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## Investigating the effect of urban form on the environmental appraisal of streetscapes

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### **Abstract**

*Urban planning decisions have long-term implications for the appearance and functionality of cities and it is therefore highly important for city planners to understand how urban structure influences the experience of a city's inhabitants. In this study, participants walked through three urban routes (the direction varied between groups) and rated their environmental appraisal both by marking their pleasure continuously on a map, as well as by rating certain checkpoints that revealed different urban scenes along the way on a semantic differential scale. Results are presented for subjective user ratings, as well as in relation to objective, formal measures of spatial qualities via space syntax (e.g. centrality measures integration and choice, as well as isovist properties). A factor analysis of the bipolar adjectives revealed that items were loaded on what we called appeal, activity and spatial experience of the streets. Previous experience in terms of spatial sequence did not appear to influence these evaluations. The combination of global and local spatial properties correlates more strongly with environmental appraisal, or appeal of space, than the use of either one of them. We discuss these results in the light of understanding (and attempting prediction of) to what extent environmental properties relate to users' experience of city streetscapes.*

### **Keywords**

*Urban perception, visuospatial properties, environmental appraisal, predictive model, isovist, centrality measures.*

## 1. Introduction

One of the key steps in urban design is the definition of urban form. Decisions about spatial dimensions, relations and shapes, as well as the allocation of streets and buildings strongly influence ongoing and future urban development. Once streets and buildings are built, they are difficult to adjust or redesign, with the exception of their colour, texture or vegetation. It is therefore highly important for urban planners to understand how citizens' behavioral and emotional responses relate to and are influenced by urban geometry and spatial configuration.

This article focusses on methods for measuring and predicting people's emotional response to spatial form, based on computationally derivable features of urban form. This work is motivated by the fact that cities are typically designed for long time spans and must satisfy the needs of many individuals. The actions of individuals, however, are not fully rational and hence predictable. They depend on a variety of factors that are not a direct consequence of urban design, such as prior personal experience, cultural background, health and socio-economic status. From our point of view, architectural research needs to develop and improve its methods, to identify "potentials" for promoting or avoiding certain behavioral and emotional responses to urban form and design.

Previous research has mainly investigated how certain features of spatial geometry could be related to certain human behaviors. For example, various Space Syntax studies (Hillier & Iida, 2005) showed that centrality measures of the street network (which are based on the geometry of the open space generated by the shape and allocation of buildings) can significantly impact human movement patterns. These movement patterns in turn strongly influence how people use public space; e.g. commercial spatial use is generally located at more central and easily accessible locations in a city (Hillier et al, 1993; Svetsuk, 2010). While these studies provide insight into how spatial form influences the use of space, it remains unclear to what degree spatial form relates to people's environmental perception and appraisal. Architectural scholars have frequently pointed out that such "perceptual qualities" (Ewing, 2005) are at least as important as functional qualities (Cullen, 1971; Thiel, 1961; Trieb, 1974).

The influence of spatial features on the experience of urban spaces has largely been studied (e.g. Herzog, 1992; Kaplan et al, 1972). Yet, the spatial features used for correlation analysis are usually measured based on experts' ratings and selections. For this reason, it is hard to apply these research findings to the evaluation of novel situations, as would be necessary for spatial design. Few studies propose using properties of the visual field (such as isovists) in order to objectively derive the features of the environment (Franz & Wiener, 2008; Stamps 2005; Weinkamp et al, 2014). Despite the appeal of linking visuo-spatial properties to human spatial experience, no evaluation has been undertaken of how these properties affect the spatial experience of people *moving* through an urban environment. However, the consideration of movement, when studying the effect of urban form is crucial, because cities are complex spatial artefacts that are only understood and experienced while moving through them.

### *Aims of this study*

The main goal of this study is to acquire more insight into the relationship between subjective aspects of appraisal and environmental properties. In other words, what is the most appropriate model to predict people's judgement of spatial situations based on quantifiable spatial properties? Several sub-questions need to be answered as part of this, such as: a) Do people agree in their judgements? b) Does the direction in which one is heading while passing along a street play an important role for environmental appraisal? And c) how does the sequence of spatial situations influence judgements?

We conducted a field study in which participants were asked to rate their experience during a walk through three predefined streetscapes that contained a variety of spatial situations; and then correlated these subjective ratings with the objective, spatial properties of these scenes.

## 2. Methods

### 2.1 Participants

The participants were international students of architecture and urban design aged 21 to 25 years. The composition of the participants constituted from eleven different nationalities from three continents. Their familiarity with the city ranged from subjectively perceived 'no experience' to '1 month'.

Two data sets were gathered: the first data collection took place during October 2014, with  $N=15$  participants; the second data collection took place in November 2014, with  $N=26$  participants. The temperature difference between October and November was 9°C, and the ambient light changed slightly during these autumn months.

