Predicting experiential qualities of architecture by its spatial properties

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Abstract

While experiential qualities of rectangular architectural spaces can be effectively predicted from their proportions and area (Franz, von der Heyde, & Bülthoff, 2003), these factors obviously cannot be directly transferred on open-plan indoor spaces. We introduce an approach that relates experiential qualities of arbitrarily shaped architectural spaces to their spatial form using isovists (Benedikt, 1979) that allow to generically describe spatial properties. In an exploratory psychological experiment, 33 characteristic values derived from the isovists were tested on their predictive power on experiential qualities by correlating them with averaged affective appraisals. Thirty-four virtual reality simulated indoor scenes were rated by 2x8 participants using the semantic differential. Particularly measurands capturing the qualities spaciousness, openness, complexity, and order turned out to be effective predictor variables. The findings are discussed in terms of evolutionary and information rate related theories of environmental preferences.

Introduction

Architecture has an emotional impact on humans. In the discipline of architecture, the design of spatial configurations and forms is traditionally regarded as its most prominent concern, in fact, spatial form has been called the primary dimension of architecture (cf. Giedion, 1941; Joedicke, 1985). Also several theories from environmental psychology (e.g., Appleton, 1988; Kaplan, 1988; Newman, 1996) relate human preferences and behavior to spatial properties of the environment. While the truth of the initial statement is therefore beyond any doubt, it is surprising that there is so little systematic knowledge about the fundamental relations and the most important factors. Only for rectangular rooms there are some traditional rules, and indeed, Franz et al. (2003) found high correlations between affective appraisals and room proportions, area, and openness ratio. Yet the question of how these rules and findings can be generalized to arbitrary spatial forms and open-plan indoor spaces is completely unsolved. Apart from the general problem of quantifying experiences, an empirical investigation of emotional effects of spatial form is faced with two non-trivial main problems: Methodologically, spatial properties have to be systematically varied independent from other design factors, and, analytically, spatial form has to be described quantitatively in few generically applicable meaningful dimensions.

This paper presents an empirical approach to the experience of architectural space based on a combination of virtual reality simulations and a description of spatial properties using isovist and visibility graph analysis. The method was exemplarily tested in a psychological experiment correlating affective appraisals and isovist measurands in order to determine the most promising predictor variables. For this purpose, existing theories and normative knowledge on affective qualities of space were translated into concrete hypotheses. In the following section the underlying theories and methodological prerequisites of this approach are introduced in more detail.

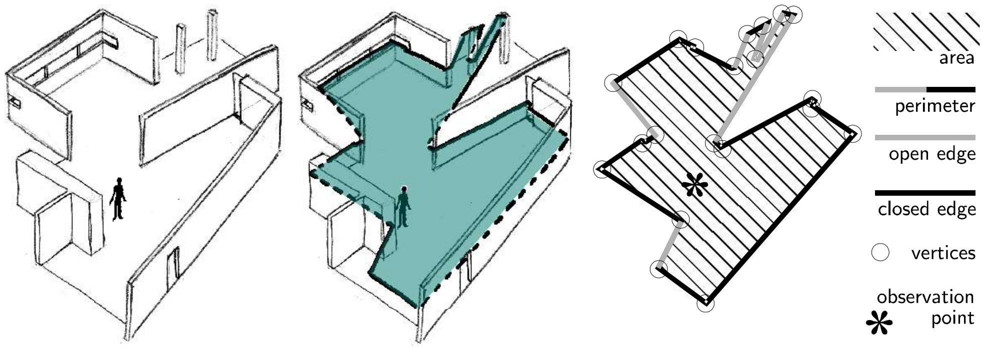

Figure 1. Generating isovists: Left: a hypothetical indoor environment; middle: the shaded area is visible from the person's observation point within the environment; right: the resulting isovist and its basic measurands.

Background

Isovist analysis. In response to the shortcomings of traditional top-down approaches, Benedikt (1979) has proposed isovists as objectively determinable basic elements for the description of architectural space. Isovists are viewshed polygons that capture spatial properties by describing the visible area from a given observation point (see Figure 1). Several quantitative descriptors can be derived such as area, perimeter length, number of vertices, length of open or closed edges. These basic measurands are directly comparable and can be combined to generate further integrative characteristic values (cf. Table 1). Isovists basically contain local physical properties of spaces with respect to single observation points. In order to describe spatial characteristics of an environment as a whole, Turner, Doxa, O Sullivan, and Penn (2001) have proposed the technique of visibility graph analysis that integratively considers multiple positions within an environment. This technique approximates isovists by an intervisibility graph on a regular grid and provides further second-order measurands (e.g., visual stability, integration). Originally derived from abstract spatial analysis, the relevance of isovists and visibility graphs was not backed initially by empirical findings. However, there is first evidence that isovists capture environmental properties relevant for spatial behavior and experience (e.g., Wiener & Franz, 2004).

