the building. It is not surprising that much of the architects' design choices and decisions are driven by the need to please these two groups

(Lawson, 2006; Zeisel 2006). Despite the best intentions of all groups involved, often times the typical design process, consisting of feedback and input from the client and the user groups, does not lead to the design of a more enjoyable or effective buildings (Lawson, 2006). This disconnect between design intent and realization within the final built-environment is due to many factors. Being largely a visual process, architectural design employs drawings as a way to predict behaviours such as path selection, and occupancy and usage of spaces within the building. Yet two-dimensional drawings and schematics and even three-dimensional models can only show us how the space will look and not how it will be used (Lawson, 2006). It has thus been suggested that such design practices serve more as aesthetic representations of built environments and do not necessarily capture usage of the completed built-environment (Lang, 1974).

Although the typical design process might not fully describe or predict how a building will be used, we would predict that it would do an adequate job of telling us how the space will be perceived and experienced. After all, it is the architect's role to create aesthetically appealing built-environments. Surprisingly, this does not appear to be the case as there appears to be disconnect between the aesthetic qualities that architects finding appealing and the qualities found by laypersons in a building (Brown & Gifford, 2001). Although both architects and laypersons base their aesthetic assessments on the concept of pleasantness rather than arousal, it appears that the features and properties of the buildings used to make these ratings varied greatly between the groups (Gifford, Muller-Clemm, Reynolds & Shaw, 2000). Architects preferred complexity and more modern forms while laypersons were partial to less complex forms (Devlin & Nasar, 1989). Not only were differences in preferred features within buildings found between architects and laypersons, but it also appears that the ways in which the physical features were conceptualized and interpreted were also quite different (Gifford, Hine, Muller-Clemm & Shaw, 2002). This suggests that the built-environment is experienced quite differently by architects and laypersons. Such differences in preferences and aesthetic evaluations might not be problematic if only architects were able to place themselves within the viewpoint of the user; a vital skill within the design fields. Unfortunately, it appears that architects have difficulties predicting which buildings will be experienced positively or negatively as they are unable to employ the same criteria used by laypersons when forming judgements (Brown & Gifford, 2001). Positive aesthetic judgement of buildings was predicted by the degree to which an architect was able to use concepts employed by laypersons; so thinking like a layperson led to the design of buildings which were experienced as more aesthetically pleasing (Brown & Gifford, 2001).

The evidence presented above suggests that, although the design process has specific goals, it often fails to successfully achieve them. Of course, this is not due to lack of effort on the part of the designers but instead perhaps due to a lack of clear understanding of the factors which shape both how we use and experience built-environments. If the role of the architect is to create environments that users experience in a positive and pleasant manner it might be useful to examine research on scene and environmental preference (Kaplan & Kaplan, 1989; Kaplan, Kaplan & Brown, 1989; Yue, Vessel & Biederman, 2007; Herzog, 1992).

Although we do experience built-environments through our other senses (such as audition and proprioception), at the most basic level the majority of our experiences with the built-environment are shaped by what we see. Thus, the research discussed here will focus on the visual properties of environments and how they may drive experience. In order to more fully understand how the visual factors may influence our experiences it is useful to consider how our visual system functions. When visual input is received by the central nervous system, the scene or object is parsed for low-level visual features. During low-level visual perception, the visual primitives of a stimulus such as edges, colour and light gradients are extracted (Henderson & Hollingworth, 1999). From here visual perception continues to build a more complex and complete representation of the stimulus, during what is known as intermediate-level visual perceptions. Here an understanding of the basic shape and relationships between various elements within the stimulus is developed. Finally, during high-level visual perception, semantic representations are activated and the stimulus identified (Henderson & 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 representations. 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 and that this directly influences intermediate and low-level visual perception (Rasche & Koch, 2002). In terms of perception of built environments it appears that a specific brain region responds preferentially to built, enclosed spaces (Epstein & Kanwisher, 1998). This region, known as the parahippocampal gyrus, is a part of the ventral visual stream; a series of neural regions which mediate object and scene identity and result in activation of associative concepts and high-level representations related to stimulus identity (Milner & Goodale, 2006). Interestingly, a high concentration of μ-opioid sensitive receptors in the ventral visual stream appears to be related to environmental preference (Xue, Vessel & Biederman, 2007).

There is a long history within behavioural research and environmental psychology examining how visual properties of a scene or environment may shape experience. One of the most widely cited concepts related to environmental preference is Appleton's (1975) duality of prospect and refuge. He argued 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. In terms of survival 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 two concepts, being provided with visibility while at the same time remaining sheltered or hidden, are referred to as "prospect" and "refuge", respectively. The features and properties of an environment which may provide an organism with prospect and/or refuge are numerous, and will shape aesthetic judgements and preference. Indeed, studies demonstrate that the concept of openness, which is closely related to prospect, is positively correlated with scene preference (Herzog & Leverich, 2003). Furthermore, 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 & Suedfeld, 1993).

One of the main tenets of prospect and refuge theory is that environments which provide an organism with visual information about their environment will be preferred because it will lead to the capture of useful environmental information. This emphasis on the informative value of an environment was expanded upon by Kaplan and Kaplan (1989). They suggested that several higher level visual properties of an environment drive preference; perhaps of most interest is the suggestion that environments which contain "mystery" are preferred. An environment is said to possess "mystery" if it suggests to the viewer that further exploration of the environment will lead to the acquisition of additional knowledge and information about the environment (Kaplan, 1987; Kaplan, Kaplan & Wendt, 1972). Thus, an environment featuring a path extending into a wooded area might be perceived as possessing "mystery" and would therefore be preferred to environment lacking such elements. In this way the environment promotes exploration resulting in an updated and more accurate cognitive map of one's environment; additional information is gathered which may lead to greater chances of survival for the organism. Thus preferences for scenes containing "mystery" have been suggested as being evolutionarily adaptive (Kaplan, 1987). Beyond the concept of "mystery" it also appears that more basic concepts describing spatial configuration of the space are relevant in regards to scene preference. In particular, it appears that open spaces which are well structured and organized are also preferred to enclosed and less organized spaces (Kaplan, Kaplan & Brown, 1987; Herzog, 1992).

The studies mentioned above rely on applying higher level cognitive concepts on to environment and scene preferences, through the application of concepts such as mystery and prospect. It is also possible to look at scene and object preference from a more basic low-level approach. 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. Following Yerkes and Dodson (1908) and Hebb (1955), 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. Environments of intermediate complexity lead to intermediate levels of arousal (Berlyne, Ogilvie, & Parham, 1968; Berlyne, Craw, Salapatek & Lewis, 1963; Berlyne, 1970). Visual complexity does not simply influence preference but it also promotes exploratory behaviour (Berlyne, 1958), leading to greater information acquisition (Berlyne, 1954). Such exploratory behaviour could also be seen as a metric of preference; if one is more likely to explore one environment as compared to another then it is can be said that they prefer this environment (Kaplan, 1987). More recent studies suggest that the concept of entropy, a measure of diversity (and thus complexity), predicts preference in a positive linear manner and not in the Yerkes-Dodson 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 experience of the environment.

The research mentioned above is not without its limitations and consensus on findings has been difficult to achieve. It is a concern that prospect and refuge theory has been mentioned in hundreds of studies (Stamps, 2006), yet very few of these studies examine the concept empirically, and, of those which do, many show ambiguous results (Herzog, 1989), or they do not support the prospect and refuge theory, particularly when examining urban environments (Herzog, 1992; Stamps, 2008a; Stamps, 2008b). Given its relatedness to the concept of mystery introduced by Kaplan & Kaplan (1989), prospect and refuge may still play a role in environmental preferences. One of the issues with much of research described above is the fact that, concepts such as openness, mystery, prospect and refuge are often ill-defined and are not objectively measured. In cases where they are measured in an objective manner, such methods may not be easily applied to a wide range of environments, especially urban and built-environments. For example many of the measures assume that an individual has a deep field of view as would be present in outdoor environments, and do not appropriately consider the enclosed nature and geometry of urban and built-environments. In order to apply theory in environmental psychology to the design process, concepts such as openness, mystery, prospect and refuge need to be clearly defined and be objectively measurable. Without a relatively simple, effective and accurate way by which to capture and describe the physical properties of an environment it becomes not only difficult but nearly impossible to apply empirical research to the design processes. Beyond the applicability of such research to the design fields, a more systematic approach to describing the physical properties of an environment may allow us to examine more deeply the cognitive basis of navigation behaviour and the experience of space. Specifically the cognitive factors which drive decision making processes behind preference and behaviour. Isovist analysis may provide us with one such rigorous basis from which to examine behaviour and experience of built-environments.

Originally described by Benedikt (1979), an isovist describes the visible space from a given observation point within an environment. More specifically, it is the two-dimensional polygon generated by the visible space from a viewpoint. An isovist is unique to its own particular viewpoint, and as an individual moves through their environment the isovist will change to reflect their changing viewpoint. From this simple isovist polygon it is possible to extract some basic, descriptive values, such as isovist area, isovist perimeter and number of vertices within the polygon. Figure 1 shows a sample environment and applies isovist analysis to it. A computational method for generate isovist properties was later developed (Davis & Benedikt, 1979) while more recently more complex isovist properties have been conceptualized by extracting higher-order values from the basic isovist properties (Franz & Wiener, 2005). Isovist analysis has recently become of interest as it is able to accurately describe both small and large-scale built-environments and it considers the role of the individual within the environment. The location of the individual is crucial, and thus isovist analysis might allow for a way to quantify the spatial properties involved in a variety of cognitive processes including aesthetic preference, navigation behaviour and spatial memory (Wiener, Franz, Rossmanith, Reichelt, Mallot & Bülthoff, 2007).

