Isovists as a Means to Predict Spatial Experience and Behavior

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Abstract. Two experiments are presented studying interrelations between spatial properties of environments and both experience and spatial behavior. In order to systematically study such interrelations, a generic description of space is required that provides comparability between arbitrarily shaped environments and captures behaviorally relevant properties of space. In this study the suitability of isovist derived measurands for this purpose was explored. Isovist-based descriptions of 16 virtual indoor scenes were correlated with behavioral data from two experimental tasks. For both tasks, an active navigation task and a rating of experiential qualities, strong correlations between subjects' behavior and measurands derived from isovist analysis were found. The general outcomes suggest that isovist measurands are indeed a promising means to predict the experience of space and spatial behavior for the chosen experimental tasks.

1 Introduction

Spatial properties of architecture influence subjective experience as well as spatial behavior. Several theories, mainly from environmental psychology, explain human behavior and experience by their interdependency with the environment. For example, evolutionary based theories of environmental preferences such as "prospect and refuge" [1] or "defensible space" [17] suggest that certain spatial settings were advantageous for the survival of a species and therefore corresponding preferences enhanced its fitness. Also the influence of selected features of space on human navigation behavior has been tested in several studies. For example, O'Neill [18] demonstrated that wayfinding performance decreased with increasing plan complexity. Wener and Long [23] have shown that the misalignment of local reference systems impaired users' ability to integrate spatial information across multiple places. Janzen, Herrmann, Katz, and Schweitzer [12] investigated the influence of oblique angled intersections within an environment on wayfinding performance. When navigating arrow-fork intersections, subjects' error rate depended on which branch they entered the intersection (see also [13]). Wiener and Mallot [24] have revealed an influence of environmental regions on human navigation and route planning behavior.

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While the truth of the initial statement is therefore beyond any doubt, few theories and empirical studies have aimed at analyzing the corresponding interrelations comprehensively, but have rather made use of qualitative descriptions of certain selected spatial situations. Therefore they are often difficult to compare and do not provide a basis for systematic spatial analysis. In order to study the relations between physical properties of spaces and both spatial experience and behavior systematically, generic formal descriptions of space are required that provide comparability between arbitrarily shaped environments and capture biologically and psychologically relevant properties of the environment.

In the following section, several description sytems are briefly reviewed. Afterwards, two experiments are presented that test an isovist based description system for its ability to capture behaviorally relevant properties of space.

2 Background

Several disciplines already offer description systems and models for aspects of spatial environments. For example, in architectural construction, buildings are specified by a combination of lists of constructive elements (walls, windows, columns, etc.) and scale plans. While this description of the *array of architectural elements* is quite elaborated and standardized, the formal structure is graphically and thus not quantitatively represented, and therefore cannot be directly compared. In architectural theory *compositional approaches* [15, 6, 16] developed more or less formal languages based on basic geometric primitives. By combining and/or transforming these primitives, more complex forms and structures can be generated. While these approaches may allow to retrace steps of the genesis of form from the top-down perspective of the designer, they are not ideal for an analytical description of the mere shape, since a decomposition of given forms is often difficult and ambiguous.

Another approach to describe environments rises from phenomenology. In everyday language, non-trivial forms are often compared using intermediate concepts such as complexity and regularity. In empirical aesthetics these properties are termed *collative variables* that have been defined as introspective assessment criteria of the structural properties of a stimulus array [3, 4, 25]. However, while collative properties offer a basis for comparing a wide range of objects and environments introspectively, they cannot be directly derived from the stimuli and therefore lack the objectivity of "real physical" properties.

In response to the reported shortcomings, the technique of *space syntax* has been developed [10, 8, 9]. Space syntax is a set of technologies for the analysis of spatial configurations using simple graphs solely consisting of paths and nodes. This analytical reduction of space to mere structural mathematical information facilitates a calculation of characteristic values such as connectivity, centrality, control level that can be directly compared. One aim of space syntax has always been the identification of variables that determine the social meaning and behavioral relevance of spaces. Original space syntax has been developed to analyze large-scale spatial configurations from the room layout of building complexes to whole cities. Hence, spatial properties of environments smaller than rooms were not adequately represented. Additionally, the initial analytical operations depended on an often ambiguous and therefore somehow arbitrary manual decomposition of space into convex subspaces and axes.

For analyzing spatial characteristics of smaller environments, Benedict [2] has proposed *isovists* as objectively determinable basic elements. Isovists are viewshed polygons that capture spatial properties by describing the visible area from a given observation point. In order to better describe the spatial characteristics of an environment as a whole, Turner, Doxa, O'Sullivan, and Penn [21] have proposed the technique of *visibility graph analysis,* that integratively considers multiple positions within an environment. This technique offers further second-order measurands like for example on visual stability that may be relevant for locomotion and navigation. A more detailed description of isovist analysis and visibility graph techniques as considered in this study is given in Section 4.3.

