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Acoustic sustainability in urban residential areas

余佳珍 Chia-Jen Yu[1] 康健 Jian Kang[2]

Abstract

Many urban areas are densely populated, often resulting in increases in various types of environmental pollution. Correspondingly, urban acoustic sustainability has become an important concern, especially in urban residential areas. This study aims at systematically examining the urban acoustic sustainability, from three main and typical facets. Firstly, it focuses on people' s perception, trying to understand the effects of behaviour/experience in residential areas. Secondly, a series of building life cycle analysis and building acoustic performances are examined in an integrative way, demonstrating that acoustic factors should be combined into the overall environmental sustainability consideration. Finally, a typical kind of renewable energy technique, wind farms, are studied from an acoustic viewpoint, showing that further attention should be paid to noise effects, especially at the planning stage. Overall, whilst the acoustic effects in the overall urban sustainability might not be always straightforward, long-term effects and multi-factors should be considered.

Keywords: acoustics, sustainability, social, life cycle analysis, wind farm

1. Introduction

In many regions urban areas are densely populated. High density buildings and high consumption of resources often result in increases in various types of environmental loads. With the growing population in urban areas, urban sustainability becomes a serious issue. Urban sustainability is related to a number of aspects, including cultural, social, economic, technical, ecological and environmental factors, and it is important to find balances between those aspects. The concept of urban sustainability is a positive concept, which is not only for protecting the environment but also for achieving human welfare and protecting natural resources. In other words, in sustainable development it is important to maintain comfortable living environment and in the mean time, to reduce environmental impacts. In 1997, Brown and Ulgiati gave a formulation for evaluating sustainability index, which is the ratio between the emergy yield ratio to the environmental loading ratio [1]. It is clear that all of the emersion might become environmental loads relating to a long term environmental effect. It is therefore necessary to consider, from various aspects, how to reduce environmental loads and develop sustainable environment.

Acoustics, or aural environment, is one of the environmental factors which should be considered in this balanced matrix. In a typical urban environment, which is densely populated, with tall buildings and high usage of resources, noise pollution and the creation of

[1]作者一，謝菲爾德大學建築學院 研究生 (PhD student, School of Architecture, University of Sheffield, Sheffield S10 2TN, United Kingdom. Email: arp04cy@sheffield.ac.uk)
[2] 作者二，謝菲爾德大學建築學院 教授(Professor, School of Architecture, University of Sheffield, Sheffield S10 2TN, United Kingdom. Email: j.kang@sheffield.ac.uk)

comfortable sound environment is a vital issue. Various types of noise exist in our daily life and have long term effects. While noise will not disappear automatically, it could be dealt with in a more sustainable manner. In particular, to create and develop sustainable acoustic environments in urban residential areas is of increasing importance. It is a crucial part of the step towards building a more complete picture for sustainable living [2].

The creation of a sustainable urban sound environment is in turn related to a number of aspects, from human well-being to controlling and managing acoustic performance, to the possibility of using renewable energy resources. Corresponding to the concept of environmental sustainability, acoustic sustainability should also consider cultural, social, economic, technical, ecological and environmental issues. Of those aspects three factors are essential and typical, namely people, buildings and resources, as illustrated in Figure 1.

Figure 1. Key factors for urban acoustic environment.

As previously mentioned, a significant feature of urban living is the high density population and thus, people's perception of sustainability is of great importance. It is vital to understand their needs in acoustic environment too, in relation to the requirements and perception on other aspects of urban living.

Another significant feature of urban living is high density buildings. The building industry is a major sector in terms of the urban sustainability. Whilst evaluating and avoiding serious impacts on the environment from building industry is an important issue of sustainability, the role of acoustics has been largely ignored. Of particular importance is the building life cycle analysis (LCA), with which environmental impacts from various stages can be analysed, including extracting and processing raw materials, manufacturing, transportation and distribution, use, re-use, maintenance, recycling, and final disposal. It is important to note that while an acoustic target is given, there is often a range of materials which could have similar acoustic performances, and consequently, the choice of materials could be based on their sustainability performances. However, little attention has been paid to the sustainability and environmental impacts of various acoustics-related materials and building elements.

The high consumption of resources is also a vital environmental issue throughout the world. A number of techniques have been developed to produce renewable energy, such as solar panels and wind turbines. There are a number of benefits from renewable energy, but on the other hand, some of such measures might bring considerable negative acoustic effects. A typical example is a wind farm. Due to the possible noise effects, especially at low frequencies, it is important to manage acoustic sustainability in its surrounding areas.

The aim of this study is therefore to explore the interrelationships between creating a comfortable acoustic environment and sustainability, through strategic urban planning and building design. Following the above discussion, three major aspects are considered, namely social/cultural aspect, building sustainability aspect, and renewable energy aspect. The study focuses on urban residential areas.

The study starts with a systematic questionnaire survey of various social aspects and focus on people's perception on their living environment which may help to build up sustainable environment. It then considers a series of case studies concerning relationships between environmental impacts of buildings and acoustic performances, by carrying out a systematic building life cycle analysis. Then the acoustic effects of a typical kind of renewable energy technique, wind farm, is examined by using a series of hypothetic case study sites and an actual site. While some of the results of each part of the study have been reported in previous papers [2-11], this paper summarises the overall results.

2. Methodology

In the first part of the study, questionnaire surveys were carried out in three stages: namely based on samples in six typical residential areas in Sheffield and Taipei; random samples in Sheffield and Taipei; and random samples in the UK and Taiwan, respectively. The questions included social and demographic data, evaluation of environmental pollution and preference of various sound sources, and perception of general living environment. A five-point linear scale was generally used in the questionnaire, for example, from –2, very comfortable, to 2, very uncomfortable. The statistic analysis using software SPSS [12] showed that the distribution of various social and demographic factors such as occupation, education, gender, and age was generally rather representative.

The second part of the study aimed at examining the differences of environmental sustainability between various architectural acoustic materials/elements, in various situations, from external envelopes to interior finishing. The software package Envest [13] was used to analyse various aspects of environmental impacts. The results in Envest are shown in terms of an overall Ecopoint, where the data in 13 impact categories are multiplied by the agreed weight for each category and combined to produce a single score. More Ecopoints indicate higher environmental impact. Both embodied Ecopoints in structure/construction and operational Ecopoints can be considered. The building life cycle analysis was carried out at four levels, in terms of the comparison between five typical house types in the UK (bungalow, detached, semi-detached, terraced, and apartments), comparison between various building elements in a typical apartment building (different building envelope materials, roof types, and number of storeys), comparison between various building openings for each of the five building types, and comparison between various combinations of materials in typical rooms.

The third part of the study, examining the acoustic impact of wind farms, was divided into two parts. Firstly, a number of hypothetic case study sites were considered, using noise mapping software CADNA [14], with different land forms, number of turbines, turbine locations, hub heights and building arrangements. Secondly, an existing wind farm site, Royd Moor wind farm in the UK, as shown in Figure 2, was measured and compared with simulation results in terms of the sound distribution patterns. By deriving appropriate sound power levels of the wind turbines, a number of hypothetic scenarios were then examined.

Figure 2. Royd Moor wind farm, Penistone, South Yorkshire, UK.

3. People: social and cultural effects

The results of this study demonstrated the importance of considering social as well as cultural factors in environmental acoustic sustainability. Table 1 shows the importance ranking of various factors when choosing a living environment. It can be seen that the