Using virtual reality to simulate architectural space. Computer based virtual reality simulations offer the potential to overcome several specific drawbacks of traditional field studies and psychophysical experiments. The unique combination of controlled laboratory conditions, interactivity, flexibility, and high perceptual realism allows a transfer of psychophysical methods on a wide range of applications (Bülthoff & van Veen, 2001), including architectural simulation. Several case studies (e.g., de Kort, Ijsselsteijn, Kooijman, & Schuurmans, 2003) have approved prior findings on classic simulation media that the key requirement for the particular purpose is pictorial realism. As long as high pictorial quality is provided, simulated rooms are evaluated widely similar to corresponding real buildings.

Quantifying emotional responses. Although emotion or synonymously affect is a complex phenomenon, there are several applied models suitable for exploratory purposes. For example, the theoretical framework of Mehrabian & Russell (1974) describes emotion by only three basic underlying dimensions (pleasure, arousal, and dominance) that widely imply related concepts such as preference or beauty. Their framework allows to quantify affective responses effectively using introspective verbal scaling techniques. Furthermore, several studies summarized by Stamps (2000, pp. 114-138) strongly suggest that, despite obviously existing individual differences, averaged appraisals indicate meaningful and stable main trends offering a basis for generalizable predications.

Theories on emotional responses to space. Several theories relate affective responses to spatial properties of environments. For example, Joedicke (1985) suggests that the most basic quality of architectural space, its *spaciousness*, is an important constituent of its affective experience. The pathological extremes of agoraphobia and claustrophobia demonstrate that direct emotional responses to experienced spaciousness can be very intensive. Additionally, the size of a space widely determines its range of potential functions. So, moderately large and differentiated shapes offering diverse ways of utilization should be tendentially preferred. Related to the spaciousness quality, the theories of prospect and refuge (Appleton, 1988) and defensible space (Newman, 1996) suggest preference patterns for certain configurations combining enclosure and *openness*. For example, Appleton (1988) proposed that, due to their evolution in the savannah, humans prefer environments that offer various cover and at the same time allow overlooking large other spaces.

A further group of theories relates affective responses to perception and information processing. Mainly going back to Berlyne (1972), it has been suggested that environmental properties determining the perceptibility affect emotional responses. For describing the underlying factors, collative concepts (i.e. introspective assessment criteria of the structural properties of a stimulus array) have been used. Within the diverse collative space, two main dimensions may be provisionally identified and termed *complexity* (incl. concepts such as diversity, entropy, richness) and *order* (incl. legibility, clarity, coherence). While architectural theory tends to stress the aesthetic value of the latter (e.g., Weber, 1995, pp. 109-120), psychological experiments have rather concentrated on complexity that is seen as directly influencing arousal. Furthermore, an indirect influence on pleasure has been assumed in form of an inverted U-shape (Berlyne, 1972). In sum, the theories suggest that pleasure is tendentially highest in stimuli that combine high levels of both complexity and order. Closely related to these static environmental properties are concepts based on *predictability* (e.g., Mehrabian & Russell's novelty and uncertainty, 1974, pp. 75-97). Also the mystery theory (Kaplan, 1988) suggests increased arousal and pleasure by environments promising new information when moving further. In addition, a very direct influence of predictability on dominance can be assumed.

Objective

Taken together, the reviewed methods and theories offer a potential to close the gap between physical properties and experiential qualities of architectural spaces. For testing the general approach, an empirical study compared isovist derivatives generically describing spatial properties and affective appraisals approximating the experience of architecture. The further exploratory aim of the experiment was to tentatively identify isovist parameters that appear to be most suitable for generally predicting experiential qualities. In order to keep the study small, a specific scenario was chosen that allowed for a free variation of spatial properties independent from other properties. Based on the theories, the exploratory study concentrated on four likely emotion-affecting spatial qualities: spaciousness, openness, complexity, and order. Theoretical assumptions were translated into concrete hypotheses on correlations between isovist measurands and affective appraisals (Table 1).