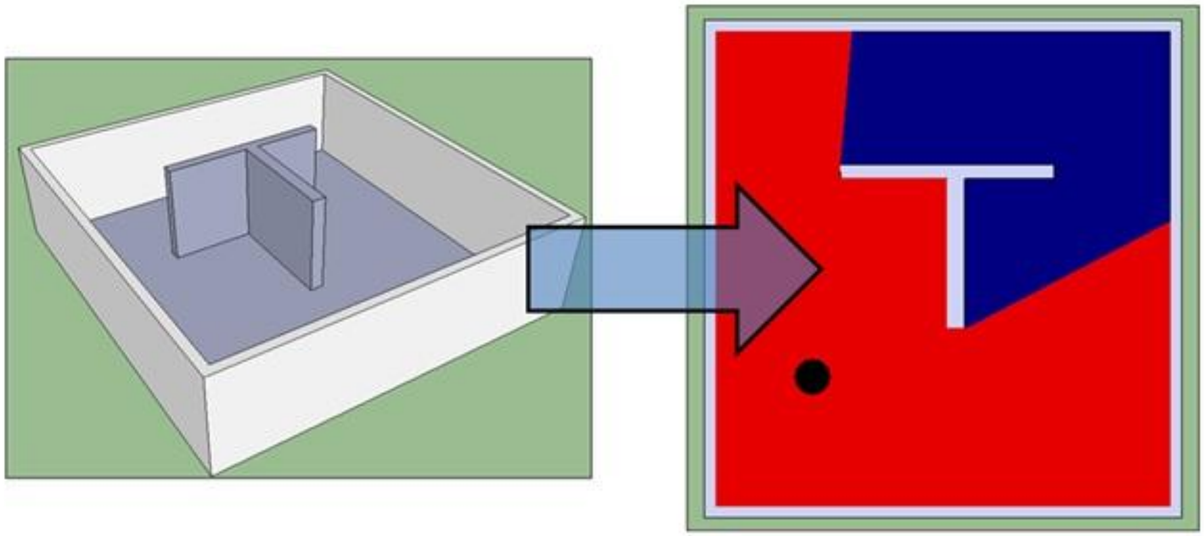


Figure 1.

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 red 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 lines of the polygon meet.

For isovist analysis to serve as a tool for elucidating topics such as aesthetic preference and navigation behaviour, it is necessary to first examine what perceptual features and properties are captured by isovist analysis in the first place. Using small scale models, Benedikt examined the influence of isovists on perception, finding that several isovist properties, including isovist area and isovist variance significantly impacted the perceptual property of spaciousness, so that viewpoints with larger isovist area and greater isovist variance were perceived as being more spacious (Benedikt & Burnham, 1981). Such a relationship between isovist area and spaciousness has been corroborated in recent studies (Stamps, 2009). Recent examinations of isovists has employed virtual-reality environments, which allows for easy manipulation of the physical properties of an environment, thus making it easy to control and modify the isovist properties of a space (Franz & Wiener, 2005). Perhaps the most thorough examination of isovist properties and their influence on the experience of environment was conducted by Wiener, Franz, Rossmanith, Reichelt, Mallot & Bülthoff (2007).

Employing virtual reality, Wiener and colleagues (2007) immersed participants in 16 unique 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 another location for the "best-overview spot"; essentially the location which would generate the smallest and largest isovist areas. Once each of these locations was reached, participants completed a semantic differential task, asking them to rate on, a seven-point Likert scale, the spaciousness, pleasantness, beauty, interestingness, complexity and clarity of each location. For each chosen location, the isovist polygon was generated from which isovist area, number of vertices and the jaggedness (isovist $area^2$/isovist perimeter) values were calculated. These isovist properties were then correlated with their ratings on the semantic differential task. They also monitored participant navigation behaviour by monitoring the time to reach each of the locations, number of stops, and the angular velocity along with several other properties of locomotion; these properties were also correlated with the isovist properties mentioned above. Their results suggested that during the "best hiding" and "best overview" tasks participants chose locations that were very similar to the actual coordinates within the environment that would generate the largest and smallest isovist areas. This finding suggests that isovist area was perceptually relevant and could be related to experience of space, specifically when considering experiences of spaciousness and visibility. Several significant correlations were noted between the three isovist properties (area, number of vertices and jaggedness) and the ratings on the semantic differential task. A number of navigation behaviours were also significantly correlated with all three isovist properties. Interestingly, many of their findings correspond to what scene and environmental preference research would lead us to expect; for example both spaciousness (isovist area) and complexity (number of vertices and jaggedness) correlated positively with pleasantness, beauty and interestingness. Thus the authors suggest that isovist analysis can predict the affective response to an environment and also influence navigation behaviour.

Such encouraging results suggest that isovist analysis may be a useful tool in both predicting how a yet-to-be-built building might be experienced or perceived (Derix, Gamleæter & Carranza, 2008), and in predicting possible navigation behaviours within an environment (Van Bilsen & Poelman, 2009). Although, isovists might predict experience of built-environments to a certain extent, all studies to date have been conducted using virtual reality, so the applicability of such findings to real world environment needs to be considered. Indeed differences between virtual and real world distance estimation have been noted (Lampton, McDonald, Singer & Bliss, 2003), as well as differences based on the type of virtual reality apparatus used (Plumert, Kearney, Cremer & Recker, 2005). Even the best virtual reality technology only approximates the real world and the applicability of virtual reality research examining isovists to the real world needs to be explored.

The goal of this thesis is to examine whether isovist analysis conducted in real-world environments captures and describes experience of built-environments in a manner similar to that which has been observed in virtual reality environments. The first experiment examines isovist analysis as it pertains to small-scale controlled environments. The second experiment attempts to apply isovist analysis to a large-scale, multi-purpose environment: *The University of Toronto at Scarborough Student Centre*. 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 one attempts to replicate the findings of Wiener and colleagues (2007) while employing a real-world environment. This would be the first step in suggesting whether or not isovist analysis captures and describes behaviour and experience of the build environment. Since this area of research is still in its infancy, due to the relatively recent developments in creating and calculating of isovists and isovist properties, the theoretical underpinnings behind isovist analysis and how they may directly influence experience of space has not been fully developed. This thesis serves as an exploration of isovist analysis and it's possible connection to experience of the built-environment.

If isovist analysis does capture properties regarding experience of built-environments, we would predict a similar pattern of findings to those made using virtual reality (Wiener, Franz, Rossmanith, Reichelt, Mallot & Bülthoff, 2007; Wiener & Franz 2005; Wiener & Franz, 2008). Although exploratory in nature, predictions can also be grounded in Berlyne's (1979) research on object complexity and aesthetic appraisals, Kaplan and Kaplan's (1989) theory on scene preference and Appleton's (1979) prospect and refuge theory. Taken together, the predicted relationships between isovist properties and experience of the built-environment are as follows:

1a. If isovist area captures experiences of spaciousness and clarity (Wiener, Franz, Rossmanith, Reichelt, Mallot & Bülthoff, 2007), it should be positively correlated with ratings of spaciousness and clarity.

1b. If this is the case, and in accordance with environmental preference research (Appleton, 1975; Kaplan & Kaplan, 1989), isovist area should also positively correlate with ratings of pleasantness and beauty.

2a. If number of vertices captures the experience of complexity (Wiener, Franz, Rossmanith, Reichelt, Mallot & Bülthoff, 2007), it should positively correlate with ratings of complexity.

2b. If this is the case, and in accordance with environmental preference research (Berlyne, 1970; Berlyne, Ogilvie, & Parham, 1968) number of vertices should be positively correlate with ratings of interestingness, and perhaps share a quadratic relation with ratings of pleasantness.

1.2 Experiment One

1.2.1 Method

Participants:

A total of 14 individuals participated in the experiment (8 female, 6 male), with ages ranging between 18 and 24 years. Participants had previously signed up for *PsychPool*, a participant directory through which they were contacted to participate in the experiment. They received $12.00 for their participation. 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 x 12 metres. By positioning eight room dividers within the room a total of 12 unique environments were created which can be seen in Figure 2. 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.

In an effort to capture participants' experience of the environments, a semantic differential task was employed; which is intended to capture experience and attitudes towards a stimulus. The environments were rated on a total of six properties including pleasantness, interestingness, beauty, complexity, clarity and spaciousness. Responses were made on a seven-point Likert scale where one represented the low/negative end of the scale and seven the high/positive end of the scale. The semantic differential task is typically conducted by presenting a rating category in the form of the question, such as: "How pleasant is the current stimulus?" The scale is identified, one would represent "unpleasant" and seven would represent "pleasant", and the participant would select a value on the one to seven scale.

Since we are attempting to examine whether or not isovist properties can capture properties that shape how an environment is experienced it was necessary for us to generate a number of isovist properties for each of our environments.