In order to assess potential differences between the ratings from participants who completed the routes in October and those who participated in November, we performed a series of Mann-Whitney U-tests, one for each of the 11 item ratings per checkpoint that are described in the next section. Out of the 736 tests evaluated, 63 yielded significant results. However, after applying the Bonferroni correction in order to control for familywise error caused by multiple comparisons, none of the tests were significant. For this reason, as well as the benefit of combining the data from the two groups, we decided to integrate the data sets for all further analyses.

### 2.2 Materials

#### 2.2.1 Questionnaire on subjective experience

Self-report, adjective-based, bipolar semantic differential scales have widely been used in psychological and architectural research to assess aesthetic and emotional responses to space (e.g. Kuliga et al, 2013; Benz & Rambow, 2011; Franz & Wiener, 2008; De Kort et al, 2003, Hershberger & Cass, 1974). Due to the number of measurement points (30 per participant) in this study, we selected a shortlist of eleven items of particular interest:

Spatial experience was assessed via the items Narrow-Spacious, Dark-Light, and Enclosed-Open. Emotional response was measured via the items Dislike-Like, Ugly-Beautiful, Chaotic-Ordered, Boring-Interesting, and Insecure-Secure. Spatial activity was measured via the items Noisy-Quiet, Crowded-Empty, Private-Public. Following Nasar's (1994) call for investigating both formal, measurable stimuli, as well as subjective, symbolic stimuli, one might argue that items such as Dark-Light are formal, as light levels are measurable, while items such as Chaotic-Ordered may depend on a mix of formal stimuli and a variety of personal variables, e.g. individual perception of other people on a street, noise levels and previous experience or preferences of cities.

Furthermore, in order to assess emotional experience directly, we asked participants to continuously draw their mood (in terms of Pleasant-Unpleasant) directly on a map of their walking path. To simplify the handling for colouring the map during walking, we used a two-sided pencil with a blue and a red side (light red meant slightly pleasant; strong red meant strongly pleasant; and similarly for blue as unpleasant). This "Colored Impression Map" gives us a rough impression of the environmental appraisal of the whole study area. This is augmented by the semantic differential, which provides detailed insight into the appraisal, although only for selected spatial situations.

#### 2.2.2 Selecting streetscapes

Three routes in the city of Weimar, Germany, were selected that cover various spatial situations, such as narrow lanes, wide streets, pedestrian zones, large and small squares, simple and complex intersections, historically evolved urban patterns (curved streets) and grid-like street patterns. We kept the length of these routes similar – 1.6km, 1.5km, 1.4km long; respectively – and the walking time was always less than 20 minutes for each of these routes.

In order to systematically investigate the effect of successively changing spatial situations on environmental appraisal, we defined the routes so that they intersected at several locations. This allowed us to evaluate a spatial situation as part of different sequences. The evaluation points for the user's experience of these paths were chosen so that all participants were facing the same direction (i.e. shared the same view regardless of the path they came by).

### 2.3 Procedure

Each participant was asked to walk along the three paths freely, while following a route description that was set up by the researcher so that participants would not lose their way during the study. In order to evaluate how spatial experience of scenes changed depending on how they appeared when walking in a certain direction, the walking direction was varied for each route. Half of the participants walked the route in one direction, while the other half walked in the opposite direction.

Participants were randomly assigned to a certain route and direction. A 20-minute recreational break was prescribed between any two evaluations in order to prevent fatigue from influencing the results. The studies were conducted during workdays between 9am and 3pm. The time for one route (including walking and evaluation) took between 30 and 40 minutes.

While walking, participants mapped their intuitive response to environmental appeal (pleasant to unpleasant) continuously by colouring-in the route they walked. The continuity and finer grain of this so-called "Coloured impression map" makes it possible to follow transitions and precisely define points of change.

Additionally, at ten to twelve predefined "checkpoints" along the path (a total of 68 on 3 routes), participants were asked to give a more detailed evaluation of the spatial situation by using the semantic differential scale as described earlier. These checkpoints were located shortly before and after turning into a different urban scene, making it possible to compare differences in visuospatial properties and the assessment of experiential changes.