For the basic *spaciousness* quality, it was expected to find high correlations with measurands such as isovist area or free near and medium space. The second quality *openness* was seen to relate to two different physical aspects, the number of vistas into adjacent rooms and the rate of physical enclosure. The former could be probably captured by the area and number of concavities or also by measurands describing the complexity of isovists, the latter simply by the openness ratio of the isovist boundary. For *complexity* it was expected to find approximations by the number of vertices, vertex density, clustering coefficient, or the isovist jaggedness and roundness. Finally, properties contributing to visual *order* were tentatively approximated by redundancy patterns such as symmetries or the fraction of unique polygon sections.

basic spatial quality	tendential emotional influence			isovist and visibility graph based descriptor variables	calculation method
	P	A	D		
spaciousness	/		∩	isovist area	neighborhood size
				free near (medium) space	n visible graph vertices at 2 (4) m distance
openness		/	\	isovist openness	length open edges / length closed edges
				jaggedness	isovist perimeter²/area
				revelation	(Σ area adjacent isovists - isovist area) / isovist area
complexity	∩	/		number of vertices	n isovist vertices, n segments
				vertex density	n vertices / area
				roundness	isovist area/perimeter²
				jaggedness	isovist perimeter²/area
				clustering coefficient	see Turner et al., 2001
order	/	\	\	symmetry	n symmetry axes
				redundancy	n segments / (n unique segments +1)

Table 1. Summary of the hypothesized connections between emotional responses in the three dimensions pleasure (P), arousal (A), dominance (D) and selected isovist measurands based on four basic emotion-affecting spatial qualities. Slashes (/) indicate expected positive linear correlations, backslashes (\) negative linear correlations, inverted U's non-linear relations.

Method

Procedure. In the empirical experiment two groups of 8 subjects rated the experiential qualities of spatial situations in a fictive art gallery. The empirical study consisted of a pilot stage comprising 18 scenes and a second main stage based on a refined set of 16 stimuli. The data was collected using a seven step semantic differential. The rating categories were represented by pairs of oppositional adjectives and comprised major dimensions of affective experience (pleasure, beauty, and interestingness) as well as denotative and collative properties related to the assumed basic spatial qualities (spaciousness, openness, clarity, and complexity). The openness rating category was only used in the first stage. Before the ratings, subjects had thirty seconds to freely explore the scenes. They were explicitly advised to survey the complete room. Subjects were instructed to respond quickly to the individually presented ratings and to base their judgments on their first impression, yet no explicit time constraint was given. The presentation order was completely randomized. In the second stage the two rating category groups were separated in subsequent blocks in order to avoid potential biases. A complete experimental session took about 45 minutes. Subjects were mostly university students at an age of 20-25; they were paid 8 € per hour.

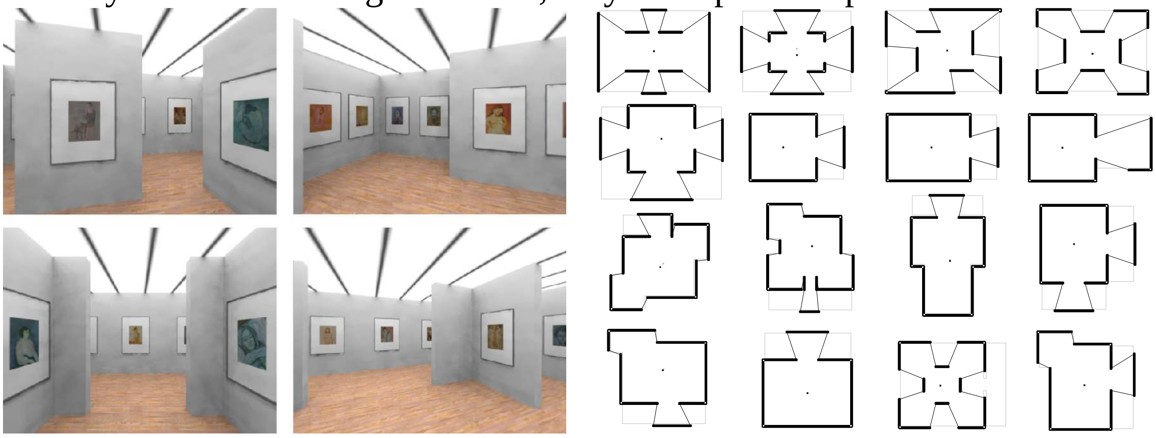

Figure 2. Example screenshots of the virtual gallery rooms and outlines of all isovists from the second stage. The dots mark the fixed observation points, thick black lines represent visible walls, thin black lines open isovist flanks, gray lines invisible space boundaries.

