Article

Urban Analytics and City Science

EPB: Urban Analytics and City Science
0(0) 1–15

DOI: 10.1177/2399808320916768
journals.sagepub.com/home/epb
SAGE

Isovist indicators as a means to relieve pedestrian psycho-physiological stress in Hong Kong

Luyao Xiang
The Chinese University of Hong Kong, Hong Kong

Georgios Papastefanou
GESIS Leibniz Institute for the Social Sciences, Germany

Edward Ng
The Chinese University of Hong Kong, Hong Kong

Abstract

The creation of a psychologically friendly outdoor environment has important quality-of-life implications for urban residents who live in cities with extremely high population density, such as Hong Kong. Prospect Refuge Theory is the most widely recognized theory that explains environmental emotional influence by referring to urban planning and architecture, and it can be quantified by applying isovist indicators. We aim to (a) conduct field measurements that record dynamic psycho-physiological stress, (b) calculate isovist indicators by introducing a new indicator-isovist time difference and then analyse their effects on stress, and (c) draw on findings to provide recommendations for urban planning and design. The experiment is conducted for the first time in a high-density city where 30 participants are asked to walk a predefined route. Each participant wears a portable smart band that records skin conductance response and a global positioning system (GPS) that records geographic coordinates. The results demonstrate that (1) an open space with a visual target set at a distance is the dominant factor that creates positive emotions in Hong Kong; (2) the new indicator-isovist time difference (D1) is valuable, as it is more significantly related to stress than the isovist level; (3) the living environment and cultural differences play an important role in the final result, i.e. people in Europe prefer relatively closed spaces while people in Hong Kong feel stress when the space is highly enclosed.

Corresponding author:
Luyao Xiang, Chinese University of Hong Kong, Rm 505, AIT Building, The Chinese University of Hong Kong, Shatin, NT, Hong Kong.
Email: XIANG.Luyao@link.cuhk.edu.hk

Keywords
Isovist, outdoor environment, Prospect Refuge Theory, real-time measurement, skin conductance response

Introduction

Good mental health influences mental and psychological well-being. A growing body of research (Kennedy and Adolphs, 2011; Lederbogen et al., 2011; Schroeder, 1942; Douglas, 2012; Abbott, 2011; Weich, 2002) suggests that city living is likely to adversely affect mental health. This insight should be understood in the wider context of the World Health Organisation's observation that depression will become the second leading cause of worldwide overall disability by 2020 and the largest contributor to disease burden in 2030 (WHO, 2012).

A large number of studies (e.g. Bratman et al., 2015; Chen et al., 2016; Lee et al., 2009; Pretty et al., 2005; Roe and Aspinall, 2011) have compared the relative impact of city and natural landscapes and concluded that the latter positively affects psychological well-being and can relieve stress in many respects. Several papers have assessed specific types of landscape (Herzog and Chernick, 2000; Parsons et al., 1998; Ulrich, 1981; Van den Berg et al., 2003) and established subcategories for natural and urban environments, which include commercial and industrial areas, forests, golf courses and scenes with different levels of openness. These studies divide physical environments into several types. Urban planners need more information to design a psychologically friendly city.

Prospect Refuge Theory, which emphasizes the visual impact of the environment on emotional response, is the most authoritative theory that can be used to construct an evaluation of environmental emotional response and stress. Isovist analysis, meanwhile, is an effective method for quantifying the physical environment. Knöll et al. (2018) refer to a set of isovist characteristics (i.e. perimeter, number of vertices, visibility) that provide the best predictor of perceived stress (explaining 37% of the total sum of the standardized beta coefficient), and which is superior (in this respect) to built environmental factors such as building density, open space typology and street networks. Visibility (i.e. isovist area) is found to be positively related to pedestrian stress ratings when compared to an isovist that is typical of several open public spaces (OPSs) (i.e. parks, squares and streets); however, it is negatively related when the study was focused on one OPS, such as a busy transport hub (Halblaub Miranda and Knöll, 2017; Knöll et al., 2019). Dosen and Ostwald (2016) investigated if human perception of a simple space directly correlates with isovist measures while Franz and Wiener (2008) used isovist indicators to quantify environmental configurations and test theories of behavioural and emotional response to environments. The isovist indicators in these studies remain static, which may ignore the effects of isovist transformation. We, therefore, introduce the isovist time difference (D1), which is a new indicator, into the analytical process.

People are able to report their perceived stress. However, psycho-physiological stress is driven and balanced by the autonomic nervous system, which people cannot control or perceive. Emotional experiences can be described by referring to valence and arousal. Valence is positive or negative affectivity, whereas arousal measures how calming or exciting information is. Electroencephalography (EEG), electromyography, functional magnetic resonance imaging and skin conductive response (SCR) are frequently used to evaluate emotional state. Aspinall et al. (2014) used EEG to record and analyse the emotional experience of pedestrians in different urban contexts. SCR is related to arousal, and it can be directly measured by the activity of palm sweat glands. It is, however, difficult to distinguish positive and negative states by referring only to SCR data. The BodyMonitor team has conducted laboratory research and identified typical combinations of responses when subjects watched positive or negative events (Papastefanou, 2013). Some experiments have also been conducted in different climate zones (Li et al., 2016; Schrenk et al., 2012) and applied the smart band provided by BodyMonitor. The current project, which focuses on analysing isovist indicators and SCR, is the first to be conducted in Hong Kong. Participants ($n = 30$) are asked to walk a predefined route in Hong Kong's city centre, while SCR and GPS data are continuously recorded. The entire project lasted for one month. After the data were collected, a logistic regression analysis was applied to explore the relationship between isovist indicators and emotional response.

