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Indicator selection combining audio and visual perception of urban green spaces

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ABSTRACT

Recent studies revealed the importance of combined qualities of sound and the visual landscape for human well-being in urban green spaces (UGS). Yet, there is a lack of implementing urban design and management in urban green enviroments that promotes audio-visual qualities for human well-being. One potential reason for this is the rather scattered results of audio-visual indicators linking either to one single type of green or to studies providing indicators that have not been tested if they are generalizable to other cities. In this study, we use two existing general perception models; perceived affective qualities of soundscape (PAQs) and perceived sensory dimensions of landscape (PSDs) and investigate their combined potential as indicators of audio-visual perception of five different types of urban green spaces and their relationship with overall environmental satisfaction. Principal component analysis, pearson correlation coefficient and multiple linear regression exploring the relationships between PAQs and PSDs and overall environmental satisfaction showed that: (1) Semi-open green space and blue space had the most abundant perceived dimensions in both visual and auditory perceptions, followed by the enclosed green space and open green space, while gray space had the least. (2) Four satisfaction models based on audio-visual perception were found in the urban green spaces. Different design measures in different urban green spaces should be taken. (3) The principal components of PAQs and PSDs explained 48% of overall environmental satisfaction, suggesting the validation of them as auditory and visual prediction models. In conclusion, this study reveals that using a combination of PAQs and PSDs provides indicators that can be used to evaluate differences in audio-visual interactions between cities, to increase the possibilities to plan and design UGS for increasing human well-being.

1. Introduction

More than half of the world's population lives in cities (United Nations, 2018). Urban green spaces are very important to the life of urban inhabitants, because they can provide not only infrastructure services such as those that would hinder flooding and protection from other natual events, but also may function to serve as leisure entertainment and help to improve people's well-being (Van Melik, 2008; Mouratidis, 2020). High-quality urban green space design contributes to social progress, economic development and improvement of public health (Duivenvoorden et al., 2021). Many countries around the world have emphasized the opportunities of green spaces in urban planning (Pulighe et al., 2016; Pauleit et al., 2019; WHO, 2017). To this end, many researchers have investigated and evaluated urban green spaces from landscape and soundscape perspectives. Although this increasing number of studies highlighting the important multisensory interconnection between sound and visual perceptions for humans, no consensus in applicable indicators combining these two senses exists. One potential reason for this is the rather scattered results of audio-visual indicators, linking either to one single type of green (Liu et al., 2013) or to commercial, residential, business and green (Joen and Jo, 2020; Jo and Joen, 2021) or to studies providing new indicators that have not been tested if they are generalizable to other cities (Hong and Jeon, 2015; Liu et al., 2019; Xu and Wu, 2021). The lack of generalization of existing

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indicators most probably hinder the guidance and implementation of quality-oriented landscape planning and design in urban green in specific. Here in this study we evaluate the combination of a visual indicator (Stoltz and Grahn, 2021) and a soundscape indicator (ISO, 2018) and their combined potential as indicators for urban multisensory in cities through surveys with a gradient in amount urban greenery.

Soundscape and landscape perception and assessment have however wildely been used in urban spaces in the past decade (Axelsson, 2015; Jeon et al., 2018; Jeon and Jo, 2020; Nilsson et al., 2012). To our knowledge only few previous studies evaluated soundscape and visual perception in combination in numerous types of urban spaces in situ (Jeon and Jo, 2020; Jo and Jeon, 2021; Jeon and Hong, 2015). They did however not in particular investiage nuaces in urban greenery but rather commercial, residential, business and recreational areas (including green) and niether a full model combining audial and visual features.

1.1. Visual landscape indicators

Related studies often take visual evaluation as the main basis for assessing the quality of urban green space. Public perception is crucial for obtaining visual evaluation. Several theories and methods based on perception have been proposed, such as the Prospect-Refuge Theory (Appleton, 1975), Information-Dispose Theory (Kaplan and Kaplan, 1989), General Paradigm of Landscape Perception (Zube et al., 1982), Stress Reduction Theory (Ulrich et al., 1991), etc. In the last three decades, several studies have found that people's experiences of urban green spaces can be divided into several perceived attributes, usually six to nine according to how people perceive and experience them (Grahn, 1991; Kyttä and Kahila, 2005; Maikov et al., 2008; Tyrväinenet al., 2007; Van Herzele and Wiedemann, 2003). Grahn and Stigsdotter (2010) investigated 953 local residents' preferences for certain qualities of green spaces based on a questionnaire survey. Through factor analysis, eight of the most popular sensory dimensions of perception were determined, which are *serene* (silent and calm), *nature* (wild, free growing lawns and untouched), *space* (spacious and free), *rich in species* (several natural plant and animal populations), *refuge* (enclosed and safe), *prospect* (plane, vista and well-cut lawns), *social* (individuals may enjoy entertainment, visit exhibitions or restaurants) and *culture* (decorated with fountains, statues and ornamental plants). These eight perceived sensory dimensions (PSDs) proposed by Swedish and Danish scholars have been widely applied to landscape assessment and design in Europe (Stigsdotter et al., 2017) and been evaluated in more than 60 studies (Stolz and Gragn, 2021). The PSDs were used to describe the differences in people's perceptions of different types of landscapes and have also been examined for applicability in the context of Chinese urban environmental settings (Chen et al., 2019; Qiu and Nielsen, 2015).