Originally derived from abstract spatial analysis, the relevance of isovists and visibility graphs was not initially backed by psychophysical empirical findings. However, isovists describe spatial properties from an inside beholder-centered perspective, and there is first empirical evidence that they capture environmental properties of space that are relevant for spatial behavior and experience. For example, case studies on spatial behavior in the Tate Gallery [11, 22] have revealed high correlations between visibility graph measurands and the statistical dispersal of visitors. Furthermore, in a recent study Franz, von der Heyde,and Bülthoff [7] compared experiential qualities of arbitrarily shaped architectural spaces with isovist measurands. They found that already a few isovist derivatives describing visual characteristics of the observation points were widely sufficient to explain the variance in the affective appraisals of the environments. Nevertheless, to the authors' knowledge, elementary studies, for example on the perceptibility of isovists, that shed some light on their biological foundations are still missing.

3 Objective

The overall aim of this exploratory study was to investigate interrelations between spatial properties of indoor environments and both spatial experience and behavior. In particular, likely predictor variables for experience and behavior in space should be identified. As stated above, isovist analysis provides a generic description of the form of architectural spaces from an inside beholder-centered perspective and may therefore offer suitable measurands that capture behaviorally relevant aspects of space. This hypothesis was tested by two experimental tasks in a set of 16 virtual indoor scenes: in an active navigation task subjects were asked to navigate to positions that either maximized or minimized the visible area. A subsequent semantic differential rating quantified the experiential qualities of the scenes. The analysis then tested for interrelations between characteristic values derived from the isovists and the behavioral data.

4 General Material and Methods

4.1 Experimental Setup

The empirical study was conducted using a virtual reality experimental setup. Virtual reality simulations combine flexibility, controlled laboratory conditions, and a good degree of perceptual realism [5] and therefore allow the systematic variation of spatial properties of the experimental environments. The experiments were conducted at the virtual reality facilities of the Max Planck Institute for Biological Cybernetics, Tübingen. The virtual environment models used in both experiments were created using AutoCAD and 3ds max (discreet). A detailed description of the virtual environments is given below. The visual scenery was rendered in realtime on standard PCs (1.0 GigaHz Pentium Pro, nVidia GForce 4 graphics card), running a C++ simulation software that was designed and programmed especially for psychophysical virtual reality experiments[1]. Subjects experienced the virtual environments in the egocentric perspective. The visual scenery was displayed with a simulated field of view of 90°x73°. Subjects were seated in front of a 21" standard CRT screen at a distance of approximately 50 cm; they interacted with the simulation using a joypad (Logitech Wing Man Rumble Pad).

4.2 The Virtual Environments

The study was based on a set of sixteen virtual indoor scenes that was derived from stimuli used by Franz et al. [7]. The scenes represented spatial situations within a fictive art gallery, they were designed by varying the number of alcoves and connections to adjacent spaces of simple rectangular rooms. The maximally visible floor area was kept roughly constant. The floor plans of these indoor scenes are displayed in Figure 1. The walls of the indoor scenes were draped with unobtrusive paintings (46 portraits of Picasso's blue and pink period) to strengthen the art gallery character. Other surface properties as well as the lighting and illumination level were constant over all scenes. Figure 2 displays example screenshots of subjects' perspective during the experiments. Note that in contrast to Franz et al. [7], a different lighting model (ambient occlusion derived smooth diffuse illumination) was used in order to make the stimuli realtime-capable.

4.3 Formal Description of the Environments

As already stated in the introduction, a generic formal description of the virtual indoor scenes was required in order to relate subjects' spatial experience and behavior in both of the experiments to the form and structure of the corresponding spaces. For this purpose, isovist and visibility graph analysis appeared to offer a promising level of abstraction, since they translate perceptual and spatial properties of architectural space into simple polygons (see Figure 3). From the isovist polygons several quantitative descriptors can be derived that reflect physical properties of the corresponding space such as area, perimeter length, number of vertices, length of open or closed edges, etc. These basic measurands can be combined to generate further integrated values.

Isovists basically describe local physical properties of spaces with respect to certain standpoints. In order to overcome this limitation, Turner et al. [21] developed the technique of visibility graph analysis that integratively considers regional or global properties of a whole environment by computing the intervisibility of positions regularly distributed

[1] For details please refer to the *Virtual Environments Library* homepage: `http://www.kyb.mpg.de/prjs/facilities/velib`.

