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Influences of cognitive appraisal and individual characteristics on citizens’ perception and emotion in urban environment: Model development and virtual reality experiment

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• Virtual environment

ABSTRACT

To model individuals’ experience of urban spaces, this study integrates knowledge from environmental psychology and artificial intelligence to propose a framework for individuals’ perceptions and emotion by incorporating individual characteristics and cognitive appraisal together with environment attributes as determinants. A path model is employed to capture how the four perceptions of environmental qualities (safety, liveliness, comfort, and legibility) and three dimensions of emotion (pleasure, arousal, dominance) are influenced by individual characteristics and cognitive appraisal using data collected in an online virtual reality experiment with 237 participants. Results show that emotional pleasure is more directly influenced by environmental attributes while arousal and dominance are closely related to a person’s current mood and personality. Perceptions of environmental qualities do have mediating effects in emotion generation, but contribute differently to the three dimensions of emotion. Cognitive appraisal variables directly influence emotion generation, with ideal values always having positive effects and expected values always negative effects. The findings can help capture the dynamic process of emotional experiences between diverse individuals and may support experience-centered simulation and prediction.

1. Introduction

Providing better experiences and perceived environmental quality for citizens is becoming increasingly important for urban public space design through healthy and inclusive city initiatives. The term “experience” encompasses a wide range of subjective meanings occurring within an individual who engages in a situation that provides physical, emotional, spiritual, and intellectual values, which is also influenced by individual factors such as age, gender, personality, and attitudes (Johansson et al., 2016; Lemke et al., 2011; Vischer, 2008). Momentary experiences can be defined as the dynamic effects of environment features on an individual’s cognitive evaluations and emotional responses of the moment (Chhetri et al., 2004; Dane et al., 2019). Momentary experiences in the built environment context are shown to not only have effects on long-term health and subjective wellbeing (SWB) (Schwanen & Wang, 2014; Wejs-Perrée et al., 2019), but also influence people’s future behaviors and intentions, thus redefining the human-environment relationship (Bornioli et al., 2019; Russell & Lanius, 1984). Therefore, to achieve healthy and inclusive urban environments and promote positive human-environment interactions, tools based on an understanding of how citizens’ momentary experiences formed by perceptions and emotions, are generated and influenced by environments are needed to support design decision making.

In recent years, urban-scale digital twins have emerged as a decision-support tool (Liu et al., 2023). The modeling of momentary experiences of citizens is an important element of the digital twins. In Artificial Intelligence (AI), Computation Models of Emotion (CMEs) are an emerging field of research which has the goal to represent and integrate human emotion in Information and Communication Technology (Reisenzein et al., 2015; Scherer et al., 2001). Various frameworks of CME have been proposed focusing on emotion generation and the effects of emotions in a given situation. Applications have focused, for example, on assisting mental health care by monitoring users’ emotional states, providing emotionally sensitive education systems, and developing emotionally intelligent social robots (Ayata et al., 2020; Kowalczyk & Crubenko, 2016). However, to date, progress in the field of CMEs is largely ignored.

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in the built environment field.

For the goal of applying CME in the built environment we identify two research gaps. First, whereas studies have shown that the affective component (emotion) and cognitive component (perception) of momentary experience coexist and are interrelated (Lynch, 1960; Nasar, 2011; Schimmack et al., 2002), a causal model of how these factors are interrelated is still missing. The built environment may trigger emotional responses (affective reactions) directly and contribute to emotional wellbeing (Mouratidis, 2021). For example, well-maintained vegetation, upkeep and order, and openness of space have all been shown to elicit positive emotional responses (Johansson et al., 2016; Tang & Long, 2019). At the same time, it has been widely shown that the built environment influences various perceptions such as safety and comfort. Positive perceptions in urban environment can have an immediate influence on physiological and psychological parameters of stress, wellbeing, cognition (Krabbendam et al., 2021), and health-related behaviors (Reyes-Riveros et al., 2021). Nevertheless, the two influence paths have not been considered in an integrative framework.