1.2. Soundscape indicators

Studies have found that public perception is not always dominated by vision (Carles et al., 1992; Larsson et al., 2007; Van Renterghem and Botteldooren, 2016; Van Renterghem et al., 2020). Scholars have done many studies on noise reduction in urban public spaces in order to increase the quality of urban green spaces from the perspective of soundscape (Hong et al., 2020; Rey Gozalo et al., 2018a,b; Sieber et al., 2018; Yang et al., 2020). However, these studies have found that noise reduction is not always feasible in order to obtain a better urban acoustic environment (Alves et al., 2015; Andringa et al., 2013; Asdrubali, 2014; Kang, 2019). Reducing noise level does not necessarily improve acoustic comfort (Ballas, 1993; Dubois, 2000), nor does it necessarily improve people's quality of life and satisfaction (Kang et al., 2016; van Kempen et al., 2014; Yang and Kang, 2005).

The paradigm of soundscape study has gradually changed accordingly. Environmental sounds are no longer seen as a waste, but as a resource (Brown, 2010; Preis et al., 2015). In 2014, the International Standard Organization defined soundscape as "the acoustic environment as perceived or experienced and/or understood by a person or people, in context" (International Organization for Standardization, 2014). This definition emphasizes the role of subjective perception in the soundscape. Hence, an important aspect of soundscape research is how people evaluate the acoustic environment (Brown, 2011). Some scholars have explored the factors that affect soundscape perception (Axelsson et al., 2014; Hong and Jeon, 2015; Jeon et al., 2018; Liu et al., 2019). Cao and Kang (2021) studied the influence of companion factors on soundscape perception in urban space through a questionnaire survey, and the results showed that people with company or close social relationships were more likely to pay attention to the sounds of human activities. Liu et al. (2019) examined the influence of socio-demographic behavioral background and other factors on soundscape perception, and found that the duration of tourists' stays in urban green space were closely related to soundscape experience, and different visiting motivations were significantly correlated with overall soundscape preference.

Commonly used soundscape perception indicators include loudness, noise annoyance, tranquillity, soundscape quality, appropriateness, etc (Aletta et al., 2016). Some scholars found that exploring multiple potential dimensions of soundscape perception helped to understand the acoustic environment (Aletta et al., 2016; Axelsson et al., 2010; Brown, 2012). Axelsson et al. (2010) integrated a large number of potential perceptual attributes and conducted principal component analysis, resulting in the development of a perceived affective quality (PAQs) model. The model includes eight dimensions: *pleasant* (sounds which made you happy, cheerful), *vibrant* (sounds full of life), *eventful* (something important was happening in the sound), *chaotic* (in a mess, out of order), *annoying* (sounds were disturbing and unhappy), *monotonous* (not interesting, boring), *uneventful* (no special event in the sound) and *calm* (peaceful and silent). The PAQs model has been written into Part 2 of International Standards (ISO, 2018) in order to unify the soundscape perception descriptors in soundscape studies, but have never been highlighted or evaluated as indicators.

1.3. Urban multisensory indicators

Although previous studies have explored audio-visual perceptions from aspects of a socio-demographic behavioral background, landscape characteristics of landscape and sound source, and types of study area, these studies have not formed a unified standard for the selection of audio-visual perception indicators. Thus, knowing that visual and sound are highly interaction for human perception and well-being in citities it is somewhat surprising that no such indicators exists. This lack of excisting indicators most probably hinder the guidance for quality-oriented landscape planning and design in practice (Hong and Jeon, 2015; Liu et al., 2019; Xu and Wu, 2021). The aim is to validate existing PAQs and PSDs to provide a selection of indicators that can be used for future audio-visual perception research as well as implementation and improving of urban green space for human well-being.

Both audio and visual perception can be used to evaluate the audio and visual perceptions from different dimensions to distinguish the differences for urban green spaces. Therefore, in this study, these two general perception models were used as evaluation indicators of soundscape and visual landscape perception. An on-site survey was conducted to explore the differences in the perception of soundscape and visual landscape in different urban green spaces, as well as their contribution to the satisfcation of the overall environment. Specific research objectives are to identify and explore:.

(1) the difference of PAQs and PSDs in different urban green spaces.
(2) the relationship between PAQs, PSDs and satisfaction in different urban green spaces.
(3) the model of audio-visual perception as an indicator for overall environmental satisfaction.

2. Methods

2.1. Study area

The study was carried out in Xi'an (33°42′∼ 34°45′N, 107°40′∼109°49′E), a recognized city in China. Xi'an is an important birthplace of Chinese history and culture, with profound historical and cultural deposits, numerous places of cultural interest and beautiful natural scenery. The urban area covers a total area of about 3,582 km^2, with a green coverage of 38.75% and a public green area of 9.98 m^2 per capita (XABS, 2020).

Based on the urban biotope mapping in terms of the horizontal and vertical structural characteristics of vegetation proposed by Gao et al. (2012), five typical types of urban green spaces in Xi'an were selected: blue space (BS), grey space (GrS), open green space (OGS), semi-open green space (SGS) and enclosed green space (EGS). In order to reduce the spatial variability, two sites with an area of about two hectares were selected for each type of space. These spaces are located in different parks and squares in Xi'an (Fig. 1). The two blue spaces are located in Qujiang Ruins Park and Yanming Lake Leisure Park, respectively, which are both characterized by a large area of water, trails along the waters and a large number of tourists. The two grey spaces are located in Cherry Blossom Square and Daming Palace respectively, which contain a large area of hard pavement and are characterized by wide views. The two open green spaces are located in the Expo Park and Daming Palace with a canopy coverage of tree/shrub<30%. The two semi-open green spaces are located in Daming Palace and Qujiang Ruins Park with a canopy coverage of tree/shrub from 30% to 70%. The two enclosed green spaces are located in Xingqing Palace and Daming Palace with a canopy coverage of tree/shrub more than 70% (Fig. 2). These sites contain rich sound resources, including human sounds (footsteps, children playing, sourrounding speech), geophysical sounds (wind, leaves rustling), mechanical sounds (music, bicycle riding, automobiles), and biological sounds (birds, dogs, insects).