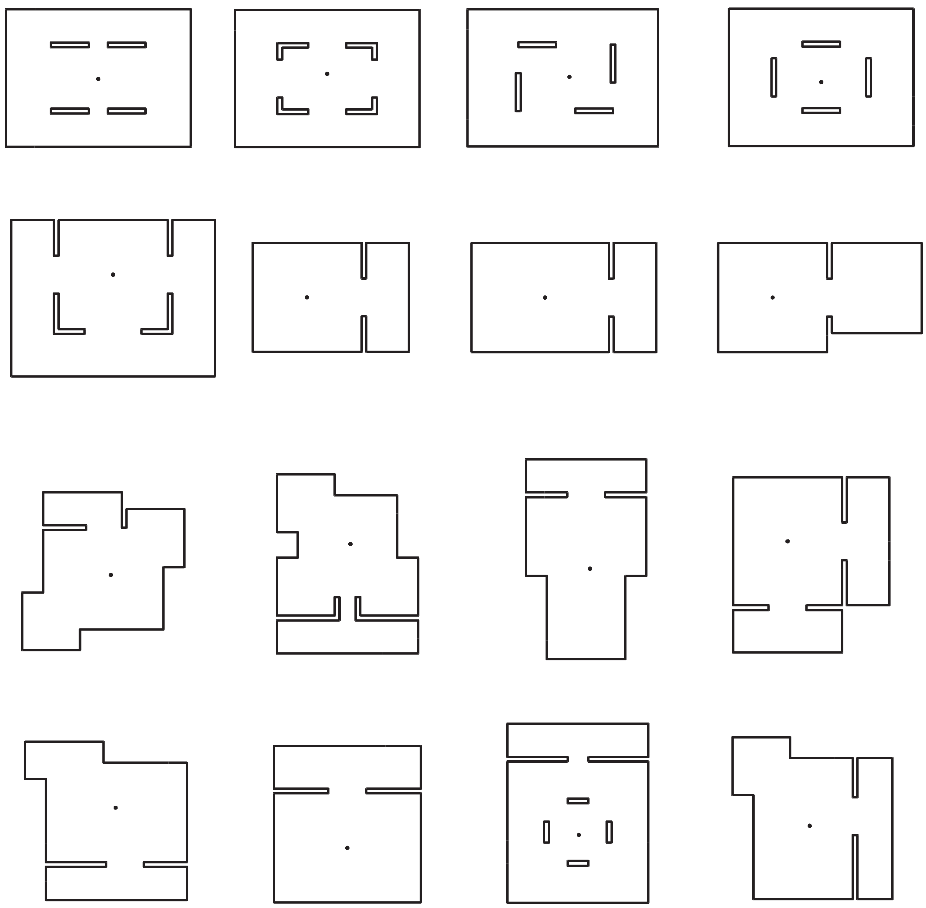

Fig. 1. Floor plans of the 16 virtual indoor scenes used in the experiments. The dot in the center of each room marks the starting position for the experimental tasks

Fig. 2. Three screenshots of the virtual indoor scenes as experienced by the subjects

over the whole environment. In order to make the computation more efficient, visibility graphs are not directly based on isovist polygons, but approximate their characteristics by a connectivity graph describing the intervisibility of multiple observation points. Typical visibility graph measurands are for instance neighborhood size (i.e. the number of directly connected graph vertices, corresponding to isovist area) and the clustering coefficient (i.e. the relative intervisibility within a neighborhood). Additionally, Psarra and Grajewski [19] have proposed further measurands that concentrate on the visibility graph boundaries (cf. openness, the relation between open and closed isovist boundaries, see below), because the boundaries are assumed to be the visually most important region of a viewshed.

For the analysis in this study, the techniques of isovist and visibility graph analysis were combined: the sixteen virtual indoor scenes were analyzed by calculating isovist measurands and visibility graphs on a 50 cm grid covering each environment. Since the correlation analysis required global characteristic values for each scene and measurand, the resulting values were averaged over each environment. A list of the isovist and visibility graph measurands that were calculated for the 16 indoor environments is given below. For the analysis a special isovist analysis tool was used, the tool is free software and available at `http://www.kyb.mpg.de/~gf/anavis`.

Isovist Derived Measurands Used in This Study. The following measurands were used to describe spatial characteristics of the simulated environments. They represented the best predictor variables according to the results of Franz et al. [7]. For a more detailed description of the measurands' mathematical and analytical background, refer to Turner et al. [21].

Neighborhood Size. The number of directly connected nodes of a visibility graph node, corresponding to the area of the isovist polygon.

Number of Vertices. The number of vertices making up the outline of an isovist polygon.

Openness. The ratio of open and closed edges of the isovist. Closed edges are defined by visible walls, open edges are generated by occlusions.

Jaggedness. The jaggedness of an isovist as an integrative measurand that is calculated mathematically as the squared isovist perimeter divided by the isovist area. It describes the convexity of an isovist polygon.

Clustering Coefficient. The clustering coefficient is a visibility graph measurand describing the relative intervisibility within an neighborhood. The clustering coefficient is calculated approximatively by dividing the sum of graph edges within a neighborhood by the squared neighborhood size.

Revelation Coefficient. The revelation coefficient describes the relative difference between a neighborhood and its adjacent neighborhoods. A low revelation coefficient indicates an area of high visual stability.