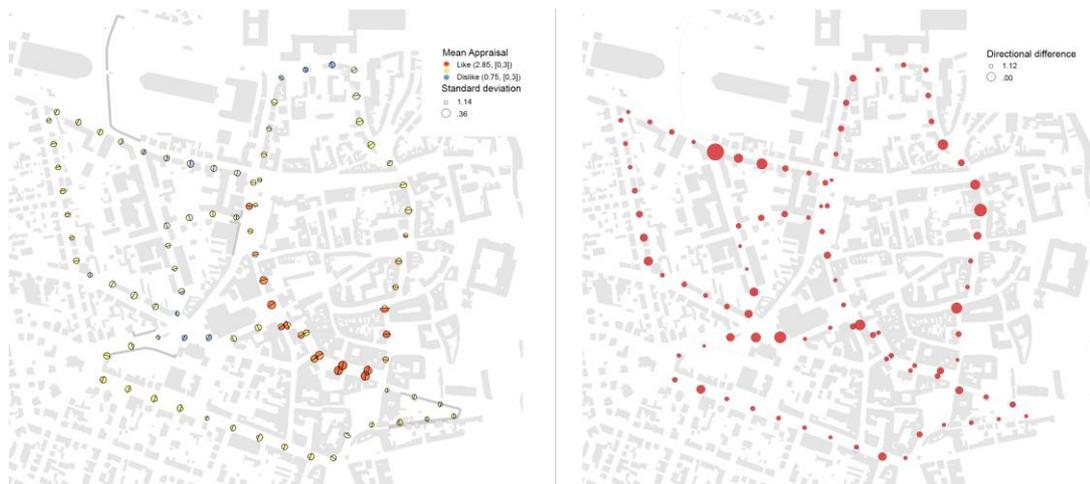
After completing each of the three walks, participants were also asked to evaluate the specific route as a whole, respectively, with the same items as for each individual "checkpoint evaluation".

## 3. Results

### 3.1 Coloured impression maps

In order to analyze the colours the participants used to mark their environmental appraisal of whole streetscapes, we had to discretize and digitalize their maps. For high detail, we chose a dense division of thirty, equally distributed points along each of the three paths. For each of these thirty points on the three routes, for which we had groups walking in either direction (resulting in 180 points in total), the respective colour was converted into numbers ranging from 0 (dislike) to 3 (like).

This process of digitalization resulted into more than 3600 evaluations. In order to explore and visualize the results, we reduced this data set by calculating mean ( $M$ ) and standard deviation ( $SD$ ) for each of the 180 points. These were then plotted on the map (Figure 1), showing the average evaluation for every point as a colour gradient (where blue = dislike, red = like) and agreement rate between different participants in the form of a negative function of standard deviation as the radius of the circle (the smaller the radius, the bigger the standard deviation = the smaller the consensus). Additionally, each point was divided in to half circles in order to visualize the difference between the two directions.



**Figure 1:** Left - Intuitive appraisal (general impression) of environment mapped displaying the average value as a colour gradient and standard deviation as radius of the circle. Right – Mapping directional differences

### Discussion

A visual analysis of the resulting map, shows a) that there are relatively smooth transitions between positively and negatively rated areas, while there are only few exceptions, where changes are abrupt; and b) that results with the most positive ratings and smallest deviations are located in the pedestrian zone of the historical center of this city, while the most negative average ratings with low level of consistency among participants are placed on crossroads exposed to heavy car traffic.

The right-hand graphic of Figure 1 shows the difference between subjective ratings for the same position, but in the *opposite direction* (the bigger the radius ( $r$ ), the bigger the directional difference ( $d$ ) in evaluation;  $(p_1, p_2) > r; f(d_1); d_2 | p_{1z} | p_{2z} |$ ). Generally, we can observe a strong linear relationship between the two opposite directions; expressed by  $R^2 = .705$ , and average difference between two points  $d_{\text{mean}} = .21$ ; range = [0-3]. However, we identified several locations with strong differences between the evaluations in two opposite view directions.

### 3.2 Checkpoint ratings (semantic differential)

Before analyzing the relationships between aspects of appraisal and environmental properties, we first identified which distinct aspects of environmental appraisal are addressed by the semantic differential, and explored the intercorrelations between the eleven items of the semantic differential. To quantify the relations between pairs of ordinal categorical variables which captured continuous data, a polychoric correlation matrix was chosen. The strong relationships between the items (Table 1) suggest that some of these semantic differential items might be measuring the same aspect of environmental appraisal and are therefore redundant.

The factor analysis using generalized least square (GLS) estimation and an oblique rotation (*Geomin Q*) on a matrix of polychoric correlations of the items resulted in three factors, as suggested by parallel analysis (Figure 2). Extracted factors account for 62% of the total variance (28%, 20%, and 15% respectively per factor) in the data. The negative effect of reducing variance in the data is in our case heavily compensated for by reducing the complexity of the analysis through focusing on three instead of 11 variables and increasing their reliability and stability.