2.2. Data collection

The field survey was conducted on sunny days from September to October in 2019. The daily questionnaire was distributed from 9:00 a.m. to 5:00p.m. Respondents were randomly selected from users in each sampling site of the selected places. First, the respondents were informed of the purposes and procedures of the survey and asked about their willingness to participate. They were then informed that their answers would be anonymous. Those who agreed to participate were then distributed the electronic questionnaires which could be completed via android pads. All respondents were instructed to complete the questionnaire independently. After completing the questionnaire, each respondent would be given a small gift such as a small electric fan or stationery product as a reward.

The questionnaire consisted of three parts. The first part consisted of the PAQs of the respondents' perceptions of soundscape. The second part included the PSDs of the respondents perception of different visual dimensions in the environment. Both parts used a five-level Likert scale (1–5 representing strongly disagree to strongly agree). The third part included quesitons aimed at evaluating the overall satisfaction of the environment, and also utilized a five-level Likert scale (1–5 representing very dissatisfied to very satisfied).

2.3. Data analysis

A total of 2034 valid questionnaires (approximately 200 per site) were collected. Firstly, the arithmetic means of audio and visual perceptions were compared to understand the difference of soundscape and landscape perception in different urban spaces. The mean values were divided into three levels to indicate the level of perception: low (1–2.5), medium (2.5–3.5) and high (greater than3.5) (Tosun, 2002). General

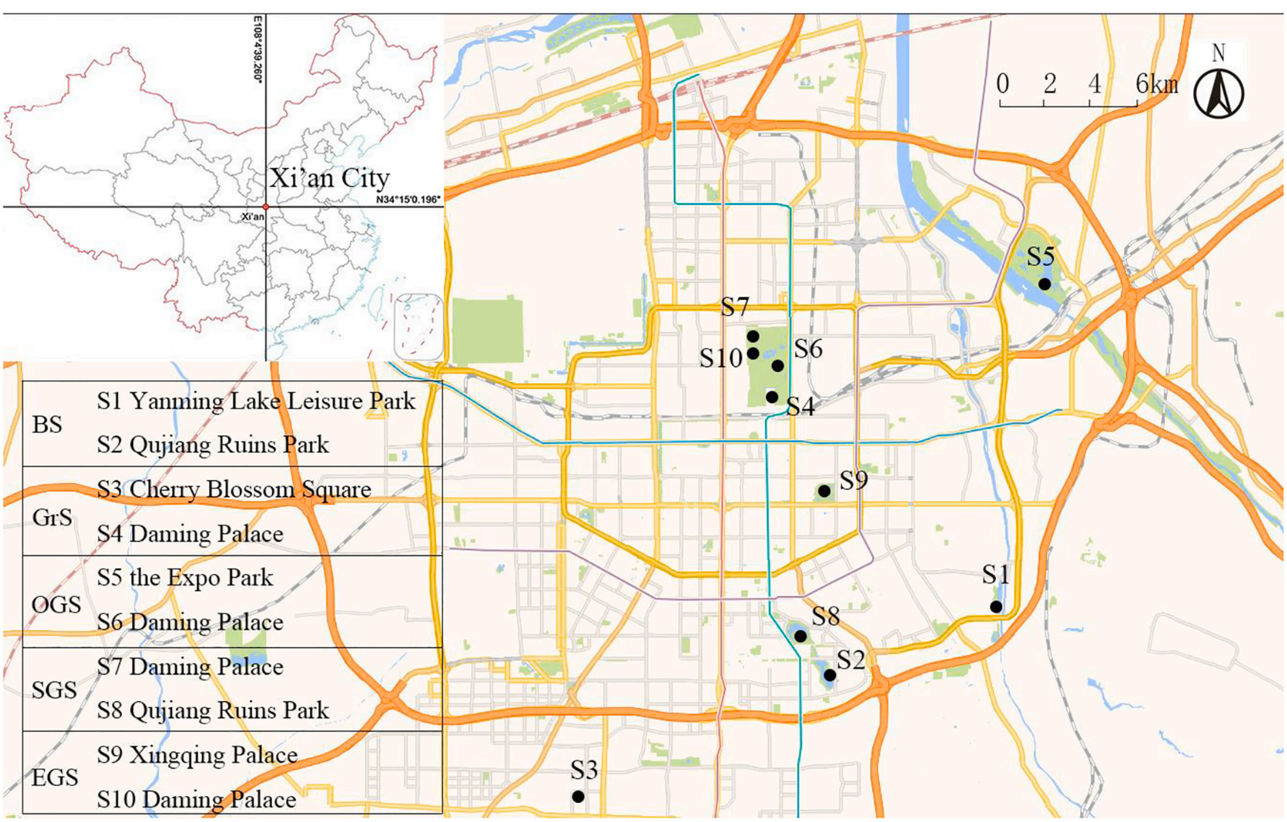

Fig. 1. Locations of the five types of urban green spaces in Xi'an, China (BS - Blue Space; GrS – Gray Space; OGS – Open Green Space; SGS – Semi-open Green Space; EGS – Enclosed Green Space; S1 – Site 1).