Second, besides influences from the external environment, internal factors specific to each individual are also essential factors for momentary experience. With regard to individual characteristics, many studies have highlighted their influence on perception and emotion (Chen et al., 2021; Kokkonen & Pulkkinen, 2001), with widely discussed characteristics including personality traits (Mount et al., 2006; Pocznet et al., 2017), mood (Vuoskoski & Eerola, 2011), motivational factors (i.e., internal drives or purpose) (Lang, 2000; Rauthmann, 2016), and cognitive style (i.e. way of thinking) (Kozhevnikov, 2007). In addition, theories and knowledge from the AI field further emphasize the importance of cognitive appraisal processes to support the modeling of emotion generation (Scherer, 2019). However, there is currently no evidence about how and to what extent these cognitions influence the emotion generation process in the built environment context.

To address these research gaps and pave the path towards computational modeling, the objective of the study is to develop a model of emotion generation in the built environment. The model represents a conceptualization of the emotion generation process derived from literature from several disciplinary fields. In the model we consider the direct effects of both the physical environment and individual characteristics on emotion generation, mediating effects of perceptions of environmental quality and the effect of cognitive appraisal on emotion generation. The environmental attributes included in the model represent design features of the public spaces. We also incorporate individual characteristics, focusing on personality, mood, and purpose of the visit, as their impact on perceptions and emotion has been emphasized. In addition, two cognitive appraisal variables, ideal values and expectations regarding qualities of the environment, are incorporated into the model due to their possible influence on how the urban environment is experienced (Clore & Ortony, 2013). We estimate the proposed model with path analysis, using data collected in an online experiment. In the online experiment, the environmental design of a train station area is systematically varied, and corresponding perceptions and emotions are measured together with relevant individual characteristics and cognitive appraisal variables. The resulting model should provide support for extending theoretical frameworks of momentary experiences formed by perceptions and emotion in the built environment, and the development of CMEs applicable to the built environment.

The paper is structured as follows. Section 2 proposes the conceptual model with the review of related work supporting the assumptions in the model. Section 3 presents the method used to estimate the model. Section 4 presents the data and the model results. Section 5 discusses the findings. Section 6 provides concluding remarks.

2. Conceptual model

To address the research objectives, we synthesize findings from the fields of environmental psychology and AI and propose a conceptual model as presented in Fig. 1. The model integrates the following hypotheses regarding the process of emotion generation in human-environment interaction: 1) Environment attributes and individual characteristics influence a person’s perceptions regarding the environment; 2) These perceptions have an influence on emotion generation in addition to the direct effects of environment attributes and individual characteristics; 3) A person’s cognitive appraisal variables influence emotion generation by moderating the impact of perceptions. The physical environment attributes and individual characteristics (e.g., personality, mood, and visit purpose) are included in the model as exogenous variables. They not only directly influence emotion, but also indirectly through perceptions. Inspired by CMEs, we incorporate cognitive appraisal variables (expectations, ideal values) and hypothesize that they have a moderating effect on emotion generation based on perceptions. This section will further describe how these hypotheses are supported by existing literature in these fields focusing successively on the perception of the built environment (Section 2.1), emotion generation (Section 2.2), and computational models of emotion (CMEs) (Section 2.3).

2.1. Environmental perception and its influencing factors

Environmental perception, as a direct sensory response, serves as the most fundamental mechanism linking humans and the environment (Rapoport, 2016). The visual domain is recognized for its dominant function in the field of urban planning and design (Li et al., 2021; Nittidara et al., 2022; Rapoport, 2016). Perceptions related to environmental quality include multiple aspects, such as safety, comfort and pleasure (Mehta, 2014), liveliness, boredom and aesthetics (Dubey et al., 2016; Verma et al., 2020), order, coherence, and legibility (Ahmadpoor & Smith, 2020; Nasar, 1994; Taylor, 2009).