In a detailed look at the three different factors, we observed that semantically related items were grouped together, which raised our confidence about their validity. We labeled the three factors *Appeal* (Dislike-Like, Ugly-Beautiful, Boring-Interesting, Chaotic-Ordered, Insecure-Secure), *Activity*

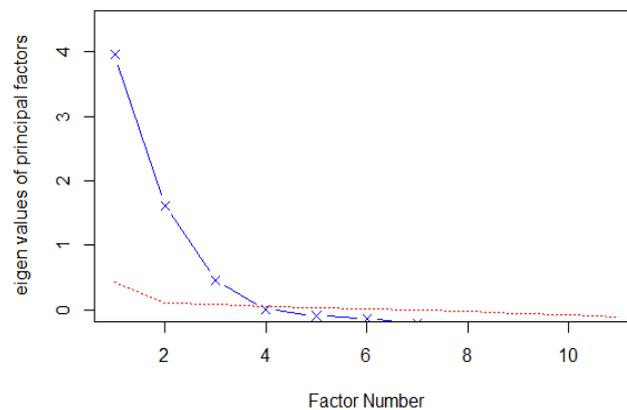
(Crowded-Empty, Noisy-Quiet, Private-Public) and *Spatial Experience* (Narrow-Spacious, Enclosed-Open, Dark-Light) (Table 2).

	Boring Interest.	Chaotic Ordered	Crowded Empty	Dark Light	Enclosed Open	Insecure Secure	Narrow Spacious	Noisy Quiet	Private Public	Ugly Beaut.	Dislike Like
boring	1										
chaotic	.229	1									
crowded	-.329	.222	1								
dark	.354	.106	-.174	1							
enclosed	.375	.079	-.245	<b>.57</b>	1						
insecure	<b>.515</b>	.342	-.119	.35	.286	1					
narrow	<b>.427</b>	.090	-.317	.52	<b>.708</b>	.317	1				
noisy	.074	<b>.460</b>	<b>.452</b>	-	-.154	.185	-.143	1			
private	.413	-.144	<b>-.555</b>	<b>.40</b>	.510	.273	<b>.531</b>	-.360	1		
ugly	<b>.764</b>	<b>.413</b>	-.117	.30	.331	<b>.526</b>	<b>.415</b>	.219	.249	1	
dislike	<b>.798</b>	<b>.460</b>	-.213	.33	.350	<b>.568</b>	<b>.406</b>	.221	.282	<b>.828</b>	1

**Table 1:** Matrix of polychoric correlations for semantic differential items, N = 1.348

	Factor 1 <b>Appeal</b>	Factor 2 <b>Activity</b>	Factor 3 <b>Spatial Experience</b>
Boring-Interesting	<b>.801</b>	-.273	-.003
Chaotic-Ordered	<b>.526</b>	.486	.062
Crowded-Empty	-.069	<b>.755</b>	.013
Dark-Light	.060	.028	<b>.647</b>
Enclosed-Open	-.073	.004	<b>.899</b>
Insecure-Secure	<b>.543</b>	.054	.173
Narrow-Spacious	.056	-.094	<b>.748</b>
Noisy-Quiet	.412	<b>.643</b>	-.082
Private-Public	.029	<b>-.537</b>	.392
Ugly-Beautiful	<b>.865</b>	.010	.034
Dislike-Like	<b>.934</b>	-.047	-.004

**Table 2:** Factor loadings for extracted three factors as suggested by parallel analysis. The highlighted items have been used to build three independent factors



**Figure 2:** Parallel analysis on matrix of polychoric correlations of semantic differential items (N = 1.348) with 100 iterations

A visual comparison of the factors plotted on the map (Figure 3) shows different patterns for each factor, which underlines the idea of identifying several distinct aspects of environmental appraisal. The relationship between two evaluations from the same position but looking in opposite directions is virtually as strong as the results of the coloured impression map. However, the values vary across the different factors. The Spatial Experience factor has the weakest relationship with  $R^2 = .49$  followed by much stronger relationship for Appeal  $R^2 = .62$  and Activity  $R^2 = .72$ . This supports the intuitive assumption that spatial qualities are highly dependent on the view direction whereas the activities in space have a wider scope of influence. Additionally, the average absolute difference between the pair of respective checkpoints was similar for all 3 factors with value of  $d_{\text{mean}} \approx .31$ ; range[0-4] (see “Analysis of coloured impression maps” for the calculation). Taking into account the different ranges of the coloured impression map and semantic differential, the absolute difference of both is almost identical.

### Discussion

Despite the fact that, on average, we can observe similar appraisals for different view directions, there are several exceptions in our data. These show consistently for all three factors in checkpoint analysis and also in the coloured impression map, and are mostly at places where there are sharp transitions between different types of urban environment (pedestrian zone – major traffic junction, park – historical old town). At these points, the two different view directions offer very different stimuli in terms of function but also morphology of the space.

By comparing the previous plot based on the coloured impression map with the three factors, we can see strong similarities to the Appeal factor. This observation was confirmed by a high value of linear correlation  $R^2 = .81$  between Appeal factor for all 68 checkpoints and the respective points on the digitalized colour map. This suggests that the coloured map could be used as an alternative data set for Appeal factor offering a significantly higher spatial density and size of the sample.



