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An empirical approach to the experience of architectural space in virtual reality—exploring relations between features and affective appraisals of rectangular indoor spaces

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Abstract

In the presented exploratory study, quantitative relations between the experience of architectural spaces and physical properties were investigated using virtual reality (VR) simulations. Geometric properties from a component-based description of rectangular rooms were tested on their suitability as predictor variables for experiential qualities.

In a virtual-reality-based perceptual experiment, qualities of 16 vacant rectangular interiors were rated in eight principal categories by 16 participants using the semantic differential scaling technique. The simulated scenes were automatically generated by means of a custom made utility that also provided for the component-based room descriptions.

The data analysis revealed strong correlations between several scene features and the averaged rated experience. For example, a preference for ratios near to the golden section could be observed for spatial proportions, which are not directly perceivable. Altogether, a set of five widely independent factors (openness, two room proportions, room area, and balustrade height) turned out to be most effective for describing the observed variance in the attributed experiential qualities.

The combination of realistic virtual reality simulations and psychophysical data raising methods proved to be an effective means for basic architectural research. Several quantitative relations between physical properties and the emotional experience of architectural space could be demonstrated.

Keywords: Experiential qualities; Psychophysics; Correlation analysis; Virtual reality

1. Introduction

It is well known that the built environment influences our emotional state. There are rooms where one immediately feels comfortable and perfectly at ease, while others are awe inspiring or even intimidating. Often, these experiences are difficult to attribute to particular properties of rooms. Architectural theory and education provide only for a few and mainly historic normative rules, ceding the liability entirely to the personal sensitivity of the designer. Several classic studies in environmental psychology

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(e.g., Ref. [1]) have shown that assessments of architectural settings contain common intersubjective patterns that must have been caused by some specific stimulus properties. In addition, it has been shown that scales based on phenomenological comparison criteria (e.g., complexity, novelty, naturalness; cf. Refs. [2,3]), allow predictions on aesthetic and emotional experience. Yet surprisingly, there are only a few systematic investigations of direct relations between physical structure and experienced architectural space.

One obvious reason for this are the methodical difficulties empirical research is faced under hardly controlled real world conditions: limited reproducibility and inflexible stimuli often restrict the scope of investigations to case studies. These drawbacks can be overcome using virtual reality (VR) technology: simulations offer the necessary flexibility under completely controlled laboratory conditions and still provide for a high degree of perceptual realism [4]. While it is sometimes claimed that quasi-photo-realistic quality is a key factor for transferability [5], several studies (e.g., Refs. [6,7]) demonstrate that already current standard virtual environments can be designed to convey experiential qualities of architecture sufficiently similar to reality. Computer simulations also greatly simplify data extraction and analysis and thereby provide for the necessary diverse comparison criteria to experience that are a prerequisite for exploratory factor evaluation studies.

On the other hand, for quantifying the complex phenomena of emotional experience and environmental preferences, environmental psychology at least provides for some basic models (cf. Refs. [8,9]). Most relevant, several practically applicable survey techniques have been described, mainly based on self-reports (cf. Refs. [10]) that, despite certain methodical drawbacks, do well for preliminary evaluations. These methods are particularly suitable for systematic evaluations of affective appraisals that have been defined as attributed emotional qualities of environments or as cognitions about expected place-elicited influences on one's mood [8]. While affective appraisals might be only a rough approximation to actual experiences, they are supposed to be particularly relevant for decisions and behavior.

The above outlined prerequisites allow for evaluations of simulated single spaces. However, another missing central requirement for a broader empirical approach are generic description models of space that provide for comparability between environments and correlate with cardinal dimensions of experience. Recent findings in empirical and computational scene and object recognition research have shown that relatively few generic pictorial features are widely sufficient for recognizing scenes (e.g., Refs. [11,12]), humans accomplish such tasks in fractions of a second, even before conscious awareness [13]. It is well known that the perception and recognition process is simultaneously accompanied by emotional responses (cf. Ref. [14]). Hence, the perceptual gist that allows for scene recognition may also contain primary factors influencing the emotional experience. As demonstrated in a previous study [15], scene descriptions based on basic image features (color distributions, brightness level, amount of edges, etc.) are significantly correlated with attributed experiential qualities.