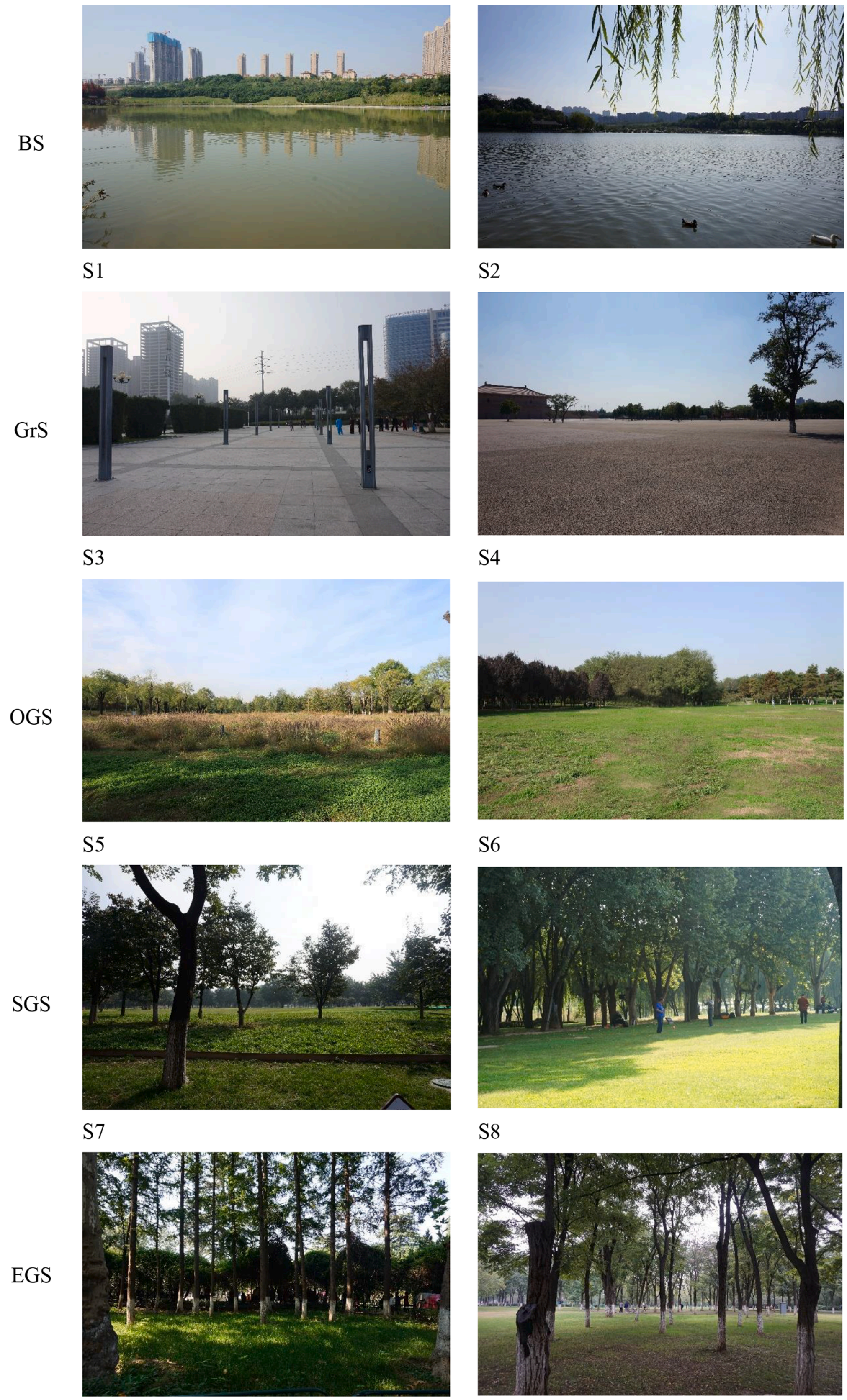

Fig. 2. Sample photos of each type of site (BS - Blue Space; GrS – Gray Space; OGS – Open Green Space; SGS – Semi-open Green Space; EGS – Enclosed Green Space; S1 – Site 1).

linear model was used to explore the differences of PAQs and PSDs among percepitons of the different green spaces. Secondly, principal component analysis and pearson correlation coefficient was used to explore components of soundscape and landscape perception in different urban green spaces and the relationship between principle components of PAQs and PSDs and environmental satisfaction. All the results passed the KMO and the Bartlett sphericity test. Finally, multiple linear regression analysis was used to explore the relationship model between overall soundscpae and landscape perception and overall environmental satisfaction. All statistical analyses were carried out using IBM SPSS Statistics 24.0 software.

3. Results

3.1. Soundscape (PAQs) and landscape (PSDs) in different urban green spaces

The results showed that *pleasant* and *vibrant* were the two qualities most strongly perceived by respondents, followed by *calm*, *uneventful*, *chaotic*, and *eventful*. *Monotonous* and *annoying* were the two qualities perceived weakest by respondents. Semi-open green space had the most highly perceived qualities (*pleasant*, *vibrant* and *calm*), followed by blue space and open green space (*pleasant* and *vibrant*). Grey space and enclosed green space had the least highly perceived dimensions of *vibrant* and *pleasant*, respectively (Table 1). The general linear model showed that there were significant differences in the perceived affective quality of different green spaces, except *eventful* and *monotonous* ($p < 0.05$, Table 1).

The results of landscape perception showed that *social*, *space* and *prospect* were the dimensions perceived most strongly by the respondents, followed by *nature*, *serene*, and *culture*. The weakest perceived dimensions were *rich of species* and *refuge*. Semi-open green space was the environmental type with the most abundant perceived dimensions of *space*, *social*, *serene*, *prospect*, *nature* and *culture*, followed by blue space with highly perceived dimensions of *prospect*, *social*, *space*, *nature* and *serene*. *Social*, *space*, *culture* and *nature* were highly perceived in enclosed green space, and *space*, *prospect* and *nature* were highly perceived in open green space. Grey space had the least perceived dimensions of *social* and *prospect* (Table 2). The general linear model showed that there were significant differences in all perceived sensory dimensions of different green spaces ($p < 0.01$, Table 2).