In the process of human-environment interaction, perceptions are affected by a combination of factors, among which physical environment attributes have been widely discussed as external factors. From a perspective of urban public space design and evaluation (Madanipour, 2021; Mehta, 2014), relevant environmental attributes can be classified into three categories. The first category refers to physical features, such as the spatial scale of the open space (Liu et al., 2022), materials (Mehta, 2014), and height and density of buildings (Lindal & Hartig, 2013). The second category is spatial functional attributes that serve specific functions such as recreation and commerce. Attributes of this category include urban greenery (Jennings & Bamkole, 2019; Rapuano et al., 2022; Schertz et al., 2022), elements such as benches, canopies, and...
artwork (Matthews & Gadadoff, 2022; Peng et al., 2019; Tudorie et al., 2020) and different types of transport services (Rossetti et al., 2019). The third category is social attributes such as the types of populations who use the space (e.g., defined by the visit purpose) and their views on the meaning of the space (Francis et al., 2012; Harun et al., 2014).

In addition to environment attributes, influence of internal factors such as individual characteristics and perceptual mechanisms on perceptions should not be overlooked. Psychological state variables such as personality and mood are proposed as important factors for perception as they influence the way individuals interpret a particular environment based on their personal tendencies (Chen et al., 2021; Huang et al., 2017). Visit purpose is another aspect of individual characteristics and is emphasized to affect perceptions through multiple dimensions (Vidal Rua, 2020). Individual perceptual mechanisms which influence information processing are also highlighted (Ruotolo et al., 2024), such as attention which acts as a filter eliminating many things to concentrate on others (Ovhalte Ojstersek & Topolsek, 2019), and the mode and speed of travel influencing the perceiver’s state (Van Dyck et al., 2012).

2.2. Emotional responses in the built environment perspective

Emotion is an important pathway connecting the environment and subjective wellbeing (Mouratidis, 2021). Being an aspect of momentary SWB, the emotional state represents an affective fluctuation within a person over a very short period of time, and can influence the long-term wellbeing (Eid & Diener, 2004; Weijts-Perrée et al., 2019). Similar to perceptions, the process of emotion generation is directly influenced by external and internal factors. Environment attributes such as the amount of vegetation and traffic, public activities, and heavy traffic have been shown to trigger different emotional responses (Ettema & Smajic, 2015; Johansson et al., 2011; Klettner et al., 2013). As for the internal factors, the individual characteristics have been highlighted as the “person” factor of person-environment fit (Lykken & Tellegen, 1996; Tay & Diener, 2011). Specifically, personality is a stable trait that tends to lead an individual to be wrapped in a mood state, which affects emotional responses (Rusting, 1998; Strickhouser et al., 2017). Compared to personality, mood is periodic but still influences emotional responses. In addition, it has been found that gender differences exist in the perception and emotional experiences in public space (i Agusti et al., 2022), but possible gender differences regarding other types of emotion remain unclear.

Besides the direct influences of the multiple variables on emotion, several studies have also stressed the causal relationship between perceptions and emotion. A perceived poor environmental quality will cause negative emotion, such as stress and concerns (Cain et al., 2017; Evans, 2003). People may “suffer from frustration” when becoming disoriented in the built environment (Durante et al., 2018), indicating that legibility is a desirable environmental quality. It is also found that the lack of variety in the environment has a negative impact on pedestrians, highlighting the importance of a lively environment rather than a monotonous one (Bornioli et al., 2018; Van den Berg et al., 2014).

2.3. Emotion mechanism – computational emotion modeling

In the field of AI, CMEs are developed to simulate human emotion processes and provide virtual agents the ability to evaluate stimuli, evoke synthetic emotions, and generate emotional responses (Castellanos et al., 2018; Osuna et al., 2022; Rodríguez & Ramos, 2014). The theoretical base of CMEs is supported by emotion theories which are represented by discrete (or categorical) emotion theory, dimensional emotion theory, and appraisal theory (Hudlicka, 2011). According to the discrete view, emotions are discrete entities consisting of a set of basic emotions (Ekman, 1992; Pankepp, 2007). The dimensional view claims that emotions can be identified using fundamental dimensions, represented by the three-dimension pleasure-arousal-dominance (PAD) model (Mehrabian, 1996; Russell, 2003).