4.4 Statistical Analysis

All data were analyzed using the open source software mathematics packages 'Octave' (`http://www.octave.org`) and 'R' (`http://www.r-project.org`). For all

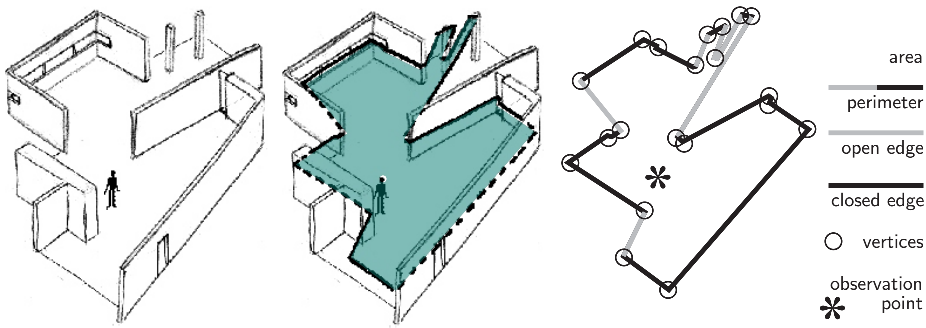

Fig. 3. Generating isovists: Left: a hypothetical indoor environment; middle: the gray area is visible from the person's observation point within the environment; right: the resulting isovist and its basic measurands

statistical analyses, the rating data was treated as even interval scaled. Correlation coefficients were calculated using linear Pearson's product moment correlation.

5 Experiment 1

5.1 Objective

In accordance with the overall objective of investigating interrelations between spatial properties and spatial behavior, the purpose of the experiment was twofold: First to test whether basic isovist properties can be perceived at all, and second, to explore correlations between global isovist measurands (see Section 4.3) and behavioral data. The behavioral data were gained both from a navigation task and a rating of experiential qualities in different virtual environments. It was hypothesized that the differently shaped environments used in this experiment systematically influenced subjects' behavior in both tasks. If the isovist measurands captured behaviorally relevant properties, significant correlations with the behavioral data were expected.

5.2 Method

Experimental Procedure. In each of the 16 indoor scenes (see Section 4.2 and Figure 1), subjects had to do a navigation task and a semantic differential rating task. Only after completing both experimental tasks, they proceeded to the next indoor scene. The order in which the 16 indoor scenes were presented was randomized for each subject. A complete experimental session had a duration of about 40 minutes.

The first experimental task was an **active navigation task**. At the beginning of this task, subjects were placed at the fixed starting position of the corresponding indoor scene (see Figure 1) facing a random direction. Subjects were then asked to navigate to the position within the scene that maximized the visible area (corresponding to maximal isovist area) as well as to the position within the scene that minimized the visible area (corresponding to minimal isovist area). Before the experiment, subjects were carefully instructed that their task was not to maximize or minimize the visible area with respect to their current heading direction, but the area revealed by a complete 360° rotation. During the experiment, the position that maximized the isovist area was referred to with the catchphrase *best overview place* and to the position that minimized the isovist area was referred to with the catchphrase *best hiding place*. The order in which subjects had to locate these two positions was randomized for each room. Subjects were instructed to solve the task quickly and as accurate as possible and to confirm a chosen position by pressing a button on the joypad. For each of the navigation tasks, subjects' final positions were recorded.

Table 1. English translations and original terms of the rating categories used in the semantic differential. The experiments were conducted in German language

Category	English low extreme	English high extreme	German low extreme	German high extreme
interestingness	boring	interesting	langweilig	interessant
pleasingness	unpleasant	pleasant	unangenehm	angenehm
beauty	ugly	beautiful	hässlich	schön
spaciousness	narrow	spacious	eng	weit
complexity	simple	complex	einfach	komplex
clarity	unclear	clear	unübersichtlich	übersichtlich

The second experimental task was a **rating of the experiential qualities** of the 16 scenes. At the beginning of each trial, subjects were automatically moved back to the initial starting position (roughly the center of the room: see Figure 1), again facing a random direction. After pressing a button on the joypad, subjects were confronted with the six ratings in a random sequence. The ratings were performed by manipulating an analog slider on the input device. In order to provide visual feedback, the scale and the currently selected value were displayed near the lower border of the screen. During the rating task, subjects were allowed to freely move through the environments.

Variables of Interest. During the **navigation task**, subjects were asked to move to the position that maximized the isovist area (*best overview place*) and to the position that minimized the isovist area (*best hiding place*). For each indoor scene, subjects' performance was evaluated by comparing the isovist area of the chosen positions with the isovist areas of the positions with the actual highest and lowest values.