Besides pictorial properties, humans directly perceive spatial features of their environment as well. Consequently, the aim of this study was to complement these precedent findings with an exploration of relations between basic spatial properties and experience. Models of object recognition that are based on geometrical primitives and a structural description of their interrelations [16] are difficult to transform into preferably few simple numerical dimensions, because decomposition is often ambiguous. Since the semantic meaning of architectural elements can normally be taken for granted, we chose a different approach that was initially motivated by the way spaces are described in colloquial language ("a narrow rectangular room with two small windows"). To a certain extend the ecological view of affordances [17] is adopted: possible interactions with spaces widely depend on the availability of functional units that correspond to structural components such as windows, doors, and floors. If sensibly arranged, their potential is primarily dependent on their geometric dimensions, only to a lesser degree on relations. Thus, the component-based description model solely consisted of the quantities and basic dimensions of the rooms, windows, and doors. To facilitate a direct comparison between different settings, topological or relational information was intentionally excluded, leaving a simple array of scalar quantities. In principle, similar descriptions should be easily obtainable from any component-based CAAD system.

2. Experimental questions and objectives

The primary goal of the empirical study was to exemplarily test quantitative interrelations between parameters from the simplified component-based spatial model and attributed experiential qualities of indoor spaces. Beyond that, the explorative question was, which combination of derivable linearly independent factors would maximize the explained variance and thereby appear most suitable as predictors for experiential qualities. While, e.g., the dimensions of a rectangular room can be defined by the three factors length, width, and height, or equally unambiguously by its volume and two proportions, it is very likely that the overall explained variance differs. For this exploration, normative architectural knowledge for instance on proportions appeared to be a suitable starting point, and besides that, it was particularly interesting whether our outcomes in VR simulations would roughly correspond to classic rules as formulated for example by Palladio [18] that to our knowledge were not yet psychophysically investigated.

3. Method

In the perceptual experiment 16 participants (8 female/8 male) rated 16 virtual rooms in eight experiential categories. For each scene the assessment was preceded by a 30 s exploration period. Subsequently, the experience of all interiors was evaluated using a scaling technique derived from the semantic differential (cf. Refs. [19,20]). Each experiential category (Table 1) was represented by a pair of oppositional adjectives and could be rated on a seven step Likert-like scale. The electronic presentation allowed for a complete randomization of the scene and rating sequence and also provided for response times. The experimental data was complemented by a postexperiment questionnaire on the experimental task and experienced presence during the simulation.

Table 1
English translations of the rating categories used in the semantic differential. The experiment was conducted in German language

Category	English low extreme	English high extreme	German low extreme	German low extreme
Pleasure	unpleasant	pleasant	unangenehm	angenehm
Interestingness	boring	interesting	langweilig	interessant
Beauty	ugly	beautiful	hässlich	schön
Normality	strange	normal	ungewöhnlich	normal
Calm	arousing	calm	aufregend	ruhig
Spaciousness	narrow	spacious	eng	weit
Brightness	dark	bright	dunkel	hell
Openness	enclosed	open	geschlossen	offen

The stimulus set was generated using a custom made modeling utility (cf. Ref. [21]) and consisted of 16 radiosity-rendered 360° panoramic images of vacant rectangular interiors (see Fig. 1). The script based generation process allowed for a large number of rooms and automatically provided the scene descriptions for the subsequent correlation analysis. For keeping this test-of-concept study manageable, only a restricted set of parameters was varied. The variance of the dimensions and positions of all structural components (e.g., walls, windows, doors, or ledges) met the normal ranges of real buildings. Other perceptual properties (surfaces, illumination, and urban background) were constant over all scenes. The scenes were subjectively preselected from a larger randomly generated set of 48 interiors in order to maximize diversity and realism.

During the experiment the virtual eyepoint was at a fixed position for each room, slightly excentric from the center at a height of 1.60 m, while the real eyeheight was at normal seating height (about 1.20 m). As display device a spherical wide-angle projection system (Elumens VisionStation™) at a resolution of 1024×68 pixels was used. The simulated geometrical field of view (FOV) matched the physical FOV of about 130×90° in the projection system. While the screen distance of the projection was fixed at approximately 75 cm, the stimuli themselves offered several monocular depth and size cues: absolute information was conveyed primarily by the virtual horizon height and inferable angular declination. In addition, the structural components and material textures provided additional cues, as their dimensions were in realistic ranges.