Recent studies of appraisal theories have emphasized that an individual’s goal-oriented cognition and its mediation effects on the emotion process should not be overlooked (Hudlicka, 2014; Reisenzein et al., 2013; Scherer, 2019). Individuals may differ on various cognitive variables which influence appraisal so that the same stimuli can elicit different emotions. The most widely used appraisal theory in CME is the one proposed by Ortony, Clore, and Collins (Ortony et al., 1990). This theory, known as the OCC model, provides a clear computational process of cognitive appraisal (Alfonso et al., 2017; Dias et al., 2014; Marsella & Gratch, 2009). According to this theory, the goal of an individual influences cognitions related to variables such as desirability, unexpectedness, realization, which will then function as appraisal criteria and mediate the emotion generation in the given situation (Gluz & Jaques, 2017). In the context of built environment, for an individual with a particular activity purpose as the goal, the cognitive appraisal variables regarding environment qualities relevant for that purpose (e.g., desire and expectation regarding comfort) can have an influence on the association between perception of the given situation (e.g., perceived comfort) and emotion.

To sum up, there is not yet a model tailored to supporting emotion computation and prediction in the built environment field. The integrative conceptual model in Fig. 1 incorporates the multidisciplinary findings and describes a more elaborate emotion generation mechanism in human-environment interaction. The following section will describe the methods used to test the hypothesized relationships in the model using experimental evidence.

3. Methods

3.1. Operationalization of the conceptual model

The proposed conceptual model is further operationalized for the research as shown in Fig. 2. Seven environment attributes are selected describing architecture, greenery, traffic, and other public space design elements. The Big five personality traits are used as dimensions of stable person disposition (Grant et al., 2009). PAD emotion theory is used to measure the affective states mood and emotion. In the experiment, the public space around the central station in Eindhoven, The Netherlands, is used as a case area and three typical activity purposes of users of a station area, are specified as possible goal settings. Furthermore, we focus on four qualities which are generally relevant for perception of the built environment, namely safety, liveliness, comfort, and legibility. Referring to OCC emotion theory, two cognitive appraisal variables, desire (the ideal value an individual assigns to a specific environmental quality) and expectations the individual has regarding the environmental qualities, are taken into account, to examine the influence of cognition on perceptions and emotion.

3.2. Experiment design

To collect the data for estimating the model, an online experiment with 3D environments embedded (desktop VR) was designed in which respondents were presented various designs of an environment and their perceptions and emotions triggered by each of the presented designs were measured. The public space around Eindhoven central station is selected as the baseline of the 3D environments. 3D environments of the station square and surroundings were created using SketchUp 2021 and Lumion 11, followed by rendering and video output.

The alternative designs of the 3D environment were created by varying levels of the seven environment attributes. This was done systematically by using a conjoint experimental design. In this experiment, each attribute has two levels (Table 1). For average building height, the two levels are set according to low-rise and mid-rise building standards. The level 1 of grass coverage is set to 40% of the station square, which is considered to be an ideal value (Yu et al., 2023). Additionally, the presence of outdoor dining, benches, and bike parking (level 1) also
brings the corresponding users (e.g., sitting diners, people resting on benches, cyclists) into the model as a by-product. Eight environment alternatives were generated in accordance with the Taguchi method’s L8 orthogonal array (Roy, 2010; Taguchi & Konishi, 1987). All eight alternatives are displayed in Fig. 3 and labelled by the combination of levels of the environment attributes.

A video of 32 s was created for each alternative that mimicked a stroll in a first-person view through the station square. This time duration proved to be optimal in a pilot experiment among a sample of 10 respondents, as it allowed the whole environment to be well perceived and also avoided fatigue. As an example, Fig. 4 shows the top view of one configuration (alternative 3) and the walking route, as well as screen shots of the view at the beginning, middle and end moments. The walking route was established such that the seven environment attributes can all be easily seen and perceived at close distance. The eight alternative videos were exported from Lumion, posted on YouTube, and embedded into the online survey software LimeSurvey.