**Figure 3:** Mapping of semantic differential items with highest loading for Appeal, Activity and Space factor, showing the average value as a colour gradient and standard deviation as radius of the circle

### 3.3 The effect of sequence

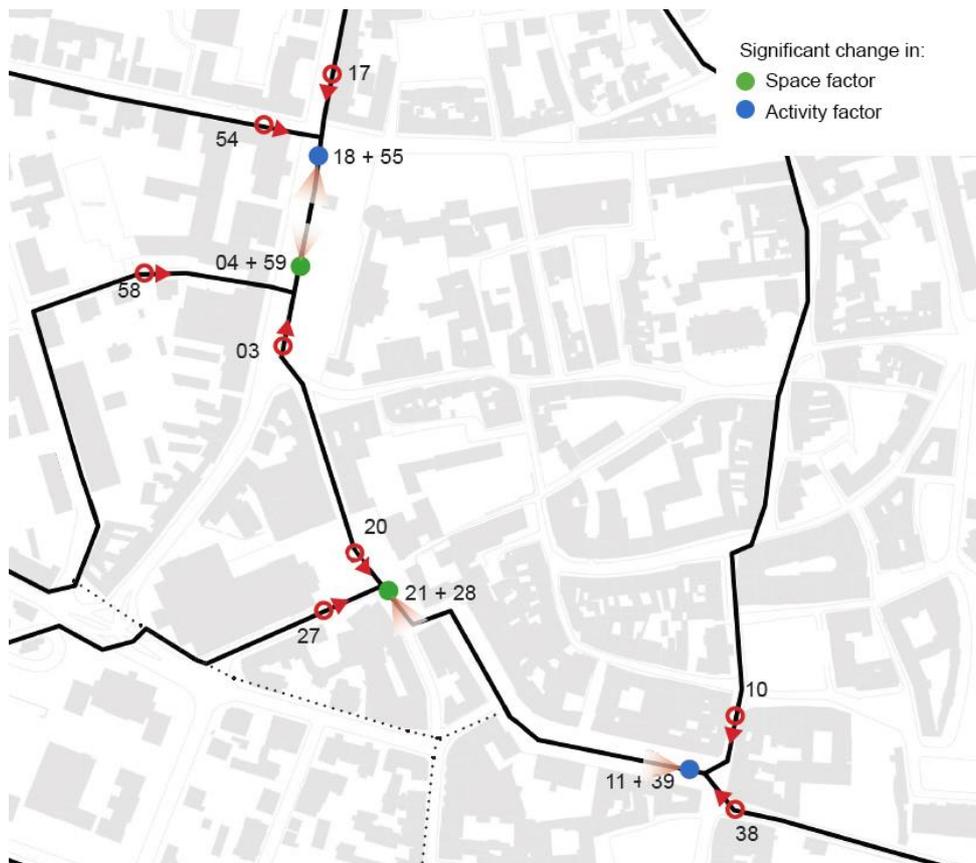
As suggested by many architecture scholars (Cullen, 1971; Thiel 1965; Gehl, 2013), the human perception of any particular environment is influenced not only by what we currently see, but also by our immediate *previous* experience, i.e. what we have just seen. This suggests that the impact of spatial sequence might be an important variable for a predictive model of environmental appraisal. The study was explicitly set up so that we can observe the immediate effect of different spatial experiences on environmental appraisal in a real-world environment. We achieved this by crossing the routes in such a way that one evaluation point is reached from two different positions (Figure 4): checkpoints 18 and 55 are the same points in space sharing the same view direction but have been reached from two different positions: the route Old town B – checkpoint 17 and route West B – checkpoint 54.

In the evaluation process, we first tested the similarity of the environmental appraisal of the situation just before the two routes lead to the same point. We tested the null hypothesis for all four point pairs in question, by analyzing the three appraisal factors identified before. The null hypothesis, i.e. that “there is no difference between the pair of the points”, could be rejected for all twelve tests based on the  $p$  value  $\leq .05$  (three appraisal factors for all four pairs of precedent points). Once we knew that the evaluation at the starting position, and thus the sequence, is in all cases significantly different, we can test whether the mutual checkpoints sharing the same position and view also differ.

Out of the twelve statistical tests, only four turned out to be significant ( $p \leq .05$ ). For the point pairs in Figure 4, 18+55 and 11+39, there was significant difference in Activity factor evaluation, whereby the pairs 21+28 and 04+59 differ in Space factor evaluation. None of the point pairs show significant differences in the Appeal factor as well as in more than one factor at the same time. Additionally, we examined not only the significance of the difference but also the absolute value, which was on average less than .10 for range [0-4].