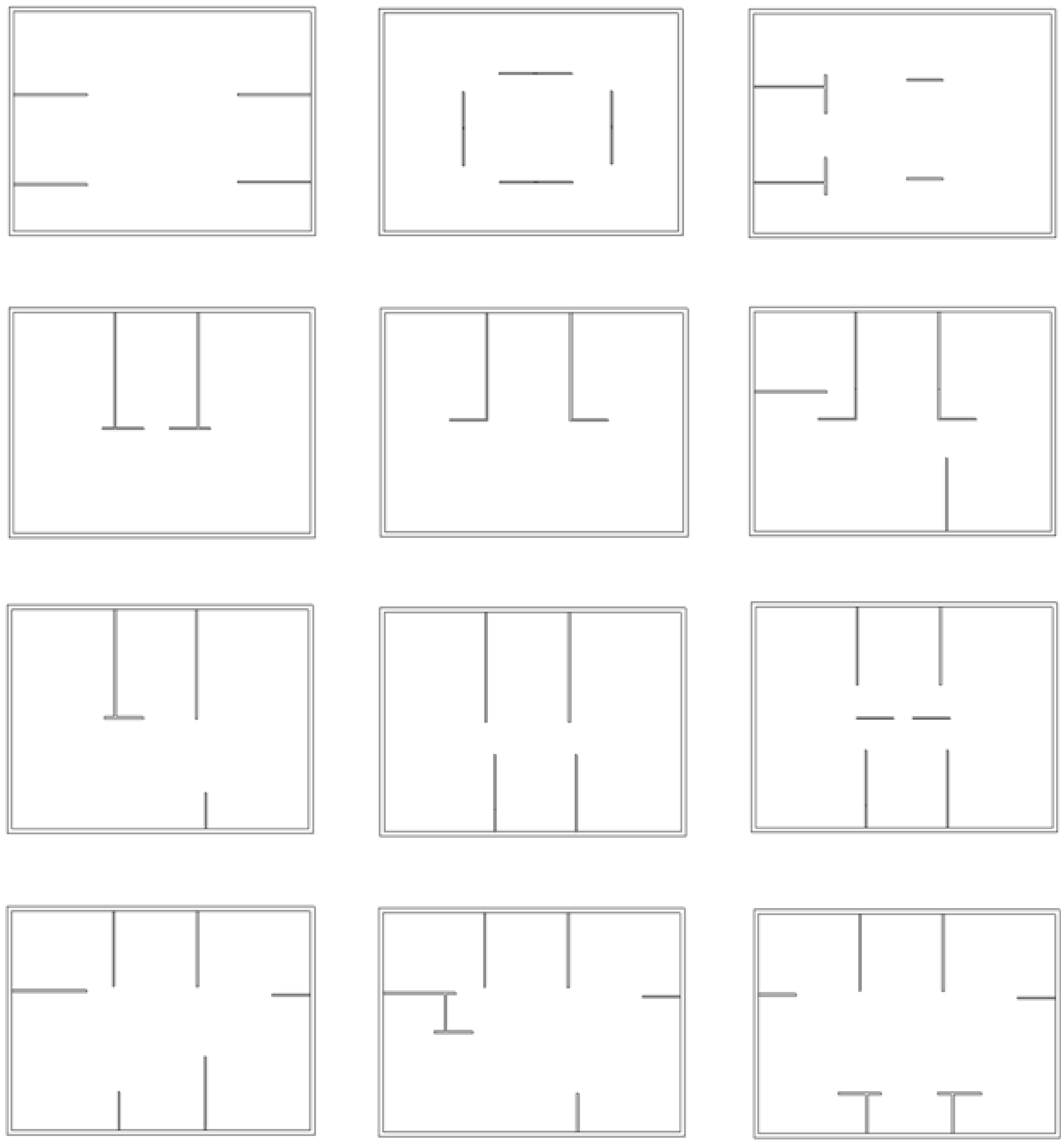


Figure 2.

Total of 12 environments were used, created by positioning eight room dividers. The room itself measured 9 x 12 metres. Tape marks on the floor along with the natural features present in the room ensured that the positioning of room dividers remained constant between participants.

We employed the program *Depthmap*to conducted isovist analysis of our environments.[1] Computer models of each of the environments were created and entered into *Depthmap.* During completion of the task (described below), each participant's selected locations were noted and then entered into *Depthmap* from which the isovist polygons and their associated properties were generated. A number of isovist properties were extracted including isovist area and number of vertices.

In addition, we conducted visibility graph analysis for each of the environments. This procedure involves the placement of a number of evenly spaced points on to each environment from which mutual visibility between the points is calculated. Through visibility graph analysis, global properties of the environment can be calculated. For the purposes of the current experiment, our aims were much more straightforward. Visibility graph analysis allows for the generation of a visual representation of visibility or isovist area for each point within the environment. A heat grid is generated where warmer colours indicate areas that are more connected within the environment, and thus have larger isovist areas and cooler colours indicate areas that are less connected and thus have smaller isovist areas. Although, we did not generate nor examine any actual visibility graph values, this visual representation of isovist area will be employed so as to examine performance on the tasks.

Procedure:

Participants were led into the environment and asked to perform two tasks adapted from Wiener et al (2007). In the first task, participants were asked to find the one location within the

[1] *Depthamp* was created by Alaistair 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 environments to be analyzed using isovist analysis, and outputs several isovist properties including isovist area, perimeter and neighbourhood size.

environment which would provide them with the largest overview of the space. This task would require them to find the location within the environment possessing 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; the ordering of tasks was randomized between participants. Upon reaching and selecting each of the two locations (largest and smallest overview locations), participants completed the semantic differential task. Responses on the semantic differential task were made verbally and recorded by the experimenter. Upon completing both tasks for a particular environment, 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.

1.2.2 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, p.1073):

$P_{max(r)} = (I_{sub(r)}-I_{min(r)})/ (I_{max(r)}-I_{min(r)})$

$P_{min(r)} = 1 – (I_{sub(r)}-I_{min(r)})/ I_{max(r)}-I_{min®})$

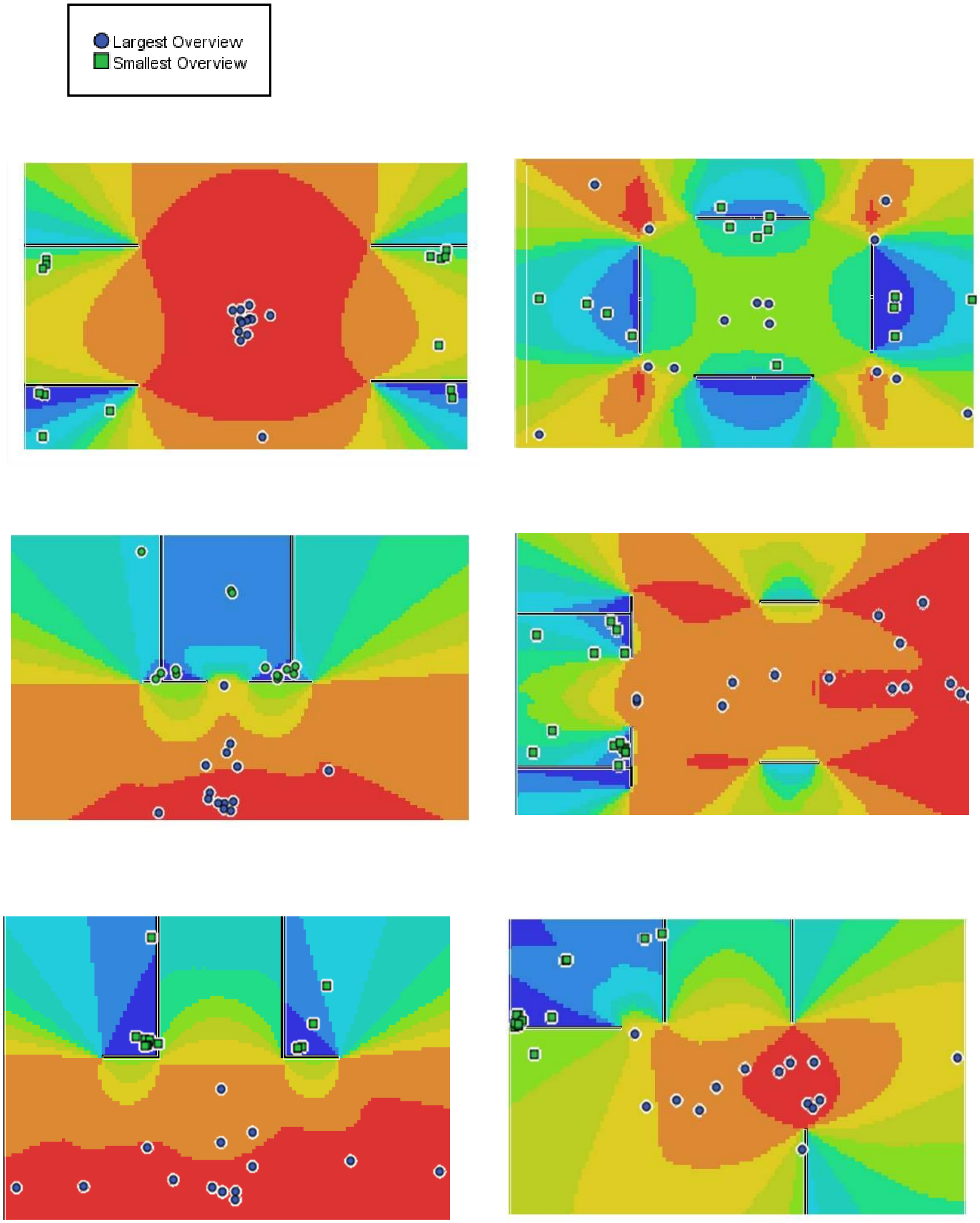
P_{max} is performance in finding the largest overview location or the maximum isovist within the environment. P_{min} is performance in finding the smallest overview location or the minimum isovist within the environment. r is the identity of the environment. I_{sub} is the value of the isovist from the participants chosen location within the environment. 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 task is scored on range of 0 to 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.