3.3. Survey design

This section describes the measurements of the variables included in the path model (Fig. 2). The survey consisted of two parts. At the start of the survey, each respondent was randomly assigned one activity purpose from the possibilities going shopping, taking the train, or taking a walk.

In the first part, respondents were asked to report their ideal values and expectations regarding four environmental qualities of the area which are safety, liveliness, comfort, and legibility (dimensions of perceptions) on a seven-point Likert scale with the activity purpose concerned always being highlighted. Table 2 presents an example of the expressions used in the questionnaire when the visit purpose is going shopping. To save space, only the textual part is shown, excluding the Likert scales. The understandability of this task has been tested in the pilot study. Personalities were measured using the Ten-Item Personality Inventory (TIPI) based on the Big Five personality trait instrument (Gosling et al., 2003). The five personality traits were: extraversion (extraverted, enthusiastic); agreeableness (warm, sympathetic); conscientiousness (reliable, self-disciplined); neuroticism (calm, emotionally stable); and openness (imaginative, open to new ideas). For the measurement of mood, the Self-Assessment Manikin (SAM), a non-verbal pictorial assessment technique for quick reports of pleasure, arousal, and dominance (Bradley & Lang, 1994), was used. To avoid a weakness of the original SAM as being prone to misinterpretation (Montefinese et al., 2014), pairs of adjectives were added on both sides of the SAM pictures as opposites (see Fig. 5). Considering that mood and emotion have comparable dimensions, differing only in that mood is a longer-term basic affective state that exists before perceptions (Gray et al., 2001), the same SAM was also used for reporting emotion after watching each video.

In the second part, each respondent received four environment alternatives randomly chosen from the conjoint analysis design. After watching each environment alternative, the respondent was immediately asked to report the emotion on each of the three dimensions of SAM. Then the perceptions of the four qualities of the specific environment shown were measured using a 5-point Likert scale.

The online experiment was conducted among 237 undergraduate students from the same university (the University’s name is masked). The station area presented in the experiment is adjacent to the university.
Fig. 3. Bird-eye views of the eight alternatives. The numbers in square brackets represent the levels of the seven environmental attributes in the alternative, with specific reference to Table 1.

Fig. 4. Walking route and views of alternative 3. Only the last three views are the scenarios presented to respondents in the video. The dashed arrow marked in the top view image represents the walking route.
where the respondents are recruited, and based on such context we assume that the respondents are familiar with the station area. Incomplete or invalid questionnaires were removed. We also excluded the cases in which the respondent took less than 8.5 min to complete the questionnaire, as the pilot study showed that this was the minimum time needed to watch the videos presented fully and to read the texts in the questionnaire. Finally, 192 valid questionnaires were retained, and as each respondent watched and assessed 4 videos, there were a total of 768 cases available for analysis. Approximately half of the sample (53.7%) was female. The numbers of valid cases in the groups with the activity purpose of going shopping, taking the train, or taking a walk are 260, 248, 260, respectively. This study was approved by the university’s Ethical Review Board (ERB).

3.4. Data analysis

Path analysis was used and estimated by AMOS 26, incorporating the eight groups of variables in an overall estimate to test the conceptual model (see Fig. 2). To investigate the indirect influences of exogenous variables (environment attributes, personality, mood, and purpose) on three dimensions of emotion through the four perceptions, a 95% confidence intervals-based, bias-corrected (BC) bootstrapping approach (5000 resamples) was conducted (MacKinnon et al., 2004). In order to test the moderation effects of the two cognitive appraisal variables on emotion, the products of perception and cognitive appraisal variables were constructed as interaction terms and added to the model. In addition, a multigroup analysis was used to compare parameter estimates between the male group and the female group.

4. Results

The values of multiple fit indices for the final path model indicate that the model fits the data well. As shown in Table 3, all the indices meet the standard of a good model fit, except for the Tucker-Lewis coefficient (TLI), which is very near to the cut-off value. The (final) model is represented in Fig. 6.