### Discussion

On summing up these results, we did not find any significant influence of the sequence on the environmental appraisal in eight of twelve cases, and the differences found for the significant cases were relatively small. These might be influenced by the small size of analysis points or the chosen appraisal factors. In future studies, these should be considered in order to gain a larger statistical basis for quantifying the effect of spatial sequence on the environmental appraisal. For now, however, we see only limited benefit to including any measure of spatial sequence as a further variable in our predictive model.

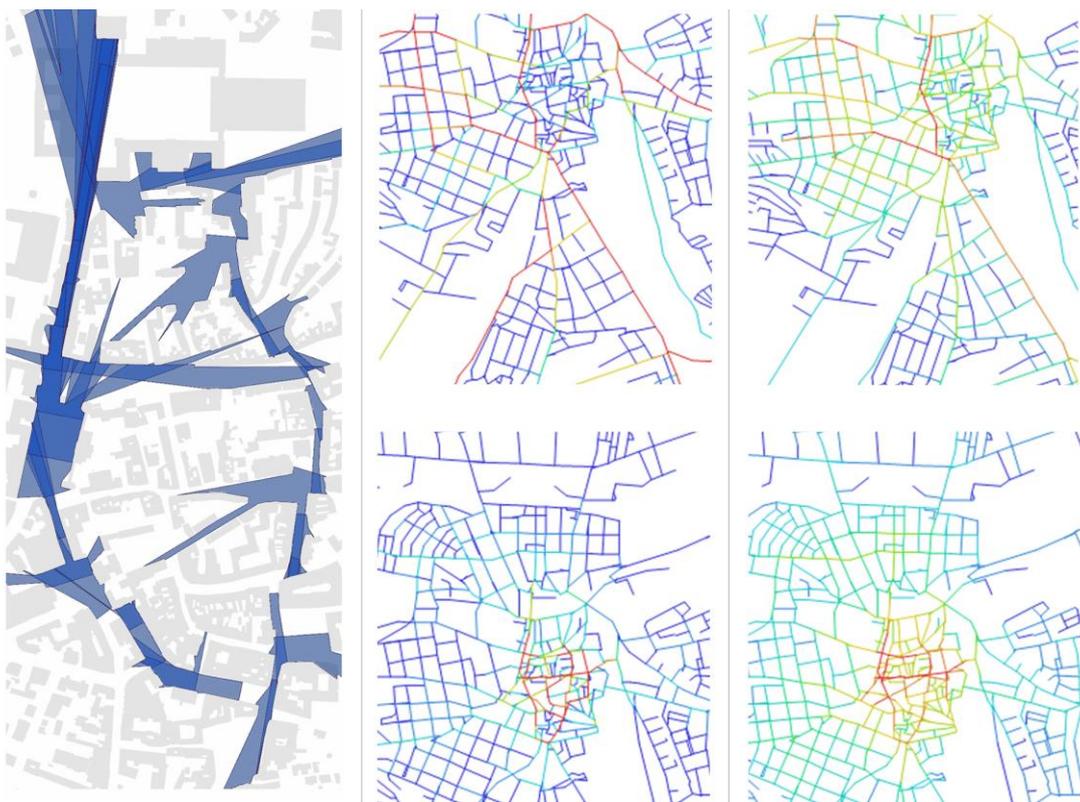


**Figure 4:** Analyzing the effect of spatial sequence on the environmental appraisal. Four significantly different evaluations were found (out of twelve possible)

### 3.4 Correlation of subjective ratings with spatial properties

In this section we correlate the results described above with several properties of urban form in order to investigate how strong the impact of geometry is on the environmental appraisal. As measures we are using 2D-Isovist and a Space Syntax Analysis of the street network. An Isovist is defined as the area that can be seen from a single vantage point. Benedikt (1979) suggested several properties that can be derived from an isovist polygon for the characterization of spatial situations. In this study we are using four isovist-properties: area, perimeter, compactness and occlusivity. Instead of a 360°-Isovist, we calculated directed 180°-Isovists in order to be able to take account of different evaluations in different directions.

Space Syntax Analysis is based on two centrality measures – closeness centrality (Integration) and betweenness centrality (Choice) to characterize the accessibility of locations. For the calculation, the angle between street segments is used as the measure for distance, relating to psychological distance (Hillier & Iida, 2005). Using this concept Closeness Centrality (Integration) is interpreted as how easy it is (in terms of direction changes) to get from one segment to all others (high values indicate central locations, low values indicate segregated locations). Betweenness Centrality (Choice) is calculated by adding the number of times segments are part of all shortest paths, whereby high values indicate important connectors. Both measures can be calculated for different radii, corresponding to different types of mobility implying different reach distances. In our study we used the radii  $R_n$  (“from all to all segments”) and  $R_{600}$  (from each segment to segments in the reach of 600m)<sup>1</sup>.