Theoretical approaches

Responding to the visual perception of environment

Prospect Refuge Theory. Appleton (1975) first discovered this theory while researching landscape preferences. It suggests that humans naturally feel safe and content in an environment that provides views and a sense of enclosure. In being applied to design, it can be combined with Berlyne's (1951) arousal theory, which suggests increased pleasure is experienced when a space or scene with a certain degree of uncertainty or novelty is encountered. De Long (1994) provides the first and most frequently cited architectural application of this theory, which proposes that the emotional response to Frank Lloyd Wright's architectural elements forms the symbols of prospect and refuge.

Components of the Prospect Refuge Theory. This theory consists of four main components:

- *Prospect* is a key aspect of the theory, which indicates a clear field of vision. Those with a large field of vision are better-placed to detect possible enemies than counterparts with limited vision. Prospect relates to the depth of the perspective, geometric features of the isovist area, maximum radial line length, openness, perceptual outlook features and spaciousness.
- *Refuge* is also a key aspect. It represents a space, which must be partially enclosed and should provide a safe hiding place in a dangerous situation. It relates to the perceptual features of enclosure and safety, and also to the spatial visual geometric features of occlusion and minimum radial length.
- *Complexity* refers to the amount of information contained in a space, along with the number of occluding edges (or vertices) and the jaggedness of its geometry.
- *Mystery* sense is associated with the lack of available information about a place and its intelligibility. It relates to drifting between spaces, changing luminosity and the degree of occlusivity.

Quantification of geometric visual perception: Isovist indicators

Traditional isovist indicators. Davis and Benedikt (1979) define isovist as 'the set of all points visible from a given vantage point in space'. Benedikt's method identifies six geometric measures: area, perimeter, occlusivity, compactness, jaggedness and the variance and skewness of the radial distances of each observation point.

The isovist area determines the polygon area.

The isovist perimeter is the total length of the boundary.

Occlusivity refers to the total length of all occluded edges, which are the undefined parts of building surfaces, i.e. the unclear or ill-defined parts, which can be expressed as follows

$$Occlusivity = P - P_f \tag{1}$$

where P is the isovist perimeter and P_f is the overall length of the solid boundaries within the isovist area (S).

Compactness describes the compact and simple degree of the visual area and can be expressed as

$$Compactness = 1 - \frac{2\sqrt{\pi S}}{P} \tag{2}$$

Jaggedness describes the complexity of the polygon based on the number of vertices and the vertex density as follows

$$Jaggedness = \frac{P^2}{S} \tag{3}$$

The *variance and skewness* of the radial distance are measured through the *maximum/minimum radial line*, and the length of the longest/shortest single radial line is used to generate this isovist indicator. The length of radial lines represents the visible distance (Dawes and Ostwald, 2014).

The *drift magnitude* is the distance between the observation point and the mass centre of an isovist polygon.

The *drift angle* refers to the angle between the (direction facing) occupant and the mass centre of an isovist polygon.

A new indicator: Isovist time difference (D1). A large number of studies demonstrate the strong relationship between isovist indicator levels and emotional response. An isovist change during the experience process has not yet been reported. Change of this kind relates to the memory of walking on a street; over time, memories that arouse a stimulus level will either remain constant or increase (Baddeley, 1982; Kleinsmith and Kaplan, 1963; LaBar and Phelps, 1998). A consideration of the time *difference in isovist* (D1) across several seconds will contribute new insights. In acknowledging that information is stored for approximately 18–30 seconds in short-term memory, we apply 20 metres (around 20 seconds) when calculating the isovist difference as follows

$$Isovist\ time\ difference\ (\mathrm{D1}) = Isovist\ (\mathrm{A}) - Isovist\ (\mathrm{B}) \tag{4}$$

where Isovist (A) and Isovist (B) represent the level of an isovist indicator (e.g. isovist area, occlusivity, compactness, etc.) at points A and B (A and B is a 20-metre interval).

Overview and research questions

Different studies confirm that an urban environment can impose various burdens on mental health. Prospect Refuge Theory is one of the theories used to interpret this impact. Some researchers seek to quantify the environment by using isovist indicators to connect the environment with Prospect Refuge Theory. Previous studies (Franz and Wiener, 2008; Knöll et al., 2017; Stamps, 2005) have identified that isovist area, maximum radial line and occlusivity will negatively impact the possibility of generating negative emotions, while other measures will have a positive impact as indicated in Table 1.

Participants walk on a predefined route in Hong Kong's city centre, while SCR and GPS data are continually recorded. The following logistic regression analysis takes isovist indicators and the isovist time differences (D1) as independent variables, whereas the change situation of emotional response is the dependent variable.

The following questions are addressed:

1. Which isovist parameters affect (negative/positive) physiological arousal in a high-density city?
2. Landscapes change at every moment of the walking period. Will these changes cause negative or positive physiological arousal?
3. Will the results of the high-density city experiment differ from those obtained by previous studies conducted in Europe?

Materials and method

Experimental design

The Chinese participants (n = 30, mean age = 24.77 years, age SD = 0.718) have lived in Hong Kong for less than three years. Although relatively familiar with Hong Kong's living environment, they are still curious about the experimental route. They do not have a history of severe mental illness, show no symptoms of systemic sweating (secondary) and have not had any accidents in the preceding months.

The predefined walking route runs through Tsim Sha Tsui, which is a famous commercial centre with large shopping malls and retail stores. The walking route has four roads, specifically Haiphong, Hankow, Nathan and Peking. Examples of the route are shown in Figure 1.

On each experimental day, two to four participants were individually asked to walk on the predefined city route around mid-afternoon, and they were requested to continuously observe the surroundings while walking. The city route has four corners and participants were required to stop walking at each one and experience the streetscape for 10 seconds.