Regarding perceptions, the results indicate that environment attributes, personality, mood, and purpose have different effects (see Table 4). Of the seven environment attributes, grass and trees have the most positive influence on all perceptions. Building height and bike parking both have negative effects on safety, but bike parking positively influences liveliness. Outdoor dining, benches, and arcade space also enhance liveliness. Three of the five dimensions of personality have significant impacts on perceptions. Openness positively influences legibility. Agreeableness has a positive effect on liveliness. Neuroticism positively influences safety but has a negative impact on legibility. As for three dimensions of mood, only arousal has positive impacts on liveliness and comfort. The purpose of going shopping negatively influences

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**Table 2**

<table>
<thead>
<tr>
<th>Statements in the questionnaire to collect cognitive values (going-shopping purpose).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ideal value</strong></td>
</tr>
<tr>
<td><strong>Safety</strong></td>
</tr>
<tr>
<td><strong>Liveliness</strong></td>
</tr>
<tr>
<td><strong>Comfort</strong></td>
</tr>
<tr>
<td><strong>Legibility</strong></td>
</tr>
</tbody>
</table>

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![Fig. 5. Adjusted Self-Assessment Manikin (SAM) for measuring mood and emotion. Pairs of adjectives added on both sides help respondents understand the images.](image-url)
Table 3
Goodness of fit indices for the path model.

<table>
<thead>
<tr>
<th>Model Fit Indices</th>
<th>Threshold For Good Fit</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>X^2/df</td>
<td>&lt;5</td>
<td>2.161</td>
</tr>
<tr>
<td>Goodness of Fit Index (GFI)</td>
<td>&gt;0.900</td>
<td>0.971</td>
</tr>
<tr>
<td>Standardized Root Mean Square Residual (SRMR)</td>
<td>&lt;0.080</td>
<td>0.035</td>
</tr>
<tr>
<td>Root Mean Square Error of Approximation (RMSEA)</td>
<td>&lt;0.060</td>
<td>0.039</td>
</tr>
<tr>
<td>Comparative Fit Index (CFI)</td>
<td>&gt;0.900</td>
<td>0.948</td>
</tr>
<tr>
<td>Incremental Fit Index (IFI)</td>
<td>&gt;0.900</td>
<td>0.951</td>
</tr>
<tr>
<td>Tucker-Lewis’s coefficient (TLI)</td>
<td>&gt;0.900</td>
<td>0.862</td>
</tr>
</tbody>
</table>

Fig. 6. Path analysis model with all the significant paths (n = 768). Red arrows indicate positive relationships and blue arrows negative relationships. The bold arrows represent the direct effects of exogenous variables on three dimensions of emotion. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Next, we consider the indirect and total effects of exogenous variables on emotion. All variables shown in Table 5 have significant total effects on emotion except for bike-parking on pleasure and personality agreeableness on arousal, due to their opposite direct and indirect effects. These results show that the environment attributes and activity purpose influence emotion particularly through indirect effects and personality and mood primarily through direct effects. For emotional pleasure, building height and bike parking have greater direct than indirect effects, while the other attributes influence emotional pleasure mainly through indirect effects. The indirect effects are much stronger for the emotional arousal and dominance, which are indirectly influenced by all the attributes except building height. As said, personality traits are characterized by the prevalence of direct effects. Hereby, extraversion and neuroticism are more important for emotional pleasure and neuroticism for the emotional dominance. Also, dimensions of mood have stronger influences on emotion through direct paths.