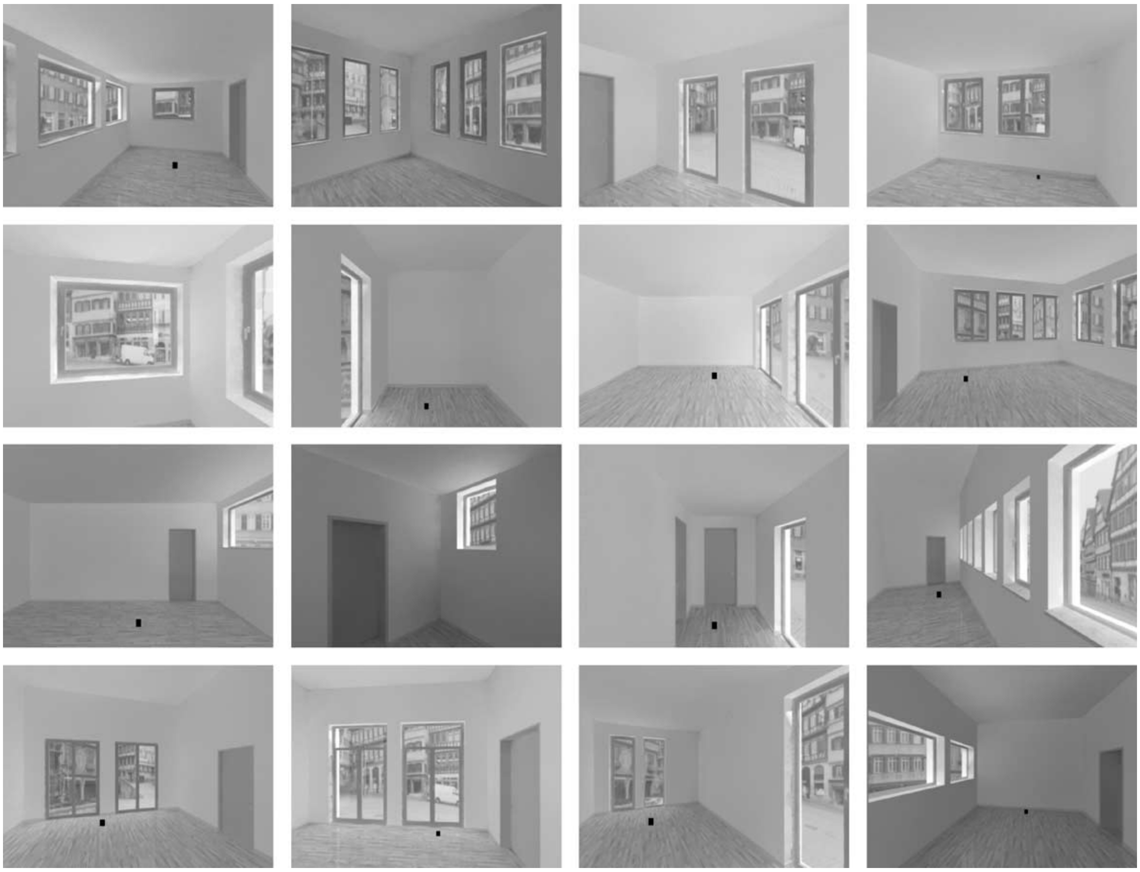

Fig. 1. Screenshots from the 16 scenes used in the experiment. The dark spots on the floor were markers for a different experiment on spatial perception in VR (see Ref. [21]).

For the correlation analysis the rating results of each scene were averaged by category over all subjects. As basic statistical parameter the linear correlation coefficient r was chosen. When theoretically justified (e.g., for proportions), additionally nonlinear trends were evaluated using quadratic regression fits. Significance levels were calculated using Pearson's product moment correlation coefficient. The part-based scene description provided 12 primary parameters, which were the base for 13 further compound measurands.

4. Results

The variance in the ratings was fairly low, the mean of the standard deviation ranged from 1.13 (brightness) to 1.51 (calm) at an average of 1.36 by an equal distribution level of 2.16, indicating unimodal distributions and therefore meaningful intersubjective mean values. The response times, z-transformed per subject, were only slightly correlated with the extremity of judgments (correlation coefficient $r_{mean}=-0.18$**), and thus not useful as additional behavioral measure. According to the postexperiment questionnaire, participants felt moderately present (average rating 62.5%) during experiment, and were widely content with the appropriateness of the medium (80.2%) and realism of the simulation (72.9%).