3.2. Relationships between PAQs, PSDs and satisfaction in different urban green spaces

In GrS, the results showed that both PAQs and PSDs had two principle components (Fig. 3 (a)). Component 1 of PAQs was negatively correlated with satisfaction ($r = -0.52$, $p < 0.01$), while component 2 was not (p greater than 0.05). *Chaotic*, *annoying* and *eventful* were negatively correlated with satisfaction, while *uneventful* and *calm* were positively correlated with satisfaction. Components of PSDs were both positively correlated with satisfaction ($r = 0.42$, $p < 0.01$; $r = 0.31$, $p < 0.01$).

In BS, PAQs extracted three principal components (Fig. 3 (b)), among which component 1 (including *chaotic* and *annoying*) was negatively correlated with satisfaction ($r = -0.16$, $p < 0.01$), component 2 (including *pleasant* and *vibrant*) was positively correlated with satisfaction ($r = 0.37$, $p < 0.01$), and component 3 (including *uneventful* and *eventful*) had no significant correlation with satisfaction. PSDs only had one component, and it positively correlated with satisfaction ($r = 0.54$, $p < 0.01$).

OGS and SGS had similarly soundscape and landscape perception patterns (Fig. 3 (c)(d)). PAQs extracted three components and PSDs extracted one component in these two types urban green spaces. Component 1 of PAQs (*Pleasant*, *vibrant* and *calm*) was positively correlated with satisfaction and component 2 (*chaotic*, *annoying* and *eventful*) was negatively correlated with satisfaction. Component of PSDs was positively correlated with satisfaction.

In EGS, both PAQs and PSDs had two principle components and positively correlated with satisfaction (Fig. 3 (e)). More specifically, *chaotic*, *annoying* and *monotonous* were negatively correlated with satisfaction, and other attributes were positively correlated with satisfaction.

3.3. Overall environmental satisfaction model based on audio-visual principal components

The results of principal component analysis showed that two principal components were extracted from PAQs (Fig. 4): component 1 explained 32.6% of variance and high loading with *pleasant*, *chaotic*, *calm* and *annoying* and was labeled as *Pleasantness*. Among them, *pleasant* and *calm* were positively correlated with *Pleasantness*, while *chaotic* and *annoying* were negatively correlated with *Pleasantness*. Component 2 explained 19.7% of variance and high loading with *vibrant*, *uneventful*, *eventful* and *monotonous* and was labeled as *Eventfulness*. Among them, *vibrant* and *eventful* were positively correlated with *Eventfulness*, while *uneventful* and *monotonous* were negatively correlated with *Eventfulness* (Fig. 4).

PSDs were also extracted two principal components and explained 34.2% and 21.7% of the variance, respectively (Fig. 4). Component 1 showed high factor loading with *serene*, *nature*, *rich of species* and *space* and was labeled *Naturalness*. Component 2 showed high factor loading with *prospect*, *social* and *culture* and was labeled *Socialness*. Note that *refuge* did not show any correlation (Fig. 4).

The multiple linear regression model using PAQs and PSDs principle components as independent variables had 48% explanatory power of overall environmental satisfaction (Fig. 4). The factors contributed to overall satisfaction included *naturalness* ($\beta = 0.48$, $p < 0.01$), *pleasantness* ($\beta = 0.44$, $p < 0.01$), followed by *socialness* ($\beta = 0.32$, $p < 0.01$) and *eventfulness* ($\beta = 0.10$, $p < 0.05$).

Table 1
The arithmetic average of PAQs in different urban green spaces.

Dimensions	GrS		BS		OGS		SGS		EGS		Total of Mean	Total of Rank
	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev		
Pleasant	3.43	0.95	**3.70**	0.85	**3.63**	0.90	**3.80**	0.86	**3.55**	0.90	**3.62****	1
Vibrant	**3.50**	0.98	**3.58**	0.87	**3.60**	0.95	**3.59**	0.92	3.43	0.96	**3.54***	2
Calm	3.01	1.07	3.45	0.92	3.37	1.00	**3.63**	0.87	3.37	1.02	3.37**	3
Uneventful	3.26	1.00	3.33	0.89	3.16	0.91	3.15	0.90	3.23	0.97	3.23*	4
Chaotic	2.83	1.01	2.44	0.96	2.51	0.98	3.25	0.88	2.55	1.00	2.72**	5
Eventful	2.69	1.10	2.65	0.97	2.78	0.95	2.59	1.05	2.71	1.06	2.68	6
Monotonous	2.62	0.95	2.58	0.92	2.68	0.94	2.52	0.92	2.57	0.99	2.59	7
Annoying	2.36	0.98	2.23	0.86	2.23	0.90	2.00	0.81	2.28	0.91	2.22**	8

Note: Averages greater than 3.5 were marked in bold, indicating a high level of perception. *$p < 0.05$; **$p < 0.01$.

Table 2
The arithmetic average of eight PSDs in different environments.

Dimensions	GrS		BS		OGS		SGS		EGS		Total of Mean	Total of Rank
	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev		
Social	**3.83**	0.86	**3.71**	0.87	3.49	0.89	**3.66**	0.88	**3.83**	0.74	**3.70****	1
Space	3.49	0.95	**3.66**	0.85	**3.72**	0.89	**3.80**	0.79	**3.66**	0.83	**3.67****	2
Prospect	**3.58**	0.98	**3.74**	0.83	**3.70**	0.88	**3.63**	0.90	3.33	0.91	**3.60****	3
Nature	2.95	1.07	**3.53**	0.93	**3.63**	0.88	**3.62**	0.92	**3.50**	0.92	3.45**	4
Serene	3.04	1.08	**3.51**	0.88	3.47	0.91	**3.65**	0.83	3.38	0.92	3.41**	5
Culture	3.42	1.06	3.36	1.06	3.20	1.01	**3.58**	0.96	**3.51**	1.01	3.41**	5
Rich of Species	2.72	0.96	3.35	0.95	3.36	0.88	3.32	0.94	3.34	0.90	3.22**	7
Refuge	2.82	1.02	3.23	0.91	3.21	0.90	3.26	0.94	3.24	0.90	3.15**	8

Note: Averages greater than 3.5 are marked in bold, indicating a high level of perception. *$p < 0.05$; **$p < 0.01$.