Next, we turn to the cognitive appraisal variables. On this level we see that several ideal-value and expectation variables directly influence emotion and some of them also act as moderators by interaction with perceptions (see Table 5). Cognitive values regarding safety and legibility appear to be important predictors of emotion. Hereby, (higher) ideal values tend to have positive effects and (higher) expectations negative effects. Specifically, emotional pleasure is positively influenced by higher ideals for safety and negatively influenced by higher expectations for safety. Emotion arousal is positively influenced by a high ideal for safety. Emotion dominance is directly affected by the ideal value and expectation value for legibility, in a positive and negative way respectively. When the main effect is not significant but the interaction effect is, the variable can be identified as having a moderating effect (Hayes & Matthes, 2009; Preacher et al., 2007). As the result shows, besides the above-mentioned main effects on emotion, the ideal value and expectation value for safety have significant moderation effects on the associations between the perception of safety and the arousal and

effects from four perceptions as well as from the exogenous variables in each of the four clusters (see Table 5). Environment attributes including building height, bike parking, grass, and trees have a significant influence on emotional pleasure. However, only trees have a positive impact on emotional arousal and none of the environment attributes directly influence emotional dominance. Extraversion and neuroticism both positively affect pleasure. Neuroticism also has a direct and positive effect on dominance. Agreeableness has a direct and negative effect on arousal. It is notable that emotional pleasure is not directly influenced by mood while arousal and dominance are. The purpose going shopping negatively influences emotional pleasure and taking the train positively influences emotional dominance.

Table 4
Estimation results of the effects on perceptions.

<table>
<thead>
<tr>
<th></th>
<th>Unstd. coef.</th>
<th>Std. coef.</th>
<th>P-value</th>
<th>Unstd. coef.</th>
<th>Std. coef.</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building height</td>
<td>-0.220</td>
<td>-0.079</td>
<td>0.012</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Bike parking</td>
<td>-0.217</td>
<td>-0.078</td>
<td>0.013</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grass</td>
<td>0.470</td>
<td>0.169</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree</td>
<td>0.396</td>
<td>0.142</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liveliness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outdoor dining</td>
<td>0.263</td>
<td>0.082</td>
<td>0.004</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bench</td>
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<td>0.083</td>
<td>0.009</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Bike parking</td>
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<td>0.120</td>
<td>&lt;0.001</td>
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<tr>
<td>Arcade space</td>
<td>0.235</td>
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<td>0.011</td>
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<td>&lt;0.001</td>
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</tr>
<tr>
<td>Tree</td>
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<td>0.314</td>
<td>&lt;0.001</td>
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<td></td>
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</tr>
<tr>
<td>Comfort</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bench</td>
<td>0.344</td>
<td>0.103</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grass</td>
<td>0.996</td>
<td>0.299</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree</td>
<td>1.186</td>
<td>0.356</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legibility</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arcade space</td>
<td>0.229</td>
<td>0.075</td>
<td>0.026</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grass</td>
<td>0.373</td>
<td>0.123</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The unstandardized coefficients, standardized coefficients, and p-values are represented. The personality variables are presented as acronyms with the prefix “P.”
Table 5
Total, indirect, and direct effects on emotion.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Direct effect</th>
<th>Indirect effect</th>
<th>Total effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unstd. Coef.</td>
<td>Std. Coef.</td>
<td>P-value</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pleasure</td>
<td>&lt;ref&gt;Table 6&lt;/ref&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arousal</td>
<td>&lt;ref&gt;Table 6&lt;/ref&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominance</td>
<td>&lt;ref&gt;Table 6&lt;/ref&gt;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The unstandardized coefficients, standardized coefficients, and p-values are represented. "ns" stands for not significant. The personality variables are presented as acronyms with the prefix “P.” The prefix “int” represents the interaction term.

dominance.

Finally, to test whether there are gender-related differences in the way the environment is experienced. A multigroup analysis was conducted considering the group of males and of females. The model comparison shows that the difference between structural weights models is non-significant but significant for the intercepts, means, co-variances and residuals model (Table 6). This indicates that path coefficients do not differ significantly between the two gender groups but there is a systematic difference in the average values of the endogenous variables or measurement errors between the groups.

Table 6
Model comparison between the female (n = 412) and male groups (n = 356).