As expected, denotative rating categories covaried with corresponding scene features (see Fig. 2 for selected correlations). For example, spaciousness correlated with the actual room area (r=0.84**), but the coefficient with overall window area was even

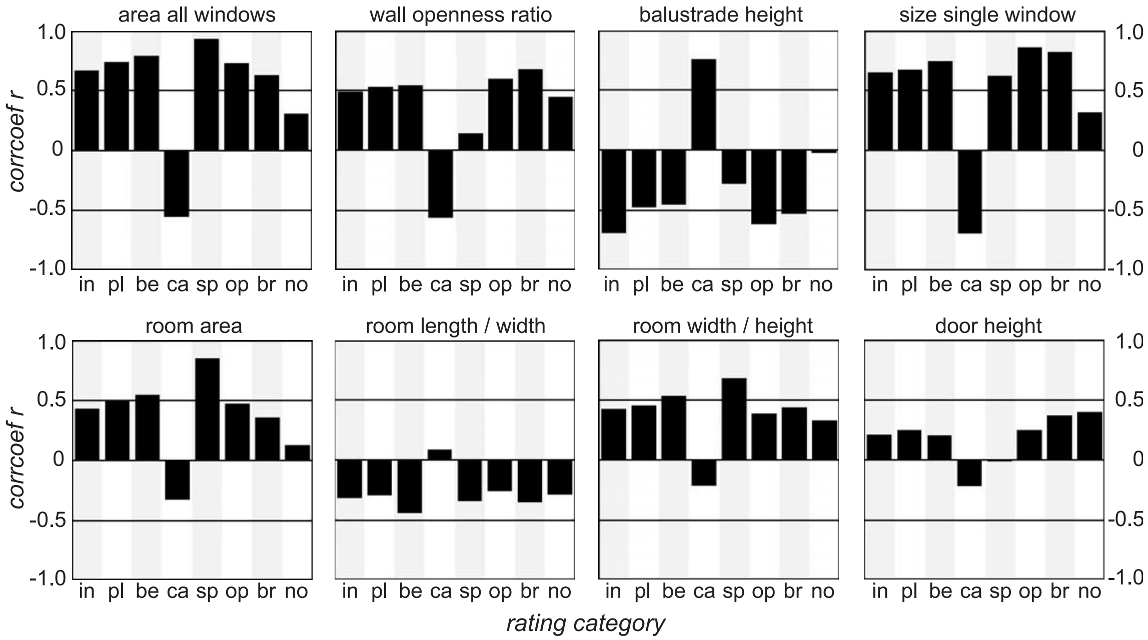

Fig. 2. Linear correlations between rating categories and selected scene features.

higher (r=0.92**). Perceived openness and brightness were highly correlated to the relative wall openness ratio (wall area/window area), which is a direct correspondent to the physical brightness of the scenes. For experienced openness, the comparison with the size of single windows rendered the highest correlation coefficient (r=0.85**). The results of rated calm were widely oppositional to rated openness, it was negatively correlated with all factors influencing relations to the exterior as for instance balustrade height (r=0.75**) and window sizes (r=−0.69**). Unlike window parameters, surprisingly door properties did not show significant effects in any rating category.

The three affective rating dimensions beauty, pleasure, and interestingness, appeared highly interrelated (correlation beauty–pleasure r=0.96**, beauty–interestingness r=0.90**). Regarding their correlations to scene features, the correlation with the physical openness ratio was highest (e.g., beauty–openness r=0.86**). Surprisingly, window proportions or numbers rendered no significant effect, apart from openness only balustrade height showed a considerable tendency (r=−0.44, p=0.08). Regarding room dimensions, from the tested combinations of independent linear factors a set consisting of room area (r=0.54*), the principal proportions width to height (r=0.53*), and length to width (r=−0.43, p=0.09) yielded the highest yet still moderate correlations with the affective rating dimensions. However, a quadratic regression for the correlations with room proportions revealed assumable dominant nonlinear trends and showed maxima near to the golden section (room length/width maximum at ratio 1.7, room width/height maximum at ratio 1.5, see Fig. 3). In addition to these parallel main tendencies, the differentiation in three evaluative experiential categories appeared informative: interestingness was relatively more correlated with window properties, whilst beauty more with room proportions.

In contrast to our expectations, the ratings of normality and interestingness were not significantly interrelated. The only highly significant linear correlation of normality was detectable to physical openness (r=0.65**). However, square fitting revealed nonlinear tendencies for several scene features (e.g., window dimensions and room propor-

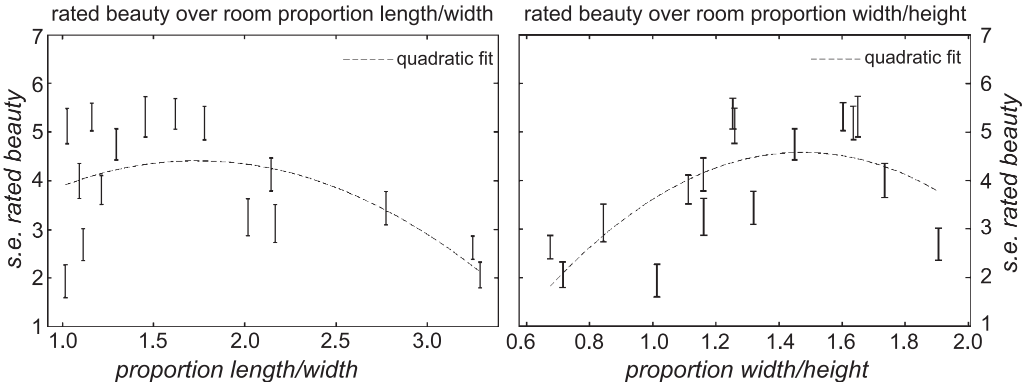

Fig. 3. Nonlinear correlations between room proportions and rated beauty.