There appeared to be a considerable amount of agreement between participants in regards to locations which captured the largest and smallest overviews within the 12 environments. Although some variability is present it is important to note that different locations within the environments could posses very similar isovist areas, this is particularly relevant for symmetrical environments. (Figure 3). Examining the at the visibility graphs in Figure 3, it is clear that selected locations for largest overview are typically found on bright red areas, indicating large visibility and isovist areas. Selected locations for smallest overview, appear to be concentrated on dark blue area, indicating low visibility and smaller isovist areas. 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).(Figure 4). Participants were equally good at locating both the largest overview and the smallest overview, (t_{11} = 1.348, p = 0.18).

When it comes to possible relationships between isovist properties and ratings on the semantic differential task, we are specifically interested to see if any correlations exist within participants. By using multiple linear regression and treating participants as a categorical variable through dummy coding, it was possible to generate a partial correlation coefficient expressing the relation between our isovist properties and ratings while removing variations due to participants (Bland & Altman, 1995; 1994). Several significant correlations were found between isovist area and a number of rating categories. Isovist area was significantly positively correlated with ratings of spaciousness ($r(334) = .51, p < .01$) and clarity ($r(334) = .34, p < .01$).

Additionally, isovist area was positively correlated to both ratings of pleasantness ($r(334) = .25$, $p < .01$) and beauty ($r(334) = .26$, $p < .01$). Number of vertices also appears to be significantly correlated with a number of rating categories. Number of vertices was positively correlated with ratings of complexity ($r(334) = .3$, $p < .01$). Additionally, number of vertices was positively correlate with ratings of interestingness ($r(334) = .16$, $p < .01$) but was not significantly correlated to ratings of pleasantness ($r(334) = .01$, $p = .99$).

In accordance to hypothesis 2b, curvilinear regression was conducted to examine if a non-linear relation was present between number of vertices and ratings of pleasantness. The relation was tested by placing the squared value of number of vertices in an additional block within the linear regression model, allowing for the description of any possible quadratic relationships. Pleasantness was set as the dependent variable, while blocks featured both our categorical participant variables, isovist area and number of vertices. Although the model itself was significant ($R^2 = .32$, $F(16,319) = 6.02$, $p < .01$), the quadratic number of vertices term did not significantly add to the predictive power of the model ($\beta = .18$, $t = .7$, $p = .48$).


Largest Overview
Smallest Overview

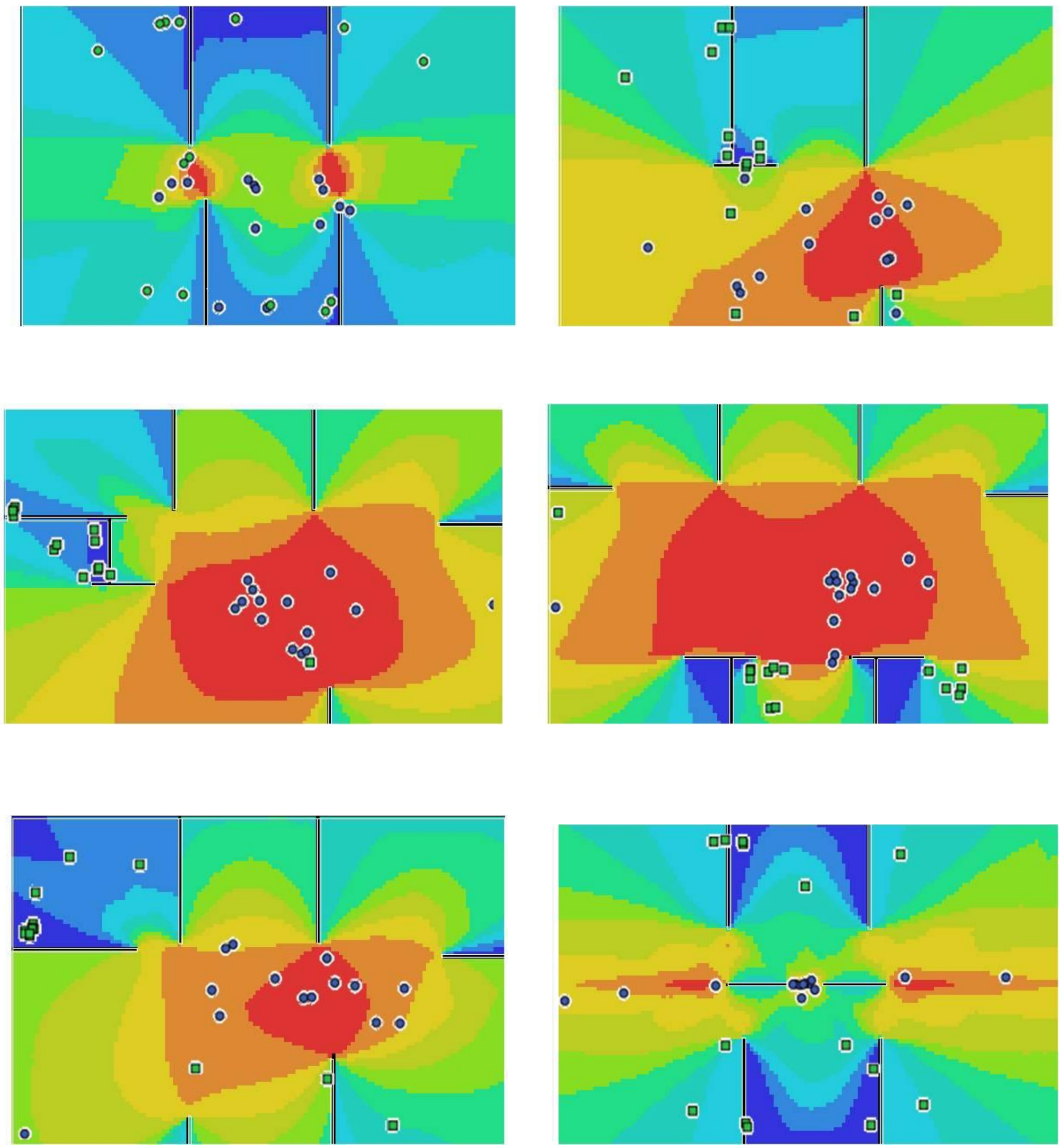


Figure 3.

Performance for each of the 12 environments is shown above. Blue circles represent the chosen locations for largest overview, while the green squares represent chosen locations for smallest overview. Locations are overlaid on the visibility graph, heat-map for each environment. Warmer colours represent areas with larger visibility and thus larger isovist areas while cooler colours represent areas with smaller visibility and thus smaller isovist areas . It appears that selected locations are relatively consistent between participants. It is important to note that certain locations may generate similar isovist polygons and isovist properties despite being in different spots within the environment. Generally, locations for the largest overview appear to be clustered on warmer regions on the visibility graph, while locations for smallest overview appear to be clustered on cooler regions on the visibility graph.

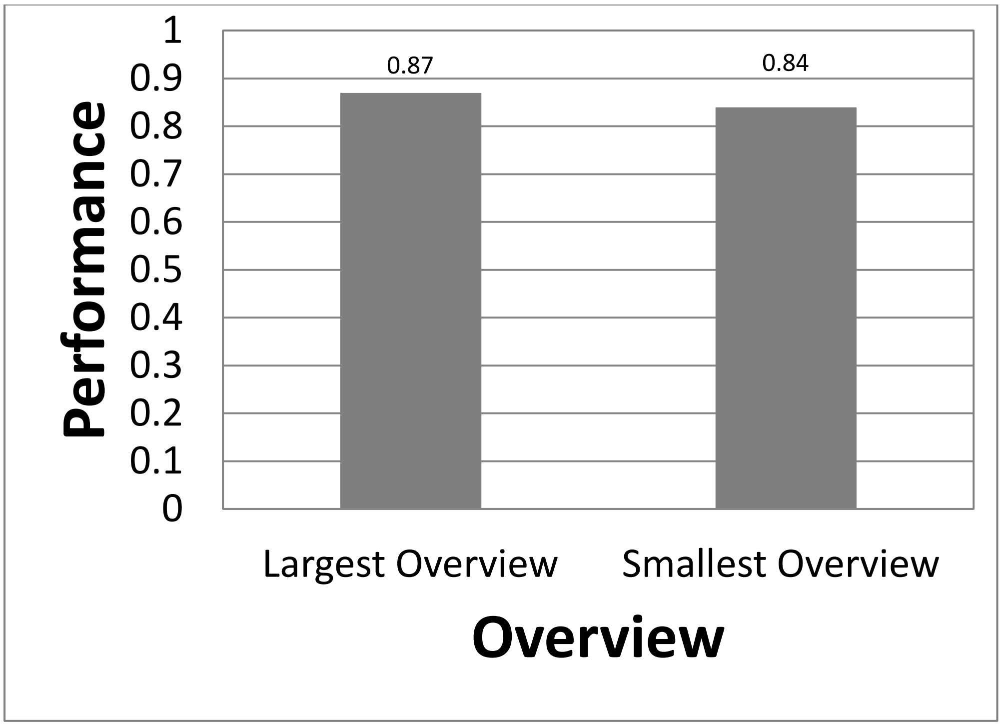


Figure 4.