4. Discussions

4.1. Differences in soundscape and landscape perception in different urban green spaces

The differences in the PAQs indicated that respondents could correctly identify and make judgments concerning the soundscape in different urban green spaces. In the blue space, open green space and semi-open green space, *pleasant* and *vibrant* were the highest perceived soundscape qualities by the respondents. This can be explained by the complexity of individuals and situations in soundscape perception (Tarlao et al., 2021). Those who were willing to fill in the questionnaire were usually in a group of two or three who came to the site specifically for sightseeing and relaxation, and these individuals, being more socially connected, tended to report higher levels of pleasure than others (Steffens et al., 2017). Compared with blue space and open green space, *calm* was the soundscape quality that was most highly perceived in semi-open green space. Semi-open green spaces have more dense vegetation, less human activity and higher biodiversity. Natural sounds such as bird songs, insects and rustling leaves may increase the sense of calm in this particular space (Hong et al., 2020). In gray space, *vibrant* was the quality highly perceived by respondents. In fact, during the survey, people often performed singing, square dancing, swordsmanship and other activities in the gray space, which produced a lot of noise. However, *chaotic* and *annoying* were not the qualities most highly perceived by respondents. Perhaps because people who were willing to stay in such spaces tend to be the ones who liked to be lively and enjoyed watching performances, and thus they would perceive the sounds in the spaces as vibrant rather than noisy (Rey Gozalo et al., 2018b).

The performance of PSDs in urban green space was consistent with previous landscape studies, in which *social* was the dimension with the strongest perception of respondents in the Chinese urban environmental settings (Chen et al., 2019). This may correspond to the fact that residents consider urban green space as a place for social activities. The dimensions in green space and blue space were well perceived by the respondents, except for those of *refuge* and *rich of species*. This indicated that the selected green space and blue space have been well equipped with *nature*, *space*, *prospect*, *culture*, *social*, *serene* and other sensory dimensions, and *refuge* and *rich of species* could be appropriately added to enhance their attraction. Grey space had the least amount of dimensions that were highly perceived, which may be because the landscape features of gray space were relatively simple, with only large areas of hard pavement and a few shrubs (Benchimol et al., 2017). However, the grey space was the most crowded of all the survey sites. Perhaps in addition to the features of the site itself, the activities carried out on the site also attract people to recreation (Sharif, 2020).

4.2. The design methods of audio-visual in different urban green spaces

The relationship between audio-visual perception and satisfaction of respondents in the five typical urban green spaces can be divided into four modes, which refined the application of PAQs and PSDs models in the different types of urban green spaces. The results can provided reference for the prediction and improvement of audio-visual perception of different urban green spaces.From the relationship between the audio-visual principal component and satisfaction, it can be seen that the negative sound qualities such as *chaotic* and *annoying*, as well as all the landscape attributes are important to the gray space. It's not hard to explain. The gray space provides a lot of space for residents and attracts a variety of outdoor activities, such as square dancing and singing performances, resulting in *eventful* and *chaotic*. Therefore, the design of gray space needs to increase the application of vegetation as much as possible on the basis of preserving the public activity space, and provide visual noise masking effect on the basis of preserving the original vitality of the site, such as setting green walls or adding tall canopy trees, which can not only increase the visual enjoyment but also preserve the activity space (Massaro et al., 2021).

Rich of species is very important to the overall satisfaction of blue space, and the results reflected the needs of respondents for the perception of *rich of species*. Studies have shown that the interconnection of blue space and blue-green space is conducive to the conservation of biodiversity (Hyseni et al., 2021). Therefore, blue space needs to design a variety of water forms through ecological approaches, and adopt a more natural and ecological form to connect water and land, so as to create a good biodiversity environment and audio-visual environment.

Although open green space and semi-open green space had similar satisfaction models, semi-open green space had lower tolerance for noise and annoyance. This may be because respondents have different soundscape expectations and activity purposes for the two green spaces (Bruce and Davies, 2014). It is found in the survey that people usually like to do mental activities such as sit quietly and meditate in semi-open green spaces. Respondents in semi-open green spaces come to find privacy and quiet space and do not want to be disturbed. Therefore, seats and other rest facilities should be provided for tourists in semi-open green spaces, and a private space with a sense of belonging should be created by setting a hedge or landscape wall around the seats, so as to improve the satisfaction of tourists' experience.

Enclosed green spaces are usually the quietest spaces and attractive. For this reason, people like to do some social or exercise activities in the enclosed green space, bringing a variety of sounds. Therefore, enclosed green space needs to balance people's pursuit of nature and the noise generated by pursuing nature. In urban green space design, the number of enclosed green space can be appropriately increased, so as to increase the carrying capacity of tourists and realize crowd diversion. In addition, the space construction under the tree canopy of enclosed green space is usually neglected, so the design of underforest pavement and green belt can also guide the crowd diversion.