The virtual indoor scenes differed with respect to the size of the isovists at the positions with the largest and smallest isovist area. In order to compare performance between different environments, subjects' navigation data were normalized according to the range of isovist sizes occurring in the particular scene (see Formula 1 and Formula 2). This performance measure ranges from 0 to 1. If subjects showed perfect behavior with respect to finding the positions that maximized and minimized the isovist area, performance was 1.

$$P_{max(r)} = \frac{Iso_{sub(r)} - Iso_{min(r)}}{Iso_{max(r)} - Iso_{min(r)}} \quad (1)$$

$$P_{min(r)} = 1 - \frac{Iso_{sub(r)} - Iso_{min(r)}}{Iso_{max(r)} - Iso_{min(r)}} \quad (2)$$

with:
r = idendity of virtual indoor scene
$P_{max(r)}$ = performance for finding the position with the highest control value for room r
$P_{min(r)}$ = performance for finding the position with the lowest control value for room r
$Iso_{sub(r)}$ = size of isovist corresponding to subject's chosen position
$Iso_{min(r)}$ = size of isovist corresponding to position with lowest control value for room r

The **rating task** was performed using the semantic differential scaling technique. Six dimensions of environmental experience were represented by pairs of oppositional adjectives (cf. Table 1). Subjects could differentiate their appraisals using a seven step Likert-like scale. The rating categories were selected to represent major dimensions of affective experience (pleasure, beauty, and interestingness), as well as denotative and collative properties that were expected to be potentially relevant for the navigation task (experienced spaciousness, clarity, and complexity). For the correlation analysis, the rating results of each scene were averaged by category over all subjects.

Participants. 16 subjects (8 female, 8 male) voluntarily participated in the experiment, they were paid 8 Euro per hour. Subjects were mostly university students at an age of 20-25 years.

5.3 Results

Navigation Performance. Overall, subjects showed comparable good performance (P) in finding the position with the smallest isovist area and the position with the largest isovist area (smallest isovist: P=.92 ± .02; largest isovist P=.90 ± .02, t-test: t=.96, df = 29.97, p=.3). In some of the virtual indoor scenes subjects reached performance measures over .97, in indoor scene 10 subjects actually reached 1 for finding the *best hiding place*, which means that all subjects found the position that minimized the visible area.

While performance of female and male subjects did not differ with respect to finding the *best overview place* (female: P=.88 ± .02, male: P=.91 ± .02, t-test: t=1.00, df=29.52, p=.3), male subjects showed better performance in finding the *best hiding place* as compared to female subjects (female: P=.88 ± .03, male: P=.96 ± .02, t-test: t=2.44, df=25.21, p=.02).

Figure 4 displays subjects' performance of finding the *best hiding place* and subjects' performance of finding the *best overview place* for each of the 16 indoor scenes separately.

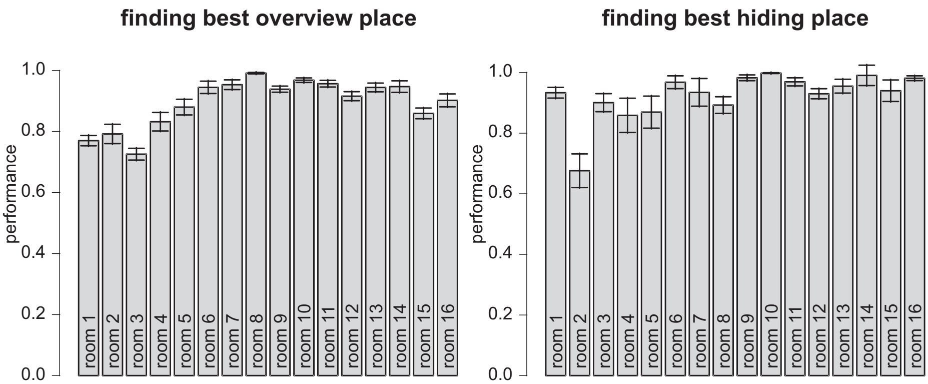

Fig. 4. Subjects' average performance per scene; left: finding the position that minimizes the isovist area (*best hiding place*), right: finding the position that maximizes the isovist area (*best overview place*). The error-bars display the standard error of the means

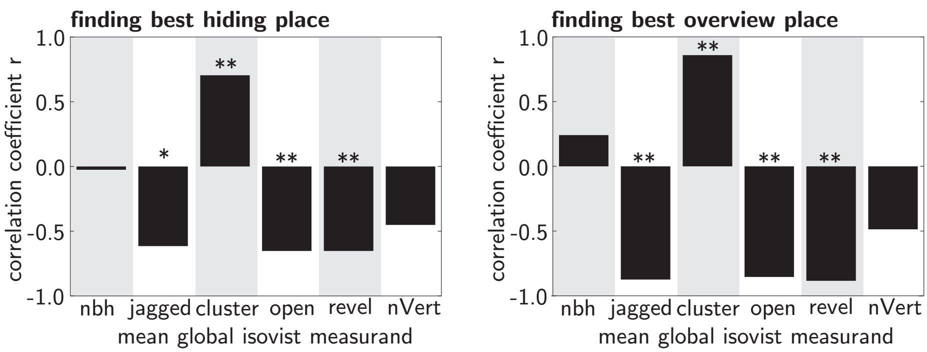

Fig. 5. Correlation between subjects' navigation performance and the isovist measurands neighborhood size (***nbh***), jaggedness (***jagged***), clustering coefficient (***cluster***), openness (***open***), revelation coefficient (***revel***) , and number of polygon vertices (***nVert***)