Performance in finding the largest and smallest overview locations is shown. On the x-axis the overview condition is shown, either largest overview and smaller overview. On the y-axis performance is shown. Performance is measured on a 0 to 1 scale, where 1 represents perfect performance.

1.2.3 Experiment One Discussion

It appears that isovist analysis could be relevant for experience of real-world environments, and perhaps extended beyond virtual environments. Firstly, individuals can locate locations within the environment which correspond to areas with largest and smallest isovist areas. Thus appears that isovist properties are perceptible and could potentially drive behaviour. Secondly, isovist properties appear to be related to experience of the environment. As isovist area increases so do ratings spaciousness, clarity, pleasantness and beauty. Although, it is correlated with fewer of the rating categories, number of vertices is positively correlated with ratings of complexity and interestingness; so that as the number of vertices within the isovist increase so do ratings of complexity and interestingness.

Small-Scale Environments and Isovist Area

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 of 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 been 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 & 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 to explain such relationships through some of the theories mentioned previously. Appleton's (1975) prospect and refugee theory place importance on the individual's 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 the environment and thus might find such a location pleasant and perhaps beautiful. It is important to note that an environment does not have to provide both prospect and refuge; the theory posits that providing either is acceptable. It also appears that Kaplan and Kaplan's (1989A) informative environment theory might apply when examining the relationships between isovist area and pleasantness and beauty, in the sense that the informative nature of an environment might drive preference. Positive judgements should increase as the amount of visible space increases and this is indeed what is suggested by the correlation analysis. Saying this, Kaplan and Kaplan do not directly address the total amount of information available in a certain environment. Instead they discuss the nature qualitative properties of an environment by examining such concepts as legibility or coherence of an environment or the information which might be gained in the future (mystery) (Kaplan & Wendt, 1972). The concept of mystery is not captured by the isovist properties we examined here; but methods by which to quantify mystery could be developed in the future. The findings here appear to be more in line with more recent research, theorizing that scene and environmental preference is driven by the richness or quantitative experience of information within the environment (Biederman & Vessel, 2006).

Small-Scale Environments and Number of Vertices

Vertices within an isovist polygon are areas where two lines within the polygon meet; these can be created by locations in the environment where two walls meet but can also be created through obstruction of view. (Figure 1). Each of these vertices is descriptive of the environment as it provides visual information about the design and layout of the environment. Our data suggests that the number of vertices capture properties within an environment which relate to subjective experience of complexity. The relationship between estimated complexity and number of vertices held when controlling 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 (Stamps, 2006; Herzog & Shier, 2010) or Yerkes-Dodson (Berlyne, 1970) relationship between complexity and aesthetic experience of preference. Interestingly, neither of these two relationships was found here, as number of vertices did not appear to linearly nor curvilinearly correlate with ratings of pleasantness nor beauty. Thus it seems that the number of individual elements within an environment should predict perceived visual complexity, within these controlled environments the number of properties which could influence visual complexity was somewhat minimal. An environment which features many lines and thus many vertices would be more visually complex than an environment which features less lines and less vertices. In Experiment one, as the number of vertices increases the amount of visual information about the environment provided to the viewer also increases and thus perceived complexity may also increase.

Isovist Area and Number of Vertices in Relation to Previous Research

Overall, our findings modestly matched what has previously been shown by Wiener and colleagues (2007). Our correlations between isovist area and ratings of spaciousness, pleasantness, and beauty are in accordance with Wiener et al (2007). Although, these significant correlations were present, they were not nearly as strong as what was seen in Wiener et al. (2007), while their effects are classified as strong, many of the effects noted here are weak and moderate (Cohen, Cohen, West & Aiken, 2003). Indeed correlations between isovist area and the rating categories in Wiener et al. (2007) ranged from 0.65 to 0.80, much higher than what was seen in our study, with correlation coefficients ranging from 0.25 to 0.51. In addition our strongest correlation was between isovist area and spaciousness with an r value of 0.51, while in Wiener et al. (2007) the strongest correlation was that between isovist area and pleasantness with an r value of 0.80. Additionally, we also found a significant correlation between isovist area and ratings of clarity, which was not seen in Wiener et al. (2007). Such a relation seems reasonable as an environment with a larger isovist area could potentially be seen as more clear, if clarity is related to how obscured an individuals' view of their environment is. Thus, the lack of correlation between isovist area and clarity in Wiener et al. (2007) is surprising.

The correlations between number of vertices within a isovist polygon and ratings on the rating categories, once again, only modestly match those relationships noted by Wiener and colleagues. The finding that number of vertices positively correlates with ratings of interestingness and complexity supports the Wiener et al. (2007) findings, although the strength of the correlations once again differs dramatically. The correlations reported by Wiener et al. (2007) would be considered strong relationships possessing values of over .7. Wiener et al (2007) r-values of 0.81 and 0.78 for complexity and interestingness, respectively, are much greater than the r-values of 0.3 and 0.16 noted here. Interestingly, Wiener et al. (2007) also demonstrated correlations between number of vertices and the rating categories which were not demonstrated here, specifically a positive correlation between number of vertices and pleasantness ratings.

The lack of relationship between number of vertices and pleasantness ratings could be as a result of our environments and experimental design. The relation between complexity and pleasantness revolves around the notion that more complex environment provide more useful information to an organism and are thus found enjoyable and preferred. Thus the relation is explained within an ecological framework, since complexity provides information and this information is seen as providing a benefit to chances of survival. Within this experiment, since the environments were simple and participants were given two very straightforward tasks, perhaps this relation between complexity and pleasantness was not activated. Within a more ecologically valid, realistic environment the relation might be more likely. Although, Wiener et al (2007) employed simple, but realistic art-gallery environments, they might have been seen as more realistic and natural than our simple and unnatural environments.

The strength of the relationships between our variables could have potentially been influenced by the way our environments were created. The use of movable room dividers allowed us to easily and quickly create unique spaces, but each environment shared exterior walls, which were defined by the room within which we conducted the experiment. Additionally, the room-dividers did not rise all the way to the ceiling of the room, allowing participants to see the walls of the actual room. Finally, connecting the room dividers was also somewhat problematic since they small gaps were often left between individual dividers. Such concerns are not present in virtual reality studies, where much more control is present in regards to how the environment appears and is experienced. It is important to note that although our correlations were not as strong as what has been reported previously, many of the same predicted relationships were seen in Experiment one.

The results of this small-scale real-world isovist analysis suggest that isovist analysis might capture properties relevant for experience of real-world environments. This serves as a first step in possibly applying isovist analysis within the design process and explaining factors which drive experience. Participants were able to successfully find locations corresponding to the largest and smallest overviews within the environments. These locations correspond to positions within the environment which posses the largest and smallest isovist areas within the environment. Such findings support the notion that isovist properties (isovist area in particular) are perceptually relevant and perceptible by individuals within real-world environments. Many of the hypothesized relationships between isovist area and number of vertices with our rating categories, intending to capture experience of environment were seen. The next step in our research was to examine whether such relationships can be observed within complex, real-world environments. As researchers we often strive to create controlled environments where we vary only small aspects of the environment in order to answer very specific questions. Although such an approach is vital to the scientific process, for such findings to be applicable within architectural design we need to be aware that built-environments are not laboratory settings. In addition, by examining a complex real-world we might uncover other possible factors which may shape our experience of the built-environment. The visual properties of an environment, as captured by isovist analysis, do most likely shape experience, but they alone might not tell us the whole story. Thus, this study not only serves to examine the robustness of isovist analysis but also serves as an examination of other factors involved in experience of space.

1.3 Experiment Two

The goal of this study was to examine the relationship between isovist properties and experience within a complex real-world environment. In Experiment two we examined experience of the student centre at *The University of Toronto at Scarborough.* Such a space would provide us with a number of distinct spaces with naturally varying degrees of isovist properties. In addition, the multipurpose nature of the building would allow us to examine the robustness of the findings of Experiment one. Would isovist properties predict experience despite difference in building usage and programming of the various spaces within the building?

1.3.1 Method

The Building

The University of Toronto at Scarborough Student Centre was designed in close collaboration and paid for by the *University of Toronto Student Union*. The design was intended to have a "students first" approach and was intended 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 (Figure 5). It is located on the periphery of campus and serves as an entrance point to the rest of the campus (Figure 6).

Participants

A total of 61 participants participated in the study (male = 18, female = 43); average age was 20.91 years. Experimenters set-up a table explaining the purpose of the study in the student centre, and participants were recruited as they passed through the building. Participants received a Tim Horton's gift card, values at $5.00, for their participation in the study, which lasted approximately 30 minutes. On average, participants had 2.79 (SD=1.61) years of experience with the building and rated their familiarity with the building a 7.8 (SD=1.5) on a ten point scale, where ten represents extremely familiar. In regards to building usage, participants used the facilities in the building approximately 5.02 (SD=5.02) times a week, and simply passed through the building without using the facilities or spaces in the building approximately 9.3 (SD=6.17) times a week.

Figure 5.