4.3. Audio-visual indicator potential

Combining the PAQs and PSDs in an overall model including all UGS revealed that soundscape and visual perception are highly interwound. In the principal component analyses factors linked to human well-being were highest for naturalness (PSD), followed by pleasantness (PAQ),

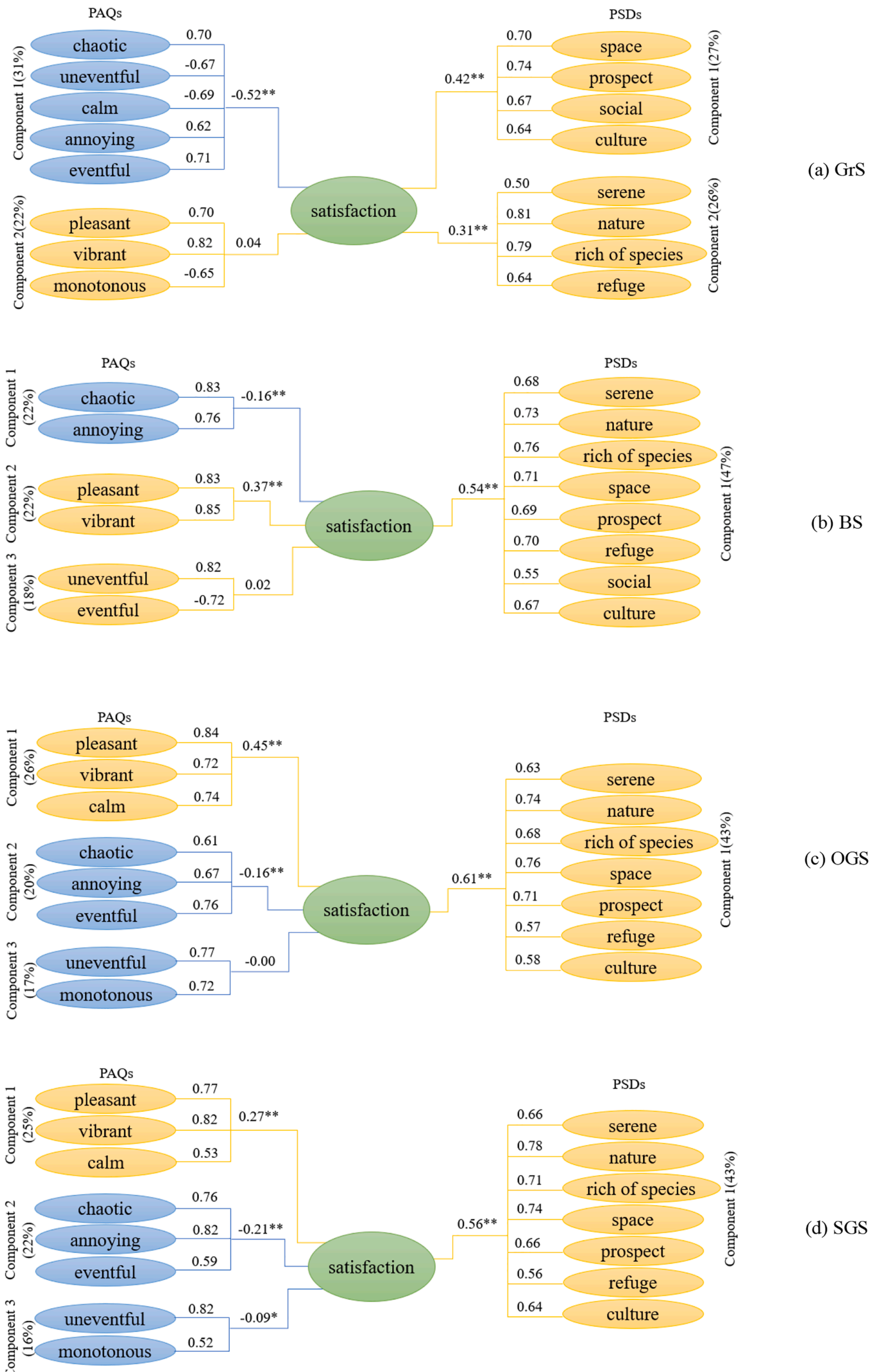

Fig. 3. The correlation between principle component of PAQs and PSDs and satisfaction in GrS (a), BS (b), OGS (c), SGS (d) and EGS (e).

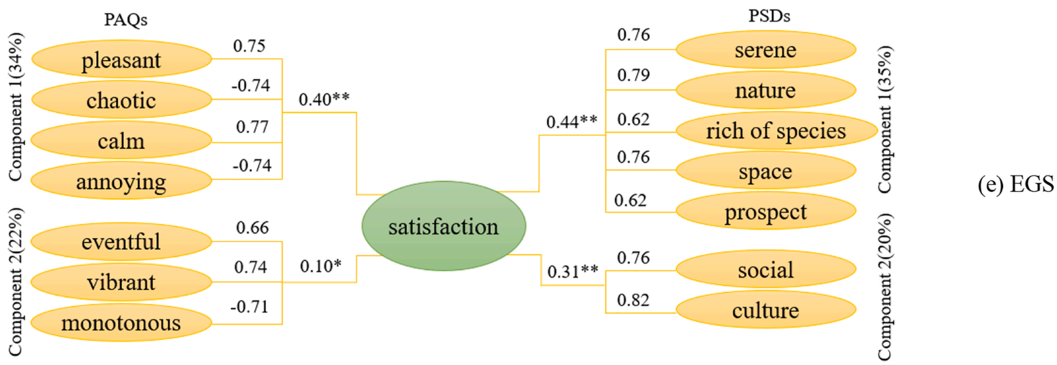

Fig. 3. (*continued*).