Table 1. Prospect refuge components and isovist indicators.

Spatio-cognitive components	Perceptual property	Corresponding isovist indicators	Emotional response possibility
Prospect	Spaciousness, openness	Isovist area	Positive
		Isovist maximum radial line length	Positive
Refuge	Enclosure, safety	Occlusivity	Positive
Mystery	Intelligibility of information	Occlusivity	Positive
	Luminosity	Isovist time difference (D1)	Negative
	Drift between space		
Complexity	Volume of information	Number of including edges	Negative
		Jaggedness	Negative
		1/Compactness	Negative

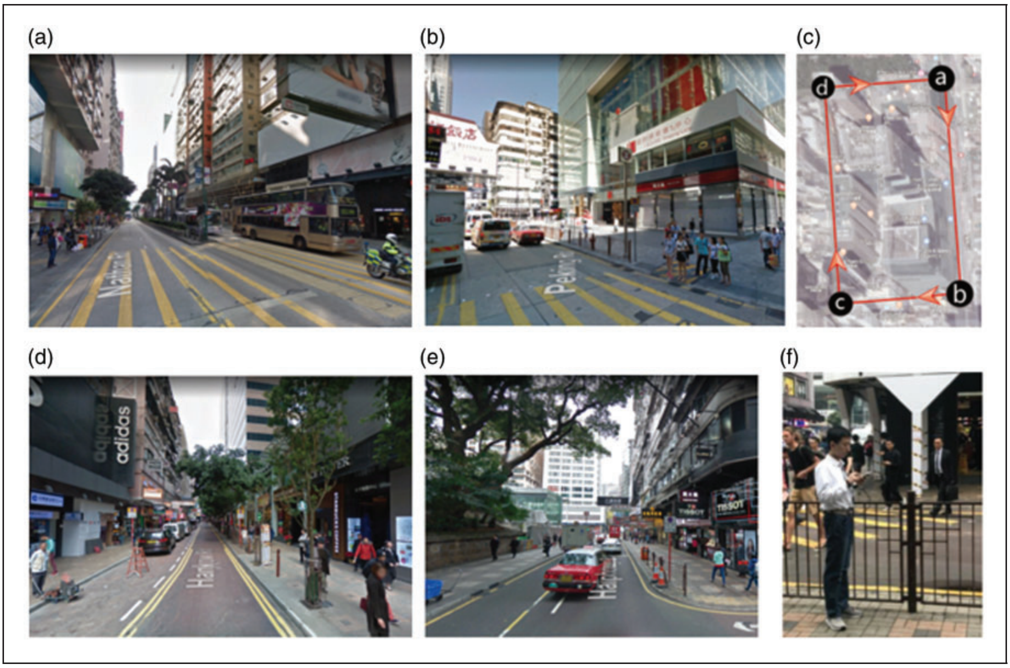

Figure 1. Street views of each section route. (a) View from point a to b: The four-lane main street has high-rise buildings on both sides; (b) view from point b to c: The mall's entrance plaza has buildings on both sides; (c) the walking route: Participants began at point a and walked in a clockwise direction; (d) view from point c to d: The single lane street with retails on both sides; (e) view from point d to a: The double-lane median street that has retail stores on one side and large trees on the other; (f) subject in the experiment.

This was to establish an initial impression of the streetscape before experiencing it, to prevent numbness from walking and to allow the participants to immerse themselves in their surroundings.

Equipment used in the study

The smart band for measuring SCR. The smart band is made by the BodyMonitor Company, and it has been developed by the GESIS – Leibniz Institute for the Social Sciences. Its validity is confirmed in experimental research (Papastefanou, 2013) and several field studies (Hijazi et al., 2016; Hogertz, 2010; Steinitz et al., 2014; Taha et al., 2012). The band sensor captures skin conductivity and skin temperature at a rate of 10 Hertz. Equipment is applied in accordance with the theoretical approach of basic emotion theorists (Ekman, 1992; Levenson, 2003), who ascribe a specific physiological arousal to specific emotional responses. The outcome includes binary data (i.e. 0 for no response and 1 for a response) that applies to every moment during measurement. The BodyMonitor's algorithm provides a function that makes it possible to sort emotions into balance, positive, negative and retraction (Hijazi et al., 2016). In this study, we only analysed positive and negative responses.

The GPS antenna for recording geographic coordinates. In addition to the smart band, a GPS antenna was placed on each participant's shoulder to capture the geographic coordinates (1 time/s) with sub-meter accuracy, utilizing the EGNOS satellite correction as well as a bipolar antenna to reduce multipath signal bias. After collecting the geographic-coordinates