<table>
<thead>
<tr>
<th>Effect</th>
<th>DF</th>
<th>CMIN</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>22</td>
<td>27.449</td>
<td>0.195</td>
</tr>
<tr>
<td>Structural weights</td>
<td>51</td>
<td>201.258</td>
<td>0.000</td>
</tr>
<tr>
<td>Structural means</td>
<td>263</td>
<td>729.305</td>
<td>0.000</td>
</tr>
<tr>
<td>Structural residuals</td>
<td>277</td>
<td>740.233</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Note: The degrees of freedom (DF), chi-square values (CMIN), and p-values are represented.
5. Discussion

Regarding urban perceptions, environment attributes appear to have much stronger effects than personality, mood, and purpose. Trees and grass have strong positive effects on all perceptions, which underscores the importance of urban green (Nguyen et al., 2021; Peschardt et al., 2016). The other two attributes with large positive effects are benches, which increases comfort and liveliness, and the arcade space, which increases liveliness and legibility. Though disorganized traffic is assumed to have a negative effect on perceptions (Carmona, 2010), the presence of bike parking and cyclists is found to have a positive impact on liveliness in this study. Another noticeable variable is the mood arousal, which positively influences comfort and liveliness. This can be explained by arousal theory which states that when people are more aroused, they may pay more attention to positive stimuli and may prefer environments that offer more variety, complexity or novelty (Schreuder et al., 2016), which make them perceive the surroundings as more comfortable and livelier.

As for emotion generation, the result shows that the three dimensions of emotion do have different influence mechanisms. The emotional pleasure is more strongly influenced by physical attributes through direct paths compared to arousal and dominance. Four of the seven environment attributes directly influence the emotional pleasure. Of these bike parking and building height have negative effects on pleasure, which have been discussed in previous studies (Ortiz-Ramirez et al., 2021; Xiang et al., 2021). The other two significant factors are trees and grass, confirming prior research that established a positive influence of urban green on emotional wellbeing (Roberts et al., 2019; Zhu et al., 2021).

In addition, the personality variables extraversion and neuroticism appear to have an influence on the emotional pleasure. The positive effects of extraversion on perceived happiness have been widely demonstrated (Pishva et al., 2011; Watson & Clark, 1997). The effects of neuroticism appear to be more complex. Even though it is typically associated with negative emotions, its association with positive emotions is controversial across studies (Ching et al., 2014; Leger et al., 2016). Some studies have found that people with higher levels of neuroticism are not only more sensitive to negative stimuli, but also to positive ones (Hisler et al., 2020; Ng, 2009). This may lead to an overall positive effect on the experience of emotional pleasure. Openness and agreeableness are also found to have significant indirect effects on emotional pleasure in this study, but the effects are much smaller.

Regarding emotion arousal, the presence of trees is shown to be the only one direct positive predictor among the seven environment attributes. Prior studies indicate that moderate levels of tree density are assumed to have a negative effect on perceptions (Carmona, 2010), the presence of bike parking and cyclists is found to have a positive impact on liveliness in this study. Another noticeable variable is the mood arousal, which positively influences comfort and liveliness. This can be explained by arousal theory which states that when people are more aroused, they may pay more attention to positive stimuli and may prefer environments that offer more variety, complexity or novelty (Schreuder et al., 2016), which make them perceive the surroundings as more comfortable and livelier.

6. Conclusion

This study proposes an extended model to investigate individuals’ perceptions and emotion when interacting with the environment. Emotional pleasure is more directly influenced by the physical environment while arousal and dominance are more closely related to internal individual characteristics. The mediating effects of perceptions in emotion generation are confirmed, and the direct influence of cognitive appraisal variables on emotion is proven to be non-negligible. The emotion-generation model proposed in this study supports the development of a CME to simulate and predict citizens’ momentary experiences in urban environment and could support urban designers, planners, and policy makers in experience-centered decision making.

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.
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CRediT authorship contribution statement
Sengi Yang: Writing – review & editing. Writing – original draft. Visualization, Investigation, Formal analysis, Data curation, Conceptualization. GAMEZ DANE: Writing – review & editing, Supervision, Methodology, Conceptualization. Pauline van den Berg: Writing – review & editing, Supervision, Methodology, Conceptualization. Theo Arentze: Writing – review & editing, Supervision, Methodology.

Declaration of competing interest
The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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