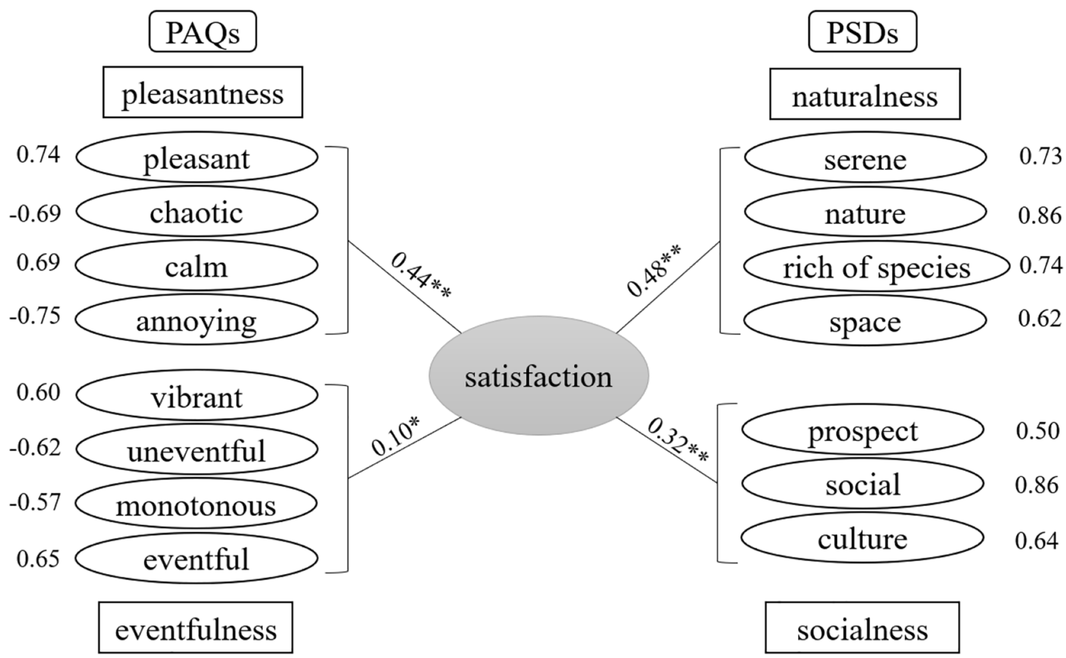

Fig. 4. Overall environmental satisfaction model based on PAQs and PSDs principal components. *$p < 0.05$, **$p < 0.01$.

socialness (PSD) and eventfulness (PAQ). Yet, interestingly (as seen above), each type of UGS had different factors that were linked to well-being depending on the type. This study provides a suggestions of combined indicators as a way forward in urban planning of how to deal with the complex intercorrelations between sound, vision and well-being. Previous studies of indicators of soundscape *per se* and visual perception *per se* in urban green are numerous, but the existing indicators for audio-visual, well-being in UGS is rather scattered and have not been evaluated in a new context. E.g. Joen and Jo (2020) studying urban context and soundscape did not investigae sound and visual in a full model but rather serach for correlations found that "*statistically significant relationships were also found between perceived sound sources and visual quality*". By including audio-visual in a full model, in this study, we can reveal that the inerconnection is more complex than previous findings (see Figs. 3 and 4) where the visual and sound perceptions vary in their dominations depending on type of green and type of sound. Here we suggest that the two general perception models (PAQs and PSDs) are robust and provide enough nuances to be used in design in different UGS as urban planning indicators. Using them it is enables not only, possibilities to change the management and design of existing parks to increase desired outcomes towards human satisfaction, but also provide long term monitoring of audio-visual perceptions as well as international comparsisons of urban green perceptions.

4.4. Limitations and future studies

First of all, the study combined perceived affective qualities and perceived sensory dimensions, which provides reference for the selection of visual and auditory indicators in future linear and non-linear models of environmental satisfaction. In addition, this study only selected typical urban green space of Xi'an, which cannot represent all urban green spaces. More cities and further subdivided green space types could be potential variables in the future. Moreover, the study did not consider the impact of demographic background on PAQs and PSDs, future study should be to distinguish the audio-visual perception of people with different backgrounds to carry out more human-oriented design. The explanatory power of soundscape and landscape perception to the overall satisfaction was 48%, this value still makes sense in on-site survey since are subject to complex factors such as smell, air quality, temperature and humidity, etc. (Gyllin and Grahn, 2015; Xiao et al., 2018). Despite these limitations, the interactive research of PAQs and PSDs as well as the overall satisfaction based on the interaction could provide specific and effective guidance for future urban green space design. For example, according to the characteristics of the site itself, landscape or auditory elements could be introduced to make up for the lack of certain perceptual dimensions, so as to improve the overall satisfaction of visitors of the site.

5. Conclusions

It is believed that this study was the first to apply PAQs and PSDs to study a combined audio-visual perception and explore their relationship with environmental satisfaction, which makes up for the existing imperfection of indicators in previous studies. The results revealed the following conclusions: (1) The type of urban green space was the main factor that distinguished the PAQs and the PSDs in which the visual perception dimensions were more abundant in the same space. Semi-open green space and blue space had the most abundant perceived dimensions in both visual and auditory perceptions, followed by the enclosed green space and open green space, while gray space had the least. (2) Four satisfaction models based on audio-visual perception were found in the five types of urban green spaces, deepening the application of PAQs and PSDs models in urban green spaces. The adjustment of different audio-visual perception dimensions can provide reference for the improvement of satisfaction of different urban green spaces. (3) The principal components of PAQs and PSDs explained 48% of environmental satisfaction, suggesting the validation of the selection of PAQs and PSDs as auditory and visual prediction models. It also provides a reference for the selection of visual and auditory indicators in future research.

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CRediT authorship contribution statement

Yi Xiang: Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft. **Marcus Hedblom:** Methodology, Validation, Writing – review & editing. **Sen Wang:** Investigation, Visualization. **Ling Qiu:** Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – review & editing. **Tian Gao:** Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – review & editing.

Declaration of Competing Interest

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

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