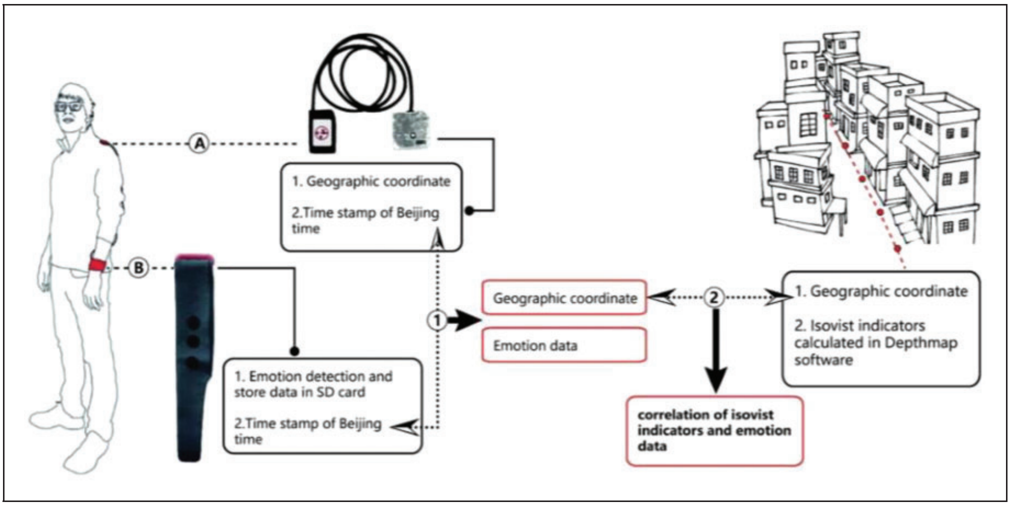

Figure 2. Diagram of the portable experimental equipment. Each subject wears a GPS receiver (with active GPS antenna) and a BodyMonitor smart band (that records skin conductivity). Both items record the time stamp of Beijing at the same time, and we therefore assigned the emotional data to the geographic coordinate and built a relationship between emotional data and isovist indicators through the geographic coordinate.

data, we could assign SCR data to the corresponding coordinate through the time stamp data. The data collection process and equipment used to collect the data are shown in Figure 2.

Calculating isovist indicators using Depthmap

We used the UCL Depthmap (Varoudis, 2012) to calculate isovist and map generations. The software provides two types of visibility analysis, specifically isovist analysis and VGA. The former is appropriate for predefining observation points, while VGA is suitable for providing an encompassing overview of visibility distribution. The isovist field of view also affects the result. The software has the following options: Quarter isovist, Third isovist, Half isovist and Full isovist. Research participants were required to walk the route in one direction, where their emotional response was only influenced by what was in front of them. Therefore, the 360° isovist field of view is not considered in the analysis, and only 90°, 120° and 180° are used.

Observation points are created by splitting the polyline at every 2.5 metres in AutoCAD. The file is subsequently imported into Depthmap and used as the isovist route. At the final stage, the values of each observation point are calculated in Depthmap.

Results

Correlation between isovist indicator level (L) and emotional responses

Emotions are sorted into positive and negative aspects by referring to the BodyMonitor's algorithm. These are the dependent variables, whereas the isovist indicators are the independent variables in the logistic regression. Isovist indicator level (L) does not significantly influence the occurrence of positive emotions in the city environment, but negative emotions are found to be strongly related to isovist indicators (Table 2). Under a 90° field of view,

Table 2. Logistic regression: negative emotion and isovist indicators.[a]

Odds ratio of isovist parameters on momentary negative EDA responses (separates logistic regression with robust cluster estimation)

Normalized isovist parameter	90°	Wald chi square	120°	Wald chi square	180°	Wald chi square	N of observations	N of cases
Isovist area	0.945*	2.59	0.948	2.24	0.962	1.11	232,010	30
Isovist compactness	1.045	2.98	1.04	1.38	1.039	1.18	232,010	30
Isovist drift angle	0.946*	2.88	0.948	2.58	0.976	0.41	232,010	30
Isovist drift magnitude	0.919***	7.66	0.92**	6.08	0.934**	3.72	232,010	30
Isovist max-radial	0.923***	7.46	0.925**	5.54	0.946	2.2	232,010	30
Isovist occlusivity	0.964	1.46	0.974	0.62	0.985	0.18	232,010	30
Isovist perimeter	0.934**	5.25	0.942*	3.54	0.963	1	232,010	30
Isovist jaggedness	1.085**	5.84	1.089***	6.89	1.068**	4.91	232,010	30

***$p<0.01$, **$p<0.05$, *$p<0.1$.

[a]The colour red indicates a negative correlation, while green indicates a positive correlation. The same applies in Tables 3 and 4.

isovist indicators are most strongly related to negative emotional response. Among all the indicators, drift magnitude and maximum radial line significantly affect negative responses. Pedestrians are also more likely to experience negative emotions when physical isovist jaggedness increases.

Correlation between isovist indicator difference (D1) and emotional responses

This section presents the emotional influences of isovist transformation during walking. The previous section demonstrated that current isovist indicators have a slight effect on positive emotions. But when isovist fields of view are 120° and 180°, a change in the streetscape's isovist indicators will intensively impact positive emotional response (Table 3). Differences in isovist compactness and area will positively affect positive emotional response when the isovist field of view is 120° or 180°. In contrast, pedestrians are less likely to show a positive emotional response when differences in drift magnitude, maximum radial line and perimeter are under the field of view of 120°.

In addition, the impact mechanism of isovist indicator differences on negative emotions varies from the momentary responses (Table 3). First, no isovist indicator difference presents a significant relationship with negative emotions under the field of view of 90°, whereas the majority of differences demonstrate a momentary significant effect on negative emotions. Second, only compactness transformation negatively affects the occurrence of negative emotions. An increase in the remaining indicator differences increases the probability of negative emotions. But when the isovist field of view is 180°, the isovist change is not negatively related to negative emotions.

Figure 3 shows several dominant D1 indicators of geographic distribution when the isovist field of view is 120°. D1 fluctuation amplitudes are relatively larger in b–c and c–d sections compared to the other two sections where D1 indicators almost maintain the same trend. This fits the real conditions, namely that the profile buildings in the b–d section are varied and change substantially; meanwhile, in the other two sections, the building profiles are almost present flat and ordered.

Table 3. Logistic regression: positive emotion and D1 and negative emotion and D1.