Correlations Between Navigation Performance and Isovist Measurands. Several strong correlations between subjects' performance and visibility graph measurands were found (see Figure 5). Subjects' performance in finding the *best hiding place* for the 16 indoor scenes significantly correlated with the global measures for jaggedness (r=-.62, p=.01), clustering coefficient (r=.70, p<.01), revelation (r=-.65, p<.01), and openness (r=-.65, p<.01), while performance did not significantly correlate with the global measures for neighborhood size (r= -.03, p=.93) and the number of isovist vertices (r=-.45, p=.08).

Subjects' performance in finding the *best overview place* for the 16 indoor scenes significantly correlated with the global measures for jaggedness (r=-.87, p<.001), clustering coefficient (r=.86, p<.001), revelation (r=-.88, p<.001), and openness (r=-.85, p<.01), while performance did not significantly correlate with the global measures for neighborhood size (r=.24, p=.37), and the number of isovist vertices (r=-.49, p=.06).

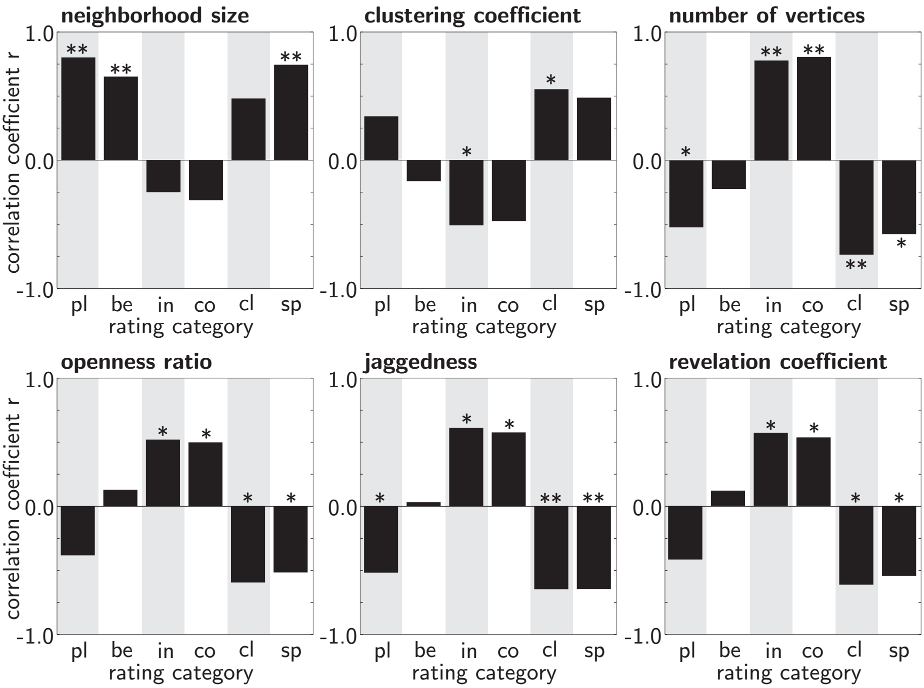

Fig. 6. Linear correlations between the selected global isovist measurands and averaged rated experiential qualities of the scenes in Experiment 1. The rating categories were ***pl***easure, ***be***auty, ***in***terestingness, ***co***mplexity, ***cl***arity, and ***sp***aciousness

It has to be noted that the global measurands jaggedness, openness, revelation, and clustering coefficient were highly intercorrelated in the 16 scenes ($r>.81$).

Rating Task. Also several strong correlations between the global isovist measurands describing the scenes and the corresponding averaged ratings were found (see Figure 6). Most prominently, average neighborhood size (corresponding to isovist area) was highly correlated with rated pleasure (correlation coefficient $r=.80$, $p<.01$), beauty ($r=.65$, $p<.01$), and spaciousness ($r=.74$, $p<.01$). Likewise, the average number of isovist polygon vertices turned out to be strongly interrelated with experienced complexity ($r=.81$, $p<.01$), interestingness ($r=.78$, $p<.01$), and clarity ($r=-.73$, $p<.01$). Additionally, several significant yet slightly lower correlations to the further characteristic values were found. However, due to the high level of intercorrelations within the measurands, they indicate the same statistical relations and are therefore not further discussed.