Setup and stimuli. The stimuli were presented as 360° panorama images on a spherical wide-angle virtual reality system (Elumens VisionStation™). The simulated visual field matched the physical field of view of 130°x90°, the screen width was 151 cm, participants experienced the virtual environments from an egocentric perspective at a screen distance of about 90 cm. The virtual observation points were fixed, but subjects could choose their gaze direction freely. They interacted with the simulation using a trackball for navigation and a standard keyboard. The two scene sets mainly differed with respect to the variance range of visible room area, in the second scene set (Figure 2) this parameter was much more restricted. Additionally, the walls were draped with unobtrusive paintings (46 portraits from Picasso s blue and pink period) to tentatively increase curiosity and thereby the effects of occlusions and vistas. Other surface properties and also the illumination level were kept constant. The geometry models were created in AutoCAD, the physics-based radiosity illumination was generated using POV-Ray.

Analysis. For the spatial analysis, isovist and visibility graph measurands were calculated on a 50 cm grid covering the 35 environments using a custom-made software tool (*http://www.kyb.mpg.de/~gf/anavis*). In the statistical analysis, averaged ratings from 8 participants in each stage were compared with altogether 33 characteristic values describing the isovists from the particular observation points in the scenes (See Figure 2 right). The rating data was treated as even interval scaled. Linear correlation coefficients r were calculated using Pearson's product moment correlation, p-values indicate the probability of the non-directional null hypothesis. P-values below .05 were treated as significant correlations. Confidence intervals (*95% CI*) describing the likely range of the general population correlation coefficients were obtained from a Fisher r-to-z transformation. Nonlinear relations were evaluated qualitatively via fitting square regression functions, but no significant non-linear interrelations became apparent. The statistical analysis was performed using the mathematical software GNU Octave and SPSS.

Results

Pilot stage. The first experimental stage revealed isovist area as the dominant factor. It was highly correlated with all rating categories (explained proportion of variance r^2 from .67 to .82, $p<.01$) except for clarity which showed a high negative correlation with vertex density ($r=-.81$, $p<.001$, 95% CI -.93 to -.52). Consequently, all other rating categories were highly interrelated ($r^2>.47$, $p<.01$). Most prominently, rated spaciousness and enclosure turned out to be almost identical ($r^2=.96$, $p<.001$). So, for the next stage the enclosure rating category was dropped and the variance of the isovist area was restricted.

Second stage. In the second scene set, rated spaciousness ($r=.83$, $p<.001$, 95% CI .57 to .94) and beauty ($r=.73$, $p<.01$, 95% CI .36 to .90) were still strongly correlated with isovist area, but the introduced constraint allowed further observations (cf. Figure 3): A multivariate linear regression analysis found pleasingness to be best explained by the additional factor enclosure ratio ($R^2=.69$, $p<.01$), and interestingness by the number and density of vertices, and the roundness and openness of isovists ($R^2=.73$, $p<.01$). Also, complexity was correlated highest with the number of vertices ($r=.81$, $p<.001$, 95% CI .52 to .93), while rated clarity showed a strong correlation with isovist roundness ($r=.93$, $p<.001$, 95% CI .80 to .97). Regarding measurands related to order, in particular the number of symmetries turned out to explain additional variance (e.g., correlation pleasingness $r=-.75$, $p<.001$, 95% CI -.90 to -.40). Also redundancy was significantly correlated with rating results (e.g., pleasingness $r=.66$, $p<.01$, 95% CI .24 to .87, clarity $r=.63$, $p<.01$, 95% CI .19 to .85). Altogether, the explained variance of the averaged ratings varied between .69 (pleasingness) and .94 (clarity), the variables rendering the highest correlations were isovist area, openness, roundness, number of vertices, vertex density, and number of symmetries.