Normalized isovist parameter	90°	Wald chi square	120°	Wald chi square	180°	Wald chi square	N of observations	N of cases
odds ratio of isovist parameters on momentary positive EDA responses (separates logistic regression with cluster robusts.e.estimation)								
Isovist area	0.775	0.53	0.88	0.32	1.337**	4.25	232,010	30
Isovist compactness	1.202	2.01	1.157*	3.66	1.003	0	232,010	30
Isovist drift angle	1.964	1.7	1.482	0.86	1.142	2.39	232,010	30
Isovist drift magnitude	0.487	1.68	0.542*	3.68	0.966	0.05	232,010	30
Isovist max-radial	0.511	2.44	0.625*	3.43	1.052	0.22	232,010	30
Isovist occlusivity	0.793	0.94	0.738	2.66	1.113	2.27	232,010	30
Isovist perimeter	0.696	1.71	0.636*	3.4	1.134	2.6	232,010	30
Isovist jaggedness	0.898	0.19	1	0.01	0.99	0.1	232,010	30
odds ratio of isovist parameters on momentary negative EDA responses (separates logistic regression with cluster robusts.e.estimation)								
Isovist area	1.427	0.55	1.523	3.11	1.174	1.21	232,010	30
Isovist compactness	0.916	0.63	0.882**	6.45	0.975	0.22	232,010	30
Isovist drift angle	0.767	0.41	1.015	0	0.995	0	232,010	30
Isovist drift magnitude	0.952	0.01	1.524**	4.41	1.402***	7.03	232,010	30
Isovist max-radial	1.245	0.36	1.333**	4.31	1.252**	5.07	232,010	30
Isovist occlusivity	1.359	1.19	1.404**	5.95	1.135**	4.23	232,010	30
Isovist perimeter	1.305	0.82	1.501**	5.21	1.130*	3.23	232,010	30
Isovist jaggedness	1.359	1.2	0.984	0.21	1.014	0.09	232,010	30

***$p<0.01$, **$p<0.05$, *$p<0.1$
EDA: electrodermal activity.

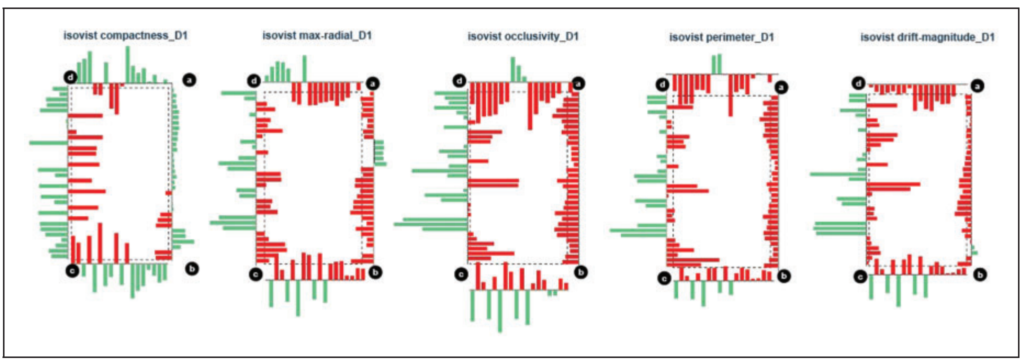

Figure 3. Distribution of isovist indicators D1 (120°) over the experimental area.

Discussion

Research question 1: Which isovist parameters affect (negative/positive) physiological arousal?

Table 2 shows that an increase in isovist area and maximum radial line indicators causes less negative emotional responses. In Prospect Refuge Theory, isovist area and maximum radial

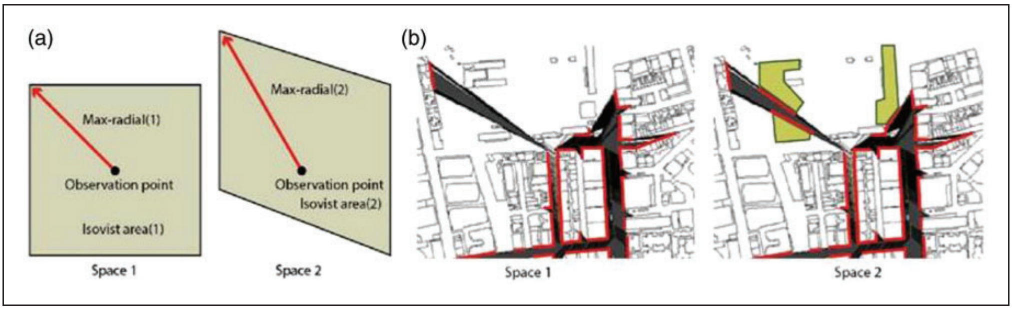

Figure 4. Isovist Max-radial and occlusivity. (a) Isovist area (1) =Isovist area (2); observation point is fixed; Max-radial (1) < Max-radial (2); Space 1 is more likely to cause negative emotions than Space 2; (b) the red line is the solid boundary within isovist area (Pf); P(1) = P (2), Pf(1)< Pf(2); Occlusivity (1)> Occlusivity (2); Space 1 is more likely to cause negative emotions than Space 2.

line are the representative physical indicators for *prospect*, whereas occlusivity relates to *refuge*. The isovist area can trigger the ability of pedestrians to oversee space, and this provides them with a sense of security. The isovist maximum radial line length strengthens this sense of security and enables pedestrians to detect the space from a distance. Figure 4 depicts two (green) buildings added to increase isovist perimeter and further reduce occlusivity level. The main practical insight is that, apart from creating an open vision, an unobstructed visual focus should be constructed at a distance when the surroundings are monotonous or uninteresting.