Correlations Between Navigation Performance and Ratings. A comparison between rated experience and subjects' performance in the navigation tasks rendered an uneven result for the two navigation tasks. For finding the best hiding place, no significant correlation with any rating dimension was found (explained variance $r<.11$). However, the environments in which subjects performed well in finding the best overview place were rated less interesting (r=-.63, p<.01), less complex (r=-.54, p=.03), but more clear (r=.57, p=.02) and spacious (r=.58, p=.02). Additionally, a moderate statistical relation between navigation performance and experienced pleasantness of the rooms was probable (r=.45, p=.08) , although this result was not significant.

5.4 Discussion

Overall, subjects showed remarkably good performance in both of the navigation tasks (finding the *best overview place* and finding the *best hiding place*), demonstrating that subjects were able to perceive the sizes of isovists very well. The basic initial hypothesis that isovists capture behaviorally relevant environmental properties was further supported by the result that the isovist measurands jaggedness, openness, revelation, and clustering coefficient were strongly correlated with the navigation performance. The question of how to qualitatively interpret these statistical relations is however not obvious. The high level of intercorrelations between the isovist derivatives jaggedness, openness, revelation, and clustering coefficient suggests that these measurands captured similar aspects of the environments and basically describe the same property. One possible interpretation could be based on jaggedness: Studies on polygon outlines [4] and building silhouettes [20] have found that the jaggedness measurand corresponds well to introspectively rated shape complexity. Pointing in the same direction, the results of the rating tasks showed positive correlations between jaggedness and rated complexity, and negative correlations between jaggedness and clarity. It is hard to explain, however, why number of vertices was the best predictor measurand for rated complexity, while the correlations with navigation performance were lower in comparison to jaggedness. Taken together, jaggedness, clustering coefficient, revelation, and openness ratio can be seen as measures describing similar aspects of environmental complexity. It is assumed that navigation in complex environments requires an increased mental or computational effort resulting in a negative influence on navigation performance.

The apparent statistical relations between the navigation task and the rating results may however be also interpreted in a different way: Since the navigation task preceded the ratings, the latter might have been influenced by the subjective experience of the former task. For example, the rated complexity of an indoor scene may basically mirror the effort or the subjectively perceived difficulty of the navigation tasks within that scene. This interpretation gains some support by the positive correlation between experienced pleasure and navigation performance, although this relation did not reach significance level. In order to test this alternative explanation, Experiment 2 was designed.

6 Experiment 2

6.1 Objective

This experiment was designed to discriminate between the alternative explanations of Experiment 1 (see Section 5.4). For this purpose, solely the rating task of Experiment 1 was repeated, the navigation task was skipped, and the ratings were done from a fixed central observation point. Comparing the rating results of the two experiments allowed to determine the impact of navigation on the experiential qualities in Experiment 1.

6.2 Method

Experimental Procedure and Variables of Interest. The procedure of this experiment was identical to the rating task of Experiment 1 (see Section 5.2), except for the fact that subjects' movements were restricted to rotational movements only. That is to say, subjects were stationary at the starting position marked in Figure 1. Subjects had to complete all six ratings for each room before they proceeded to the next scene. Again, the scenes were presented in random order. A complete experimental session had a duration of about 20 minutes.

Participants. 13 naive subjects (7 female, 6 male) voluntarily participated in the experiment, they were paid 8 Euro per hour. Subjects were mostly university students.

Analysis. The analysis compared the means and the variance of the samples between the experiments using a two sided t-test and tested for correlations. For the correlation analysis, the rating results of each scene were averaged by category over all subjects.

6.3 Results

No significant differences were found between the mean ratings of the two experiments (see Figure 7 left). If anything, a moderate tendency (p=0.22) was found that scenes were perceived as more interesting in Experiment 2. The ratings of the both sessions were all positively correlated (see Figure 7 right), the correlation coefficient r varied from .49 (beauty) to .88 (spaciousness and complexity). The overall variance between the scenes was almost identical in both experiments (cf. Figure 8 right). The variance within the scenes was very similar between the two conditions except of spaciousness (Figure 8 left): In Experiment 2 spaciousness ratings differed more between subjects than in Experiment 1 (p=.01, not corrected for multiple comparisons).

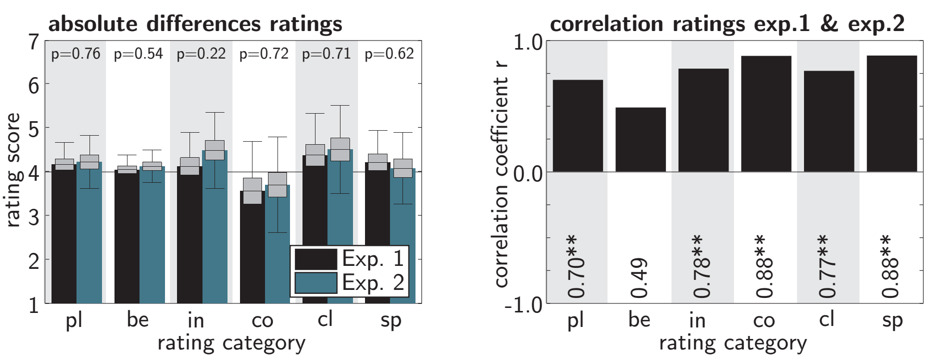

Fig. 7. Mean scores over all ratings and correlations between the ratings of Experiment 1 and Experiment 2. The rating categories were ***pl***easure, ***be***auty, ***in***terestingness, ***co***mplexity, ***cl***arity, and ***sp***aciousness