**Figure 5:** Visualisation of the spatial properties (left: Isovists along the path; Centre: Integration ( $R_n$  und  $R_{600}$ ) and Right: Choice ( $R_n$  und  $R_{600}$ ) of the street segments

<sup>1</sup> The latter we previously identified to match best with the pedestrian movement pattern in the centre of Weimar.

The results of both types of analysis are shown graphically in Figure 5. While Isovists can be characterized as local properties (since they are directly observable from a single point in space), the centrality measures are usually referred to as global or relational properties since their meaning can only be experienced by traversing a spatial environment.

As a first step in investigating the relationship between dependent (three factors of environmental appraisal) and independent (isovist and centrality measures) variables, we used a Spearman's rank correlation matrix (Table 3). This correlation measure was chosen due to the strong deviations from normal distribution for most of the variables. Additionally Bonferroni  $p$ -values were calculated to identify significance of the correlations ( $p \leq .05$ ).

The correlation matrix shows clear differences between the two sets of independent variables. There is no significant correlation for any of the isovist measures, whereas the centrality measures are significant in seven out of twelve cases. The strongest relationship is most obvious between the activity factor of environmental appraisal and the pedestrian radius centrality measures (Integration R600:  $R^2 = .524$  and Choice R600:  $R^2 = .508$ ). This result matches the theoretical model of natural movement (Hillier et al, 1993) and confirms previous field studies that link pedestrian flow and centrality measures. Even though the Activity factor of environmental appraisal is the outcome of manifold cognitive processes, these results suggest that the objective frequency of pedestrian flow might play important role in it.

Both local centrality measures (integration and choice) have been tested as significant predictors of the Spatial Experience factor with similar  $R^2 \approx .22$ . Finally we found only one relationship between appeal factor and the independent variables, which shows that on their own they have very limited predictive power (Integration Rn:  $R^2 = .034$ ).

While some aspects of environmental appraisal can be predicted quite well using only one independent variable (Activity & Centrality measures), there are others which are expected to be a more complex product of multiple simultaneous variables acting together. To increase the predictive power of our model, we analyze the simultaneous influence of isovists and centrality measures by adopting the multiple linear regression function. In order to fulfil the core requirement for the multiple linear regression function, it is necessary to prove the mutual independence of all explanatory variables. After examining the correlation matrix for all eight variables, we found that all four isovist measures have a strong and significant mutual relationship to one another (Table 4). The same applies to the centrality measures while any significant correlation between these two groups (centrality and isovist measures) was found.

Isovist	Area	Perim.	Occl.	Comp.	Centrality	Int.	Int. Rn	Ch R600	Choice
Area	1	-	-	-	Int. R600	1	-	-	-
Perim	<b>.878*</b>	1	-	-	Int. Rn	<b>.425*</b>	1	-	-
Occl.	<b>.856*</b>	<b>.987*</b>	1	-	Ch R600	<b>.893*</b>	.376	1	-
Compact	<b>-.499*</b>	<b>-.837*</b>	<b>-.835*</b>	1	Choice	<b>.537*</b>	<b>.967*</b>	<b>.482*</b>	1

**Table 4:** Spearman's rank correlation matrix showing the correlation coefficient R for Isovist and Centrality measures. Significant correlations are mark with \* ( $p$  value  $\leq .05$ )

The consequence for the regression function is that not all eight measures can be used as explanatory variables, however there might be one principal component defining most of the variance for each group. The principal component analysis (PCA) extracted one component for each group. The first principal component in the isovist group accounts for 82.7% of the total variance, while the first principal component in the centrality group accounts for 67.4% of the total variance.