tions), indicating that extreme values were seen as strange.

5. Discussion

The strong and widely linear relation between physical openness and the affective rating categories were not expected. We suppose that this was partially caused by the particular attractiveness of the urban background. Additionally the short period of exposure to each room, and a missing simulation of potentially incommoding environmental factors such as noise level and reduced privacy by passersby may have contributed to the entirely positive response to openness. The remarkably high correlation between rated spaciousness and window size may be interpreted as compound effect of room size and openness, since obviously room size directly affects available wall area for openings, and an additional effect of the surrounding outdoor space is indicated by the correlation level with the physical openness ratio (r=0.68**).

Overall, the results appear reasonable, since denotative ratings almost covary with corresponding scene features and expectations based on normative rules were confirmed. These outcomes clearly support the validity of the simulation and show a substantial potential for empirically investigating experiential qualities. Many of the sometimes unexpectedly high correlations virtually provoke for further speculations on causalities. As this is always problematic for correlations, we prefer to consider them as descriptors or indicators that allow for probable inferences on experiential qualities. Altogether, from the tested combinations a set of five almost independent factors (openness ratio, two room proportions, room area, and balustrade height) appeared to be a very effective set of descriptors for the variance in the ratings of this scene set. While an entire linear separation of the factors certainly is mathematically possible, e.g., by dividing openness by balustrade height, this set has the clear advantage of obvious interpretability.

Let us return to the theoretical origins of our component-based description model, and what are the implications of our findings? First of all, the factors are not meant as a model for mental representation or empirical scene and object recognition. Their primary objective is to effectively describe the differences in the scene set that are most correlated with attributed experience. Besides functional and spatial information, general perceptual properties such as brightness or pictorial frequencies (e.g., via the number of openings) are indirectly included in the measurands that would presumably emerge in other models. While, therefore, the importance of the implemented ecological aspect should not be overstressed, it is on the other hand a thought-provoking source for interpretations. For example, had doors no effect because they were without function in the experiment? Or was room area so effective on pleasure, in contrast to the normal connotation of coziness, as it just linearly increased the functional potential? Pointing in a similar direction, several participants reported that it would have changed their experience if they had known which purpose the rooms were meant for.

Hence, as suggested by Kaminski [22] (pp. 255–257), a consideration of action and defined function could allow further refinements.

While for the purposes of this study configurational information was apparently negligible, the results of course do not implicate that relations between components are of minor effect. In fact the tuning of the scene generator utility for producing just similarly "normal" configurations was a process of many successive refinements. Most architects would presumably consider this aspect of composition more delicate than reducing buildings to an array of roughly specified features. The scope of this test-of-concept study was deliberately limited to some variations of standard closed rectangular rooms. The chosen descriptors were particularly suited to capture the gist of these kinds of spaces with a low complexity level and consisting of simple structural components with unambiguous composition. Of course, for being generally applicable, the description model would have to be extended and adapted. While most individual results of the study appear generally convincing, due to the small and preselected scene set they certainly cannot claim general external validity. The method itself, however, has successfully shown its generic potential. In sum, the revealed factors appear promising candidates for further investigations.

6. Conclusion

In this study, we quantitatively explored correlations between basic spatial properties of rooms and their attributed experiential qualities. Virtual reality simulations proved to be a powerful means for basic architectural research that allows for optimized empirical methods. The results generally back the principal approach that aspects of emotional experience are empirically investigable and have determinable correspondents in the physical environment. The interaction of five widely independent factors (openness, two room proportions, room area and balustrade height) from a component-based description appeared to be very effective for describing the observed variance in the ratings. The high level of correlation is particularly remarkable for affective and aesthetic rating categories that cannot be trivially attributed to just one scene feature. The chosen model representation offers evidence both for the importance of perceptual features as for an affordance-based view. Since architecture is both functionally motivated and art, we think that the profession as well as occupants will benefit from reliable quantification methods for experiential qualities that allow to consider them as objective design criteria.

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