With regard to complexity and mystery, an increase in jaggedness is more likely to create negative emotions. But this contradicts the claim of Prospect Refuge Theory that a degree of visual complexity enhances a sense of safety. Evidence in this regard mostly originates in interior space studies (Dzebic, 2013; Franz et al., 2004; Scott, 1993a, 1993b; Wiener et al., 2007), which holds that the number of vertices is positively correlated with the creation of interest and the triggering of pleasure. This study was conducted outdoors and the geometric complexity of the isovist area was taken into account, which meant that it was only possible to obtain partial information on complexity. Our findings are consistent with Nasar's (1984) finding that a linear positive relationship in which preference and weight values are the lowest of all the factors related to preference. Nasar attributed the reason as the imprecise and incomprehensive measurement of complexity, while Knöll et al. (2018) found that the number of vertices (an indicator for visual complexity) is negatively related to perceived stress (i.e. decreased negative emotional response) in outdoor spaces.

The results also vary between different isovist calculated angles. The physiological eye structure and the distribution of vision nerve cells create differences in the spatial attention of the visual field. Spatial attention corresponds to an improved ability to process visual information in a selected area (from the visual field) with improved accuracy, intensity and speed. When the visual degree is within 60°, there is greater sensitivity to information in the field.

In summary, in order to avoid negative emotions, a space must be enclosed to guarantee a sense of security; in addition, an area that extends to the distance should be constructed with the aim of preventing avenues from becoming too monotonous or uninteresting.

Table 4. Comparison of L and D1.

Isovist indicators	Level of isovist indicators (L)		Difference of isovist indicators (D1)	
	Positive emotion	Negative emotion	Positive emotion	Negative emotion
Isovist area	×	\ (90°)	/ (180°)	×
Isovist compactness	×	×	/ (120°)	\ (120°)
Isovist drift angle	×	\ (90°)	×	×
Isovist drift magnitude	×	\ (90°, 120°, 180°)	\ (120°)	/ (120°, 180°)
Isovist max-radial	×	\ (90°, 120°)	\ (120°)	/ (120°, 180°)
Isovist occlusivity	×	×	×	/ (120°, 180°)
Isovist perimeter	×	\ (90°, 120°)	\ (120°)	/ (120°, 180°)
Isovist jaggedness	×	/ (90°, 120°,180°)	×	×

×: no significant effect; \ : negative effect; / : positive effect.

Research question 2: Landscapes change at each moment during the walking period. Will such change cause negative or positive physiological arousal?

Table 4 indicates that occlusivity transformation is negatively related to negative emotions. Occlusivity relates to the degree of enclosure and mystery. Its transformation along the walking path results in changes in the sense of security and level of information being accepted by pedestrians. When walking, participants are likely to experience negative emotions because there are fewer places to hide from danger.

Kaplan's (1998) theory proposes that increased arousal and pleasure can be partly attributed to new information obtained when proceeding further into the environment. A change in isovist is, therefore, a new type of information gained while walking on a street. The continual absorption of new information makes the environment more mysterious and interesting to the observer. The impact of isovist difference is more significant than isovist level (Table 4).

Table 4 shows that the emotional impacts of isovist level and isovist difference are inconsistent, which confirms positive emotions are not affected by isovist level, but several indicators significantly influence positive emotions. Changes in prospect and complexity strongly correlate with positive emotion and a considerable increase means participants are more likely to experience positive emotions because the new information triggers a sense of mystery. The difference in isovist indicators is an expected variable, which can predict emotional response in future studies.

Research question 3: Will the result of the experiment in a high-density city differ from previous studies conducted in Europe?

Previous studies (Table 5) show that occlusivity, visibility and compactness are the dominant components of isovist indicators that influence stress. Interestingly, some of these indicators contribute conversely to emotional response in Europe and Hong Kong because of the differences in culture and the living environment.

Occlusivity. Occlusivity is the enclosure degree of space, and it can theoretically provide a sense of security. Paper 1 finds that under 60°, occlusivity is statistically significant for both positive and negative emotions. However, it does not allude to a specific relationship (whether positive or negative) with emotions. Paper 2 finds that occlusivity can foster a sense of security and prevent negative emotions. In contrast, Hong Kong residents do not

Table 5. Summary of similar studies.

Papers compared	Isovist indicator	Correlation with positive/negative emotions
Paper 1: Hijazi et al. (2016) Stress data type: SCR	Perimeter (60°), Occlusivity (60°), Compactness (360°)	Statistically significant for positive emotions
Site: Zurich, Switzerland	Occlusivity (60°), Perimeter (360°)	Statistically significant for negative emotions
Paper 2: Li et al. (2016) Stress data type: SCR	Compactness, visibility	Higher compactness and greater visibility are more likely to cause positive emotions
Site: Zurich, Switzerland	Occlusivity, maximum radial	Higher occlusivity and maximum radial contribute to more negative emotions
Paper 3: Knöll et al. (2017)	Visual complexity	Complexity contributes to less stress
Stress data type: Perceived stress Site: Darmstadt, Germany	Visibility, perimeter	More likely to feel stress when areas are highly visible

rely on this sense as strongly as their Zurich counterparts. Occlusivity difference is only associated with negative emotions (Table 4) because Hong Kong residents are surrounded by high-density and high-rise blocks every day. If an avenue with a high degree of enclosure is not designed to a high standard, then it will cause feelings of depression. Thus, people prefer open and interesting spaces. Accordingly, isovist area and maximum radial line play important roles in reducing negative emotions in Hong Kong.

Compactness and complexity. Papers 1 and 2 confirm that compactness positively impacts emotions in the Zurich experiments. This is also shown in Hong Kong, where more compact visible scenery is more likely to produce positive emotions. However, paper 3 shows that a more complex environment (complexity = 1/compactness) is less likely to create stress. This conflicts with the Hong Kong and Zurich results.