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.

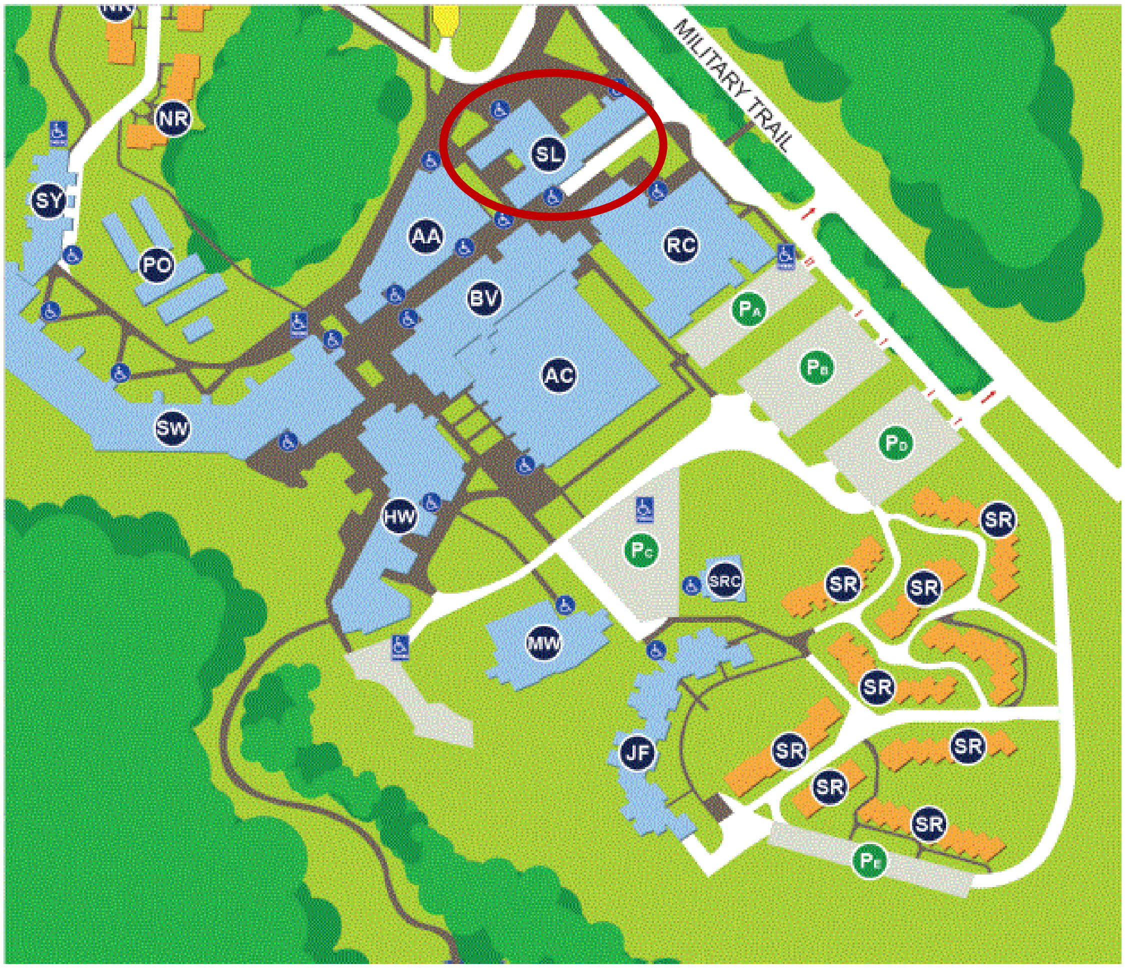


Figure 6.

Location of the student centre on campus is show above, circled in red and labeled *SL*. It is evident that the student centre is positioned on the periphery of campus and in close proximity to the main road leading into campus, *Military Trail*. Bus stops are also located directly outside the student centre. In this way, the student centre serves as an entry point to the rest of campus.

Materials, Isovist Analysis and Data Collection

A questionnaire consisting of numerous questions in regards 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 one was also administered. Here the rating categories included the original six presented in Experiment one 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 number of 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 an individual was standing in a particular location and looking into these areas of interest. By selecting areas of interest in this manner, we hoped to recreate isovists and views which would be experienced during typical usage of the student centre. The areas of interest along with the isovist generated from each can be seen in Figure 7.

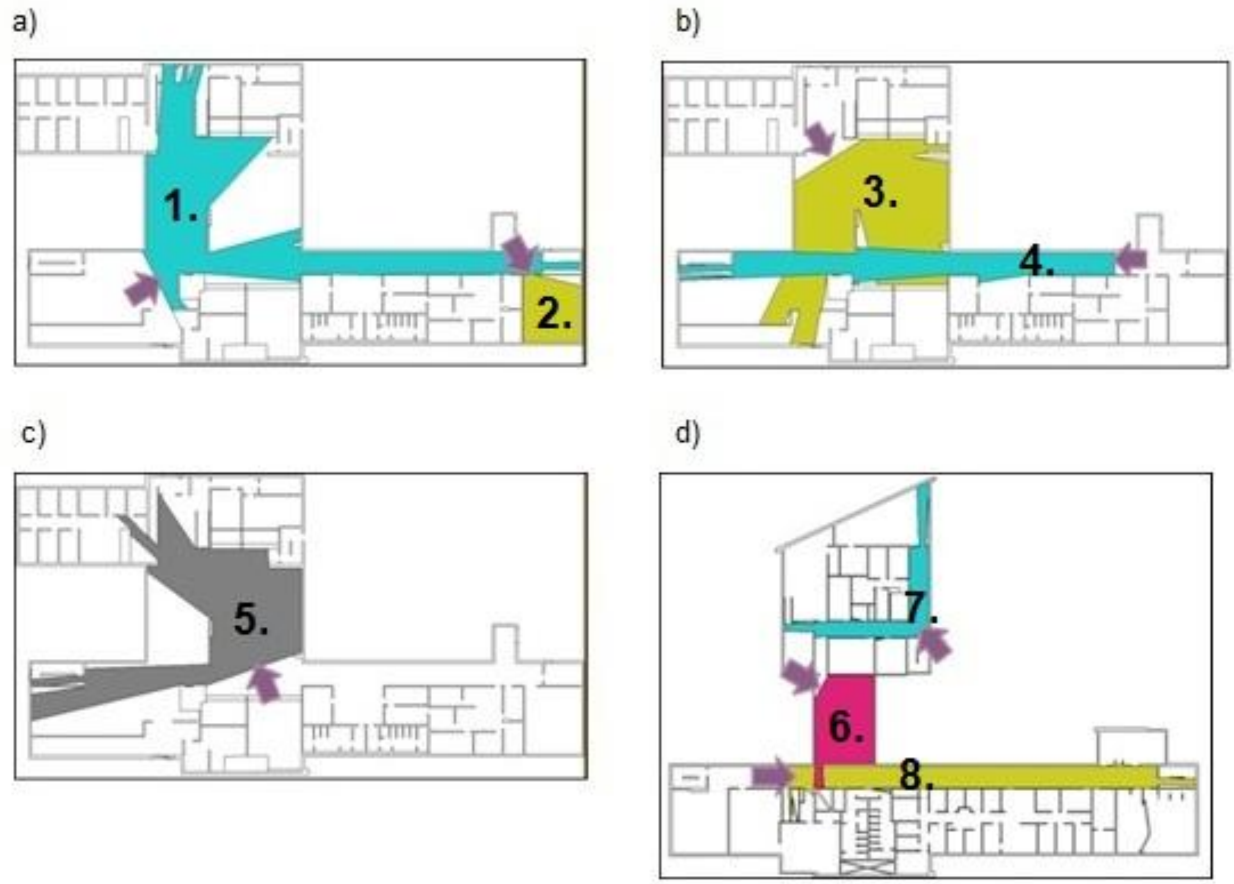


Figure 7.

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. Notice 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 by students. The presence of other individuals could potential influence how the space would be perceived. In order to examine such a possibility, we measured frequency of behaviours within each of the area of interest in the building.(Appendix A). 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 behaviour were recorded, but this was later collapsed into three categories based on the nature of behaviour; social behaviours, independent behaviours 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. In this way it was hoped that all participants would be positioned in the same location and would have the same viewpoint in each of the areas 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 one. Due to time constraints the order in which the areas of interest were entered and rated was not randomized but instead was done in a manner which made the most logistical sense in regards to the proximity of locations to one another within the building. Following completion of the semantic differential task at each of the areas of interest, participants were given a $5 Tim Horton's gift card and provided with a debriefing form.

While participants were led through the student centre to perform the semantic differential task, another experimenter performed behavioural mapping for each of the areas of interest. Behavioural mapping consisted of entering the areas of interest and recording the frequency of certain behaviours and activities. These behaviours and activities were later organized and collapsed into categories of social types of behaviour and independent types of behaviour based on the nature of the activity.(Appendix A). Total number of individuals within the areas was also recorded. As stated above, behavioural mapping occurred very close in time to the semantic differential task in an effort to capture the behaviours occurring within the areas of interest while the semantic differential task was being completed. These measures would allow us to consider the presence and behaviour of other individuals during statistical analysis, thus allowing for a more accurate examination of the relationship between isovist properties and experience.