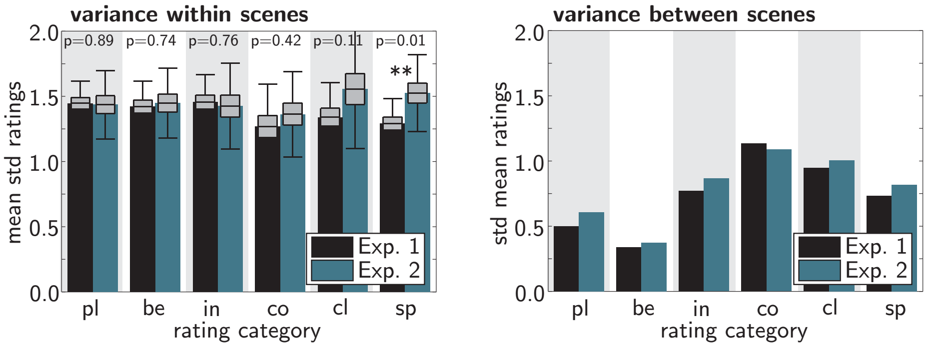

Fig. 8. Bar plots illustrating the variances of the ratings within the scenes (left) and between the scenes (right) of Experiment 1 (black) and Experiment 2 (green). The rating categories were ***pl***easure, ***be***auty, ***in***terestingness, ***co***mplexity, ***cl***arity, and ***sp***aciousness

6.4 Discussion

The high correlations between ratings of Experiment 1 and Experiment 2 together with the lack of significant absolute sample differences demonstrated that the average appraisals were very similar in both experiments. These results suggest that the navigation task including free exploration in Experiment 1 had little influence on the rating task. The potential negative influence of ego-motion on room interestingness could be interpreted in terms of the *mystery theory* [14] suggesting that spatial situations that only promise the gain of information when moving (as in Experiment 2) are more interesting than the same spatial situations after actual exploration (as in Experiment 1). Additionally, the rather low correlation in the beauty rating category (r=.49, p=.06) between experiments could indicate a moderate yet inconsistent influence of the navigation task on the experienced beauty. However, an analysis of the rating variance within and between the scenes offers a plausible alternative explanation for this potential influence on beauty: In both experiments the rating variance within the scenes was remarkably similar over all categories (Figure 8 left), while the variance between the scenes varied depending on the rating category (Figure 8 right). The differences of the mean ratings between the scenes were lowest in the beauty rating category, in other words, all scenes were perceived as being similarly beautiful. Hence, in the beauty category individual differences between the subjects had a much stronger influence on the correlation between the experiments than in the other ratings, and the apparent effect could therefore be explained by the small sample sizes.

The comparative analysis of Experiment 1 and Experiment 2 demonstrated that differences within the ratings were mainly caused by differences between the scenes, and were not an artefact caused by the navigation task. Altogether, remarkable similarities between the experiential qualities rated from a fixed position (Experiment 2) or after free navigation (Experiment 1) were found.

7 Conclusions

The experiments presented in this study investigated interrelations between spatial properties of environments on the one hand and spatial experience and behavior on the other hand. Taken together, the two experiments could demonstrate dominant influences of the environment on both experimental tasks. Beyond this qualitative statement, the technique of isovist analysis allowed to identify factors that were systematically related to both experimental tasks. For experiential qualities and navigation behavior, already single isovist measurands were sufficient to widely explain the variance in the behavioral data. The method of averaging isovist measurands over the complete indoor environments rendered meaningful and discriminatory global characteristic values. An additional indication for the behavioral relevance of isovists can be derived from subjects' remarkably good performance in the navigation task, demonstrating that the area of isovists was well perceivable.

These findings suggest that for further experiments it is worthwhile to translate qualitative descriptions and explanatory theories for spatial preferences and behavior such as "prospect and refuge" into empirically testable hypotheses that make use of isovist measurands. Of course, due to the limited number of tested scenes and the specific character of the navigation task, future work has to test the general validity of the specific findings both for a broader range of spatial situations and for different kinds of spatial behavior. Yet altogether the outcomes of this study suggest that isovist and visibility graph analysis, analyzing space from an inside beholder-centered perspective, provide generic descriptions of architectural spaces that have predictive power for subjects' spatial experience and behavior.

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