Visibility. Visibility is an important component of Prospect Refuge Theory that can be quantified by isovist area. The results of Paper 2 and our conclusions confirm Prospect Refuge Theory's hypothesis that greater visibility will create positive emotions to a greater extent. Paper 3 suggests the exact opposite, namely that negative emotions are more likely when space is highly visible.

Participants from Germany (paper 3) and Switzerland (papers 2 and 3) have similar cultural backgrounds and living environments. Theoretically, the results of papers 1, 2 and 3 should show the same trend. Observed divergences in the results may, however, be partially attributable to different types of stress. Paper 3 uses a self-reporting method to obtain perceived stress, and other studies use the smart band to record psycho-physiological stress that cannot be perceived by the individual. Future studies should simultaneously record perceived and psycho-physiological stress, as this will help to develop a comprehensive understanding of the impact that isovist indicators have on pedestrian stress.

Conclusion

In this paper, we investigated the correlative effects between the visual geometric attributes of the Hong Kong urban environment and the emotional response of pedestrians, combining the field trip method with computational aids to calculate isovist indicators. We conclude the following: (1) An open space with a visual target set at a distance is the dominant factor creating positive emotions. (2) The new indicator – isovist time difference (D1) – could be a valuable parameter for future studies because it is more significantly correlated with stress than the isovist level. (3) The living environment and cultural background play an important role in the study. When we compare our results against previous studies (Hijazi et al., 2016; Knöll et al., 2017; Li et al., 2016; Marianne and Knöll, 2017) conducted in Europe, we observe divergent effects on stress. Europeans prefer space with relatively higher occlusivity because this helps to ensure their sense of security; Hong Kong residents, in contrast, experience more stress in these spaces. (4) Knöll et al. (2017) provide novel insights when they suggest that it is better to simultaneously collect perceived and psychophysiological stress. If only one kind of stress is recorded, then one-sided and incomplete results may be obtained.

This study has some limitations. The physical aspects of the environment may contain other kinds of data, including sound, weather conditions and urban density. Future studies could attempt to account for them in the regression model, with the aim of developing a more comprehensive understanding of the relationship between the physical environment and emotional response. Moreover, we did not record participant familiarity with the experimental route or their cultural background. Finally, the spatial sequence and the design treatment of spatial nodes will theoretically influence participant perception – further studies could, therefore, add a reference group that walks the route in a reverse direction, as this will help to show sequence effects. The construction of a psychologically friendly environment has important quality-of-life implications for Hong Kong residents. Our findings could pave the way to for further studies and can have practical significance for urban planning.

Acknowledgements

We gratefully acknowledge the academic support of the Chinese University of Hong Kong during the whole project, as well as the technical support of BodyMonitor Company. The opinions, findings, conclusions and recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the sponsoring agencies.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study received financial support from the Post Graduate Scholarship Grant, Chinese University of Hong Kong and the GESIS Grant (No. GG-2017-002) from the Leibniz Institute for the Social Sciences, Mannheim, Germany.

References

Abbott A (2011) City living marks the brain. *Nature* 474: 429.

Appleton J (1975) *The Experience of Landscape*. London: John Wiley and Sons.

Aspinall P, Mavros P, Coyne R, et al. (2014) The urban brain analysing outdoor physical activity with mobile EEG. *British Journal of Sports Medicine* 49(4): 272–276.

Baddeley AD (1982) Implications of neuropsychological evidence for theories of normal memory. *Philosophical Transactions of the Royal Society of London B, Biological Sciences* 298(1089): 59.

Berlyne DE (1951) Attention, perception and behavior theory. *Psychological Review* 58(2): 137.

Bratman GN, Hamilton JP, Hahn KS, et al. (2015) Nature experience reduces rumination and subgenual prefrontal cortex activation. *Proceedings of the National Academy of Sciences*, USA 112(28): 8567–8572.

Chen Z, He Y and Yu Y (2016) Enhanced functional connectivity properties of human brains during in-situ nature experience. *PeerJ* 4: e2210.

Davis LS and Benedikt ML (1979) Computational models of space isovists and isovist fields. *Computer Graphic and Image Processing* 11(1): 49–72.

Dawes MJ and Ostwald MJ (2014) Testing the 'wright space': Using isovists to analyse prospect-refuge characteristics in Usonian architecture. *The Journal of Architecture* 19(5): 645–666.

De Long DG (1993). The wright space: pattern and meaning in frank lloyd wright's houses. *Journal of Architectural Education* 47(2): 116–117.

Dosen AS and Ostwald MJ (2016) Lived space and geometric space: Comparing people's perceptions of spatial enclosure and exposure with metric room properties and isovist measures. *Architectural Science Review* 60(1): 62–77.

Douglas MJ (2012) Making healthy places: designing and building for health, wellbeing and sustainability. *Journal of Public Health* 34(2): 316–316.

Dzebic V (2013) Isovist Analysis as a Tool for Capturing Responses Towards the Built Environment. PhD thesis. UWSpace: Waterloo, Ontario, Canada. http://hdl.handle.net/10012/7511

Ekman P (1992) An argument for basic emotions. *Cognition & Emotion* 6(3–4): 169–200.

Franz G, von der Heyde M and Bülthoff HH (2004) Predicting experiential qualities of architecture by its spatial properties. In: *Paper presented at the IAPS-conference*, Vienna.

Franz G and Wiener JM (2008) From space syntax to space semantics a behaviorally and perceptually oriented methodology for the efficient description of the geometry and typology of environments. *Environment and Planning B: Planning and Design* 35(4): 574–592.