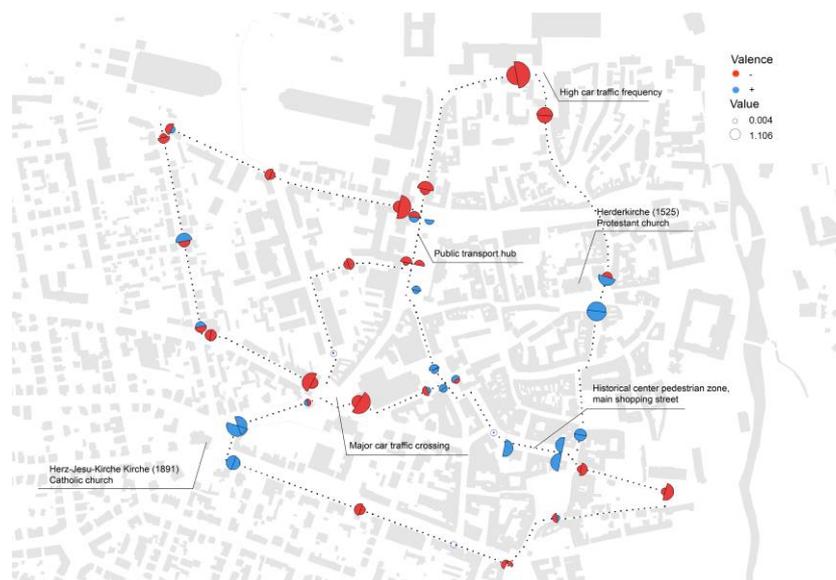
Employing these two principal components as explanatory variables, we calculated the regression function for each one of the three appraisal factors. In one out of three cases we observed significant results. The first principal components extracted from the isovist and centrality variables were significant predictors of the environment's appeal ( $\beta_i = .15$ ,  $Se\beta_i = .05$ , std. Beta<sub>i</sub> .37,  $\beta_c = .18$ ,  $Se\beta_c = .05$ , std. Beta<sub>c</sub> =  $-.31$ ,  $p < .001$ ), accounting for 19.43% of the variance ( $R^2 = .194$ ). Additionally,

we ran a set of regression trials for all combinations of isovist and centrality measure pairs; however with no improvement of the previous results.

### Discussion

The centrality measures in the form of four single variables or as the first principal component were significant predictors for all three appraisal factors. Their ability to capture the relation of particular space to the rest of the network seems to be essential. For the Spatial Experience and Activity factor the pedestrian radius centrality measures alone were best predictor accounting for 52.4% of total variance in the case of Activity and 22.2% in the case of the Spatial Experience factor. However, in the case of the Appeal factor, the one single explanatory variable turned out to be insufficient. The centrality measures alone can in the best case explain only 3.4% of the variance. On the other hand combining them in the form of a first principal component with the directed isovist in a multiple regression function makes it possible to reveal 19.4% of total variance. This means that almost 1/5 of all factors influencing the individual appeal of the study environment could be explained by these very simple abstract measures of space. The remaining 80% of variance might be caused by both the different perception among individuals and environmental properties not covered in our model. In order to reliably quantify the effect of interpersonal variability, more participants are needed. However, the preliminary calculations adopting the mixed multiple linear regression function show that the influence of individual perception explains about 11% of total variance of the Appeal factor.

If future studies with higher and more heterogeneous participant samples validate these results, it will mean that we have to look for other environmental properties that are potentially responsible for the remaining 70% of the Appeal factor variance. For now, we can search for the remaining environmental properties at least qualitatively: by visualizing the prediction residuals ( $e_i = y_i - \hat{y}_i$ , true value - predicted) of the regression function on the map (Figure 6). The highest negative residuals concentrate near to highly frequented traffic junctions, which are due to traffic regulations that were not predicted by the centrality analysis. These places have been similarly identified earlier; in the visual analysis of the coloured map and the semantic differential. Here, they were related to the high directional difference and negative appeal of the environment. The positive residuals are located, for the most part, near some architecturally prominent buildings, such as churches and museums. In order to improve the prediction model, we need to think about a reasonable way of including these properties of space in our model. However, the architectural quality and historical importance of specific buildings as opposed to car traffic frequency may prove highly problematic to quantify.



**Figure 6:** Residuals for linear regression model: Appeal  $\sim$  Isovist PC, Centrality PC. The size of the circle expresses the absolute value of the residual and the colour whether it is positive (blue) or negative (red)

#### 4. Conclusions and Outlook

The main goal of the study was to obtain more insight into the relationship between subjective aspects of appraisal and environmental properties. In particular, we wanted to build a predictive-model for human responses to spatial situations.

Based on this empirical study, we found that, firstly, participants widely agreed in their judgements. Second, walking direction played a significant role in certain locations, but not in all. Third, the effect of spatial sequences played a minor role.

Furthermore, we were able to identify a significant number of the factors influencing human spatial judgement in this context. We focused on local and global spatial properties based on simple models that we expected to be particularly useful for the design process. The isovist (local) and centrality (global) measures appeared to be valuable predictors of environmental judgements. In some cases, a combination of these two measures particularly enhanced the prediction. However, specific aspects of environmental judgement require different explanatory variables and statistical models in order to obtain better predictive power.

In order to generalize the current results, we need to assess a wider sample with more variance among participants and more locations.

We are currently preparing further studies to extend the set of measured environmental properties (such as car traffic, noise, light and temperature) in order to identify those that can significantly improve the predictive power of our model. Additionally, participants' physiological responses to the real-world environment will be measured (e.g. skin conductance, heart rate and EEG) and linked to environment properties. In a further step, we plan to use virtual reality to systematically exclude potentially confounding environmental variables, such as noise, or weather conditions.

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