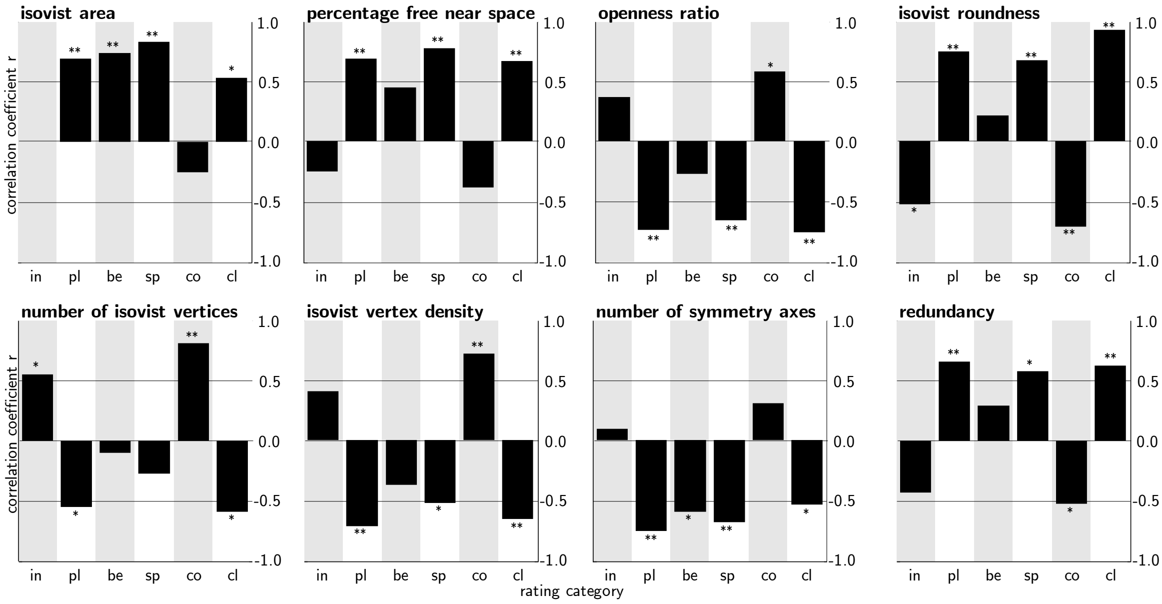

Figure 3. Most prominent results of the second stage. Correlations between selected scene features and ratings. The rating categories were interestingness (in), pleasingness (pl), beauty (be), spaciousness (sp), complexity (co), and clarity (cl). The asterisks indicate significant (*, p<.05), respectively highly significant (**, p<.01) correlations.

Discussion

The dominance of just one factor in the pilot stage may be partially explained by intercorrelations between the physical properties. Architectural forms are not scale-independent, but substantially determined by the absolute human scale. Apart from that, the results of both stages clearly support the relevance of spaciousness as a major factor for the experience of spaces. Generally, the diverse results of the second stage fitted the initial hypotheses remarkably well. The demonstrated medium or even large effect sizes approved the assumed descriptive power of the isovist measurands as well as the relevance of the four basic spatial qualities for the affective experience. The observed correlations corresponded qualitatively to the main effects reported in Franz et al. (2003). With regard to the theories underlying the initial hypotheses, the correlation between pleasingness and enclosure is particularly in accordance with Newman's (1996) concept of defensible space. Also evidence for prospect and refuge was indirectly found, since both a jagged spatial profile and large visual areas were tendentially rated to be more pleasing. The three regression factors for interestingness isovist roundness, vertex number and density were in accordance with classical information rate theories (e.g., Berlyne, 1972; Mehrabian & Russell, 1974). It is worthwhile mentioning that similar measurands that allowed predictions on the experience of facades and house silhouettes (cf. Stamps, 2000) apparently generalize on the form of indoor space. No evidence for an inverted U-curve relation between pleasure and arousal was found. However, since the range of tested complexity was arbitrarily chosen and only one visual factor was varied, the results are not really contradicting the theories of Berlyne (1972).

Regarding the real world transferability of the results, several limitations of the study have to be considered. First, the general design was a preliminary exploration; therefore, the selection of subjects and the sample size was not guided by demographic criteria. Second, consciously evaluating spatial situations during a laboratory experiment in a short exposure time is quite different from casually experiencing real spaces in normal life. Furthermore, the particular scenario art gallery was deliberately chosen to allow a wide variance of spatial situations. So, the transferability on other functional contexts cannot be taken for granted. Also interactions with other factors such as color, lighting, furniture, or presence of other people are possible that may substantially affect the observed relationships. Nevertheless, the revealed predictor variables are well interpretable and theoretically backed, hence, they are promising candidates for indicating generally relevant relations.

Conclusions

The experiment empirically demonstrated significant correlations between spatial properties and affective appraisals of spaces. Isovists and their derivatives proved to be suitable means for describing important perceptual properties of spaces generically: Already a few basic measurands explained a large fraction of the observed variance in the ratings. Since the observations fit theoretical assumptions very well, it is likely that the main effects indicate generally relevant factors. Future research should be directed primarily toward a broadening of the data basis that would allow an integrative consideration of several different factors and thereby substantially increase the real world transferability of findings. Also the methods of isovist and visibility graph analysis should be refined further and integrate the third dimension and more than one observation point. Furthermore, differences between behavioral and visual space (e.g., due to windows) need to be considered. Nevertheless, the substantial potential of the methodical approach can be generally confirmed.

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