1.3.2 Results

Partial correlations were calculated examining the relationship between isovist properties and ratings on the semantic differential task while removing variation due to participants, in the same manner as described in Experiment one. We also attempted to controlled for a number of factors including number of years the participant has used the building, how often 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 partialing-out both the number of individuals engaged in social and independent tasks during the task. Isovist area was significantly positively correlated with ratings of spaciousness (r (382)= .28, $p < .01$), clarity (r(382) = .13, $p < .05$), complexity (r(382) = .12, $p < .05$), and sociability (r(382) = .12, $p < .05$. Isovist area did not significantly correlate with ratings of pleasantness (r(382) = .05, p = .41) nor beauty (r(382) = -.06, p = .27). Number of vertices was negatively correlate with ratings of sociability (r(382) = -.18, $p < .01$). Correlations between number of vertices and complexity (r(382) = .01, p = .9), pleasantness (r(382) = -.08, p = .15), and interestingness (r(382) = .04, p = .47) were not significant.

Linear regression analysis was performed in an effort to understand what role, if any, properties other than the physical features of the environment (as captured by isovist properties) might play in shaping ratings on the semantic differential task. Linear regression was done so that each semantic differential category served as a dependent variable. Three blocks of independent variables were added. Block one featured individuals' previous experience with the building as captured by 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 two 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 three featured our isovist properties of isovist area and number of vertices. Table 1 summarizes the results. 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 ($R^2 = .261$, $F(9,374) = 14.692$, $p < .01$), with weekly passage through the building ($\beta = -.128$, $p < .01$), total amount of people present in the space ($\beta = 2.957$, $p < .01$), social behaviour observed in the space (β = -1.551, $p = .033$), independent behaviour observed in the space (β = -1.598, $p < .01$), isovist area (β = .215, $p = .037$) and number of vertices (β = -.236, $p = .012$) all significantly describing rated sociability. On the other hand, while still significant, pleasantness was least strongly predicted by the model ($R^2 = .052$, $F(9,365) = 2.265$, $p = .018$) with only usage per week significantly describing ratings (β = -.166, $p < .01$). When we consider our two most important variables spaciousness and complexity, we see that the model significantly captures ratings of both. For spaciousness ($R^2 = .094$, $F(9,372) = 4.290$, $p < .01$) both isovist area (β = .583, $p < .01$) and number of vertices (β = -.557, $p < .01$) all predicted ratings. While for complexity ($R^2 = 0.098$, $F(9,374) = 4.514$, $p < .01$), both weekly usage (β = -.122, $p = .019$) and isovist area (β = .226, $p = .048$) predicted ratings. Full results of the regression analysis can be seen in Table 1.

	Pleasant		Beauty		Interest		Complex		Clear		Spacious		Sociable	
	β	t	β	t	β	t	β	t	β	t	β	t	β	t
Years[a]			.187	3.34*	.113	2.04*								
Usage[b]	-.166	-3.13*	-.128	-2.48			-.122	-2.36	-.108	-2.09	-.136	-2.63*		
Passage[c]													-.128	-2.87*
Familiar[d]			-.179	-3.11*	-.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]							.226	1.99	.231	2.04	.583	5.12*	.215	2.09
N. Ver[i]									-.291	-2.82	-.557	-5.38*	-.236	-2.52*
Model F	2.265**		4.64**		5.51**		4.514 **		4.77**		4.29**		14.69**	
Model R^2	.052		.100		.117		.098		.103		.094		.261	

Notes.
All t-values are significant at p<.05, those marked with * are significant at p<.01.
Standardized beta 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 the semantic differential task was being administered.
h. Isovist area generated from given observation point
i. Number of vertices within the isovist polygon generated from given observation point

Table 1.

Linear regression demonstrates that a number of variables predicted various rating categories. Although, the isovist properties of isovist area and 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 .261 for ratings of sociability.

1.3.3 Experiment Two Discussion

Complex Real-World Environment and Isovist Area

Here we examined if isovist analysis could capture experience of a complex, real-world environment. Some of the results appear to match what was observed in Experiment one, 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 does the experience of clarity and spaciousness. This result is in accordance with Experiment one. Surprisingly, a positive relation was also found between complexity and isovist area, such a finding was not expected and does not appear in study one 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, perhaps areas with larger isovists also featured an overall greater degree of perceptual complexity in the form of furniture, decorations and other design features. 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. It seems reasonable to assume that as the isovist area increased so would the amount of visual complexity present from the viewpoint.

In addition, isovist area did not seem to have a positive influence on rating of pleasantness, beauty, nor interestingness. This lack of influence is not only contradictory to what study one demonstrated but appears to go directly against many theories of environmental preference. Both Kaplan and Kaplan (1989), along with Appleton (1975) suggest that the larger overviews and vistas will be preferred and seen as positive as they allow for acquisition of information in regards to ones environment. Clearly isovist area captures the visible space from a given observation point, yet in this study, this property does not appear to influence positive experience of a real-world environment. Such a discrepancy could potentially be due to the difficulties with real-world testing. Although we tried to take into account previous experiences with the space and the presence of other individuals, our methods were limited in their effectiveness to capture such factors. Such differences between controlled laboratory studies and real-world environments might be problematic, and are discussed in more detail within the general discussion.

Complex Real-World Environment and Number of Vertices

Within the University of Toronto Student Centre it appears as if the correlations found between number of vertices and experience of the space diverged greatly from what was previously seen in controlled laboratory settings. Previous work led us to believe that number of vertices would correlate positively with complexity. Yet, here the relation between the two was absent. Saying this, relationships between number of vertices and other rating categories were found which, in themselves, could relate indirectly to complexity. If number of vertices captures complexity, then the negative relationships between it and clarity, spaciousness and sociability seem justified; as complexity increases, the environment could potentially be seen as less clear, spacious and sociable. This suggestion assumes that, from viewpoints of environments with similar isovist area, complexity might negatively influence experience of spaciousness, clarity and sociability. For such a statement to be definitive, further examination between perceived complexity and clarity, spaciousness and sociability needs to be conducted. Generally, these results bring into question whether number of vertices truly capture the experience of complexity within a real-world environment.

Generally it appears as if isovist area relates in a positive manner to both spaciousness and clarity. Pleasantness, beauty and interestingness ratings, on the other hand, do not appear to be related to isovist properties as reliably. Where correlations with these properties is seen in Experiment one, they do not hold for Experiment two. Within complex environments it is possible that isovist properties might relate more strongly to our perceptions of the physical properties of a space (clarity, spaciousness) than its aesthetic properties (pleasantness, beauty, interestingness). The regression analysis presented here does appear to support such a notion. Both ratings of clarity and spaciousness are significantly predicted by both isovist area and number of vertices, while pleasantness, beauty and interestingness are not. Experiment one did show that isovist analysis might aesthetic ratings, but this may only be the case in less complex and very controlled environments. In a much more complex real-world environment, isovist analysis may be less capable in capturing aesthetic experiences.

Perception of the physical properties of space would be more closely related to low-level visual processes, whereas aesthetic judgements might be more strongly influenced by individual differences in preference. Indeed previous research does suggest that aesthetic judgements vary greatly between individuals (Sevenant & Antrop, 2010). Interestingly, such differences may also be attributed to perception and aesthetic evaluation of complex stimuli (O'Hare, 1976). Although in Experiment one we found significant correlations between isovist properties and aesthetic judgements, this might have been because the pared-down spaces of Experiment one, lacking in the human activity and surface details seen in a real lived space, were more immune to the influence of individual variability in aesthetic judgement.

In Experiment two it appears as if number of vertices does not relate to any aspect of the experience of space. In Experiment one it captured both interestingness and complexity, finding which we were unable to recreate in complex real-world environment. This could be due to several reasons. As discussed previously complex environment have a variety of location and factors which may drive experience. It is possible that wall decorations, furnishing and other factors were related to complexity above and beyond the contribution of number of vertices. Number of vertices may capture complexity within simple, empty environments, such as those in Experiment one but may fail to do so within real world environments. This finding brings into the question how robust the relation between number of vertices and complexity, interestingness and pleasantness may be, and also suggests that its application to real-world environment is limited. In the Experiment one discussion section, it was suggested that the lack of relation between number of vertices and pleasantness could be due to the fact that laboratory environment are sterile and not ecologically valid. Within Experiment two ecological validity was not an issue, instead it appears that number of vertices does not relate to pleasantness. These findings suggest that number of vertices does not appear to be applicable to real and natural interactions with the built-environment.

Complex, Dynamic Environments

The University of Toronto at Scarborough Student Centre is a large and dynamic building, and although we attempted to control for a number of factors such as previous usage and experience with the building and the presence and behaviour of other individuals within the building our ability to measure such complexities was limited. The regression analysis does support the notion that a large number of properties, other than visual features of the space, influence experience of the building. Indeed both previous experience and the presence of other individuals seems to predict ratings on the semantic differential task. Interestingly, for some rating categories such as pleasantness, beauty and interestingness, isovist properties did not significantly influence the ratings. Other categories, such as sociability, were influenced by all three groups of factors; previous experience, presence of other individuals and isovist properties. Although, the regression model provided some insight, it only explained a small amount of variance within the dependent variables. Indeed, the best fitting model, describing ratings of sociability, only described 26.1% of variance within the ratings, while the next highest, interestingness only described 11.7% of variance within the ratings. This would lead us to believe that, although we tried to control for a number of factors, numerous factors which may influence ratings were not measured. It appears that experience of complex real-world environments cannot be fully described by the visual features of the space (as captured by isovist analysis) nor by other factors such as previous usage and presence of other agents within the space.

1.4 General Discussion

The aim of this research was to examine the extent to which visual properties of space shape experience of environment. In particular, across two experiments it was examined whether isovist properties explained experience of both a small scale controlled and a complex real-world environment. Previous empirical studies (Meilinger, Franz & Bülthoff, 2012; Wiener & Mallot, 2003; Janzen et al., 2000), lead us to believe that the physical and visual elements of a space would influence how the space experienced. Isovist analysis is seen as a useful technique as it allows for the quantification of the visual and spatial properties of built-environments. This is important as many studies examining scene and environmental preference failed to systematically describe the environment and instead employ qualitative descriptors (Kaplan, Kaplan, & Wendt, 1972). Isovist analysis has been suggested as a possible method by which to quantify the visual elements of an environment (Wiener, Franz, Rossmanith, Reichelt, Mallot &

Bülthoff, 2007). Results of studies employing virtual reality environments seems quite promising, suggesting that isovist analysis could accurately describe experience of the built-environment (Wiener, Franz, Rossmanith, Reichelt, Mallot & Bülthoff, 2007; Stamps, 2009). The experiments described here attempt to examine the robustness of such findings by exploring the relationship between isovist properties and experience of both small scale controlled real-world environments and large scale complex real-world environments.

Isovist Area

Overall the results of the two experiments presented here are quite complex and bring forth some interesting findings as well as intriguing questions for future examination. Hypothesis 1a stated that isovist area should be positively correlated with ratings of spaciousness and clarity. This was perhaps the most robust finding isovist area did seem to consistently explain experience of spaciousness and clarity, regardless of the environment type. In both Experiment one and two, along with previous studies (Wiener, Franz, Rossmanith, Reichelt, Mallot & Bülthoff, 2007; Stamps, 2009) isovist area correlated with both ratings of spaciousness and clarity. So that as isovist area increased so did perceived spaciousness of the environment.

In hypothesis 1b isovist areas also predicted as possibly capturing experience of pleasantness, beauty and perhaps interestingness in accordance with virtual reality research (Wiener, Franz, Rossmanith, Reichelt, Mallot & Bülthoff, 2007; Stamps, 2009). Such findings would also be predicted by the prospect and refuge theory (Appleton, 1975) along with the Kaplans' work on environmental preference (Kaplan & Kaplan, 1989). The basic argument here is 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 analog of visible space from an observation point, one which can be applied to describe a wide range of built environments. The results of Experiment one, were quite encouraging as isovist area did seem to be related to ratings of pleasantness, beauty and interestingness. Unfortunately, these relationships do not seem to hold when examining complex real-world environments as seen in Experiment two. It is possible that within complex real-world environments, many other factors play a role in shaping experience. Previous research examining the relationship between visibility, including isovist area and pleasantness employed either natural or controlled virtual environments. Within these small-scale, controlled environments, the number of factors which may influence aesthetic appraisals is limited and thus influenced strongly by isovist properties. Within complex, urban environments, the presence of furnishing, wall decorations and other factors may overcome the influence of visibility and isovist area.

Number of Vertices

Hypothesis 2a stated that number of vertices would capture experience of complexity, so that as number of vertices increased so would ratings of complexity. The visual complexity of a stimulus is often said to be captured by the amount of density of features present within the stimulus (Willis & Dornbush, 1968; Berlyne, 1954). Indeed previous research does suggest that as the number of visual features within a scene increases so does perceived complexity (Berlyne, 1970). Number of vertices is employed as a possible way to describe the complexity of the built-environment, as any point where two points of isovist polygon meet can be considered a visual feature within the environment. In this way, as the number of vertices increases within an environment it seems likely that the perceived complexity should also increase; indeed this finding has been shown in virtual reality environments (Wiener, Franz, Rossmanith, Reichelt, Mallot & Bülthoff, 2007). Similarly to isovist area, Experiment one matched our hypothesis regarding the relation between number of vertices and complexity, while Experiment two failed to do so. The differences discovered here between experiment and one and two, both for isovist area and number of vertices can be reconciled in several ways, such differences may also illuminate some important concepts and ideas.

Possible Explanations for Discrepancies Between Experiment one and Experiment two

Some of the noted differences between experiments one and two and also between our findings and those found in previous virtual reality research could be due to the inherent difference present between methodologies. Controlled laboratory environments (such as the ones we used in Experiment one) and virtual reality environments allows researchers to create very specific and controlled environments. Such stimuli can be used to pin-point and elucidate the basic visual properties which may be relevant to experience of environment. The discrepancy between our experiments could be due to several major differences between lab controlled experiments and the real-world. Firstly, lab 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 environment is experienced (Machleit, Eroglu & Powell Mantel, 2000; Nagar & Pandey, 1987). Secondly, in the laboratory the spaces which the individuals are exposed to are typically novel; participants do not have previous experiences with the environment. In the real world you will only enter a new environment once, from that point on you will start to build memory representations in regards to the environment. All future interactions with the building will be grounded in these previous experiences and memories, whether they be negative or positive. This was seen in the regression analysis conducted in Experiment two, as previous usage and familiarity influenced ratings. Finally, lab studies typically employ environments which are devoid of true function, they are blank empty spaces which do not serve a purpose of function. In the unlikely situation that an experimental environment is assigned a function, the function is typically very simple and exploratory in nature such as the function of an art gallery. Even here such an "art gallery" function could be said as being very unrealistic and not very relevant or related to the function of real world environments.

These differences suggest that experience of real-world built-environment is complex and influenced by a number of factors. It also brings into question the significance and robustness of previous findings on isovist analysis and environmental preference research. If, as suggested in Experiment two, isovist analysis cannot explain aesthetic appraisals and preference, it becomes limited in its applicability.

Beyond Isovist Analysis: Visibility Graph Analysis as a Global Measure

Although isovist analysis appears to be useful in analysis of small scale environments, it could be developed so as to more completely describe large-scale environment. Isovist analysis describes experience of space from a solitary viewpoint within the environment, thus it is said as capturing the local properties of the environment (Turner & Penn, 1999). Although, this can at times be beneficial it is also problematic since isovists disregard the global properties of the environment, and how the current viewpoint is related to other points within the environment. Turner, Doxa, O'Sulliven and Penn (2001), devised a method by which isovists could be employed to describe the global properties of an environment. They construct a grid comprised of evenly spaced out points onto the environment; each point on this graph is considered a node.

Mutual visibility between the nodes is calculated; which nodes can be seen or accessed from each particular node and which nodes can see or access that node itself. Simply put this method is similar to generating a number of unique isovists from evenly spaced-out unique locations and then examining the relationships between these isovists. This extension of isovist analysis was termed visibility graph analysis and the properties which it generates have been shown to correlate with observed navigation behaviour in large scale built environment (Turner & Penn, 1999), which is generally thought to be dependent on the global properties of the environment (Hillier & Hanson, 1984). By extending visibility graph analysis to environments described here it might be possible to more fully examine the environment. This appears to be of particular interest for environments such as the one used in Experiment two; large environments where global features might more readily influence experience.

1.5 Conclusion

In reality would we expect the visual properties and physical features alone to predict experience of the built-environment? We know that there is something unique about the perception of built-enclosed spaces (Epstein & Kanwisher, 1998), and that visual features shape preference and usage of built-environments (Meilinger, Franz & Bülthoff, 2012; Wiener & Mallot, 2003), it is unlikely that they can tell us the whole story. This does not necessarily mean that isovist analysis does not accurately capture visual features of an environment. Indeed the results here, especially in Experiment one, suggest that isovist analysis may describe certain responses towards the built-environment. It only suggests that answers to such questions as, what factors influence an individual's experience of a building, are very complex. Although, here we discuss isovist analysis as a way in which to capture visual properties, 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 more advanced statistical methods, such as path analysis, examine the relative contributions of each factor on experience.

Built-environments are dynamic and complex and far from the simple laboratory environments often employed by researchers. Despite this, the findings presented here seem to suggest that, for certain environments and experiences, isovist analysis might allow us to predict how the space is experienced. Isovist analysis could potentially be used as tool by architects and design professionals to predict how a yet to be completed building will be experienced. Although, tools such as computer assisted design, allow architects to realistically and completely model their designs, they do not allow them to predict how the environment will be experienced. Clearly visual and spatial properties of a buildings are modified by architects in order to influence experience, and isovist analysis may be a robust and reliable way by which to quantify these properties and explain experience.

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Appendix A

	Session 1					Session 2					Session 3					Session 4					Session 5					Session 6				
	TV	Caf	Up	Ra	Lo	TV	Caf	Up	Ra	Lo	TV	Caf	Up	Ra	Lo	TV	Caf	Up	Ra	Lo	TV	Caf	Up	Ra	Lo	T	C	2	R	
TIME-------→																														
BEHAVIOUR																														
Sitting alone, inactive																														
Sitting talking, with friend																														
Eating alone																														
Eating with friend																														
Looking at computer																														
Looking at computer w.fr																														
Studying, alone																														
Studying with, friend																														
Reading book																														
Taking notes																														
Playing video game																														
Waiting for bus																														
Waiting in line/buying																														
Napping																														
W/ Significant other																														
Talking on phone																														
Other Active																														
Walking																														
Texting																														
Meeting rm																														