Halblaub Miranda M and Knöll M (2017) The Luisenplatz Study – The relationship between visual fields and perceived stress in a public transport hub. In: Heitor T, Serra M, Silva JP, et al. (eds) *Proceedings of the 11th International Space Syntax Symposium*, pp 192.1–192.7. Lisboa: Instituto Superior Técnico. http://www.11ssslisbon.pt/docs/6-posters-05072017.pdf

Herzog TR and Chernick KK (2000) Tranquility and danger in urban and natural settings. *Journal of Environmental Psychology* 20: 29–39.

Hijazi IH, Koenig R, Schneider S, et al. (2016) Geostatistical analysis for the study of relationships between the emotional responses of urban walkers to urban spaces. *International Journal of E-Planning Research* 5(1): 1–19.

Kennedy DP and Adolphs R (2011) Stress and the city. *Nature* 474: 452–453.

Kleinsmith LJ and Kaplan S (1963) Paired-associate learning as a function of arousal and interpolated interval. *Journal of Experimental Psychology* 65(2): 190.

Knöll M, Halblaub Miranda M, Cleff T, et al. (2019) Public space and pedestrian stress perception – Insights from Darmstadt, Germany. In: Vojnovic I, Pearson AL, Gershim A, et al. (eds) *Handbook of Global Urban Health*. London: Routledge, pp.269–282.

Knöll M, Neuheuser K, Cleff T, et al. (2018) A tool to predict perceived urban stress in open public spaces. *Environment and Planning B: Urban Analytics and City Science* 45(4): 797–813.

LaBar KS and Phelps EA (1998) Arousal-mediated memory consolidation: Role of the medial temporal lobe in humans. *Psychological Science* 9(6): 490–493.

Lederbogen F, Kirsch P, Haddad L, et al. (2011) City living and urban upbringing affect neural social stress processing in humans. *Nature* 474(7352): 498–501.

Lee J, Park B-J, Tsunetsugu Y, et al. (2009) Restorative effects of viewing real forest landscapes, based on a comparison with urban landscapes. *Scandinavian Journal of Forest Research* 24(3): 227–234.
Levenson RW (2003) Blood, sweat, and fears. *Annals of the New York Academy of Sciences* 1000(1): 348–366.
Li X, Hijazi I, Koenig R, et al. (2016) Assessing essential qualities of urban space with emotional and visual data based on GIS technique. *ISPRS International Journal of Geo-Information* 5(11): 218.
Marianne HM and Knöll M (2017) The relationship between visual fields and perceived stress in a public. In: *Paper presented at the 11th international space syntax symposium*, Lisbon.
Nasar JL (1984) Visual preferences in urban street scenes a cross-cultural comparison between Japan and the United States. *Journal of Cross-Cultural Psychology* 15(1): 79–93.
Papastefanou G (2013) *Reliability and Validity of RTR Measurement Device*. Retrieved from Mannheim: https://www.ssoar.info/ssoar/handle/document/33949.
Parsons R, Tassinarz LG, Ulrich RS, et al. (1998) The view from the road implications for stress recovery and immunization. *Journal of Environmental Psychology* 18: 113–139.
Pretty J, Peacock J, Sellens M, et al. (2005) The mental and physical health outcomes of green exercise. *International Journal of Environmental Health Research* 15(5): 319–337. doi:10.1080/09603120500155963
Roe J and Aspinall P (2011) The restorative benefits of walking in urban and rural settings in adults with good and poor mental health. *Health & Place* 17(1): 103–113.
Schroeder CW (1942) Mental disorders in cities. *American Journal of Sociology* 48(1): 7.
Scott SC (1993a) Complexity and mystery as predictors of interior preferences. *Journal of Interior Design* 19(1): 25–33.
Scott SC (1993b) Visual attributes related to preference in interior environments. *Journal of Interior Design* 18(1–2): 7–16.
Stamps E (2005) Isovists, enclosure, and permeability theory. *Environment and Planning B: Planning and Design* 32.
Schrenk M, Popovich V, Zeile P, Elisei P, Taha D and Bergner B (2012) (Print) Editors: Humans as Sensors to Enhance the Built Environment: a Case Study of the Eastern Harbor, Alexandria, Egypt.
Ulrich RS (1981) Natural versus urban scenes. *Environment and Behavior* 13(5): 523–556.
van den Berg AE, Koole SL and van der Wulp NY (2003) Environmental preference and restoration: (how) are they related? *Journal of Environmental Psychology* 23(2): 135–146.
Varoudis T (2012) DepthmapX multi-platform spatial network analysis software. Version 0.30 Open Source. Available at: http://varoudis.github.io/depthmapX/ (accessed 28 March 2020).
Weich S (2002) Mental health and the built environment: Cross-sectional survey of individual and contextual risk factors for depression. *British Journal of Psychiatry* 180(5): 428–433.
World Health Organization (2012a) Depression: A Global Crisis. http://www.who.int/mental_health/management/depression/wfmh_paper_depression_wmhd_2012.pdf.
Wiener JM, Franz G, Rossmanith N, et al. (2007) Isovist analysis captures properties of space relevant for locomotion and experience. *Perception* 36(7): 1066–1083.

Luyao Xiang is PhD student from School of Architecture, The Chinese University of Hong Kong. Her study interest is the relationship between outdoor building environment and human psychological stress.

Georgios Papastefanou is Senior Researcher from GESIS Leibniz Institute for the Social Sciences and also the founder of BodyMonitor Company.

Edward Ng is Yao Ling-Sun Professor of Architecture (姚連生建築學教授) at the Chinese University of Hong Kong; he is also an architect and an environmental consultant offering design and expert services to clients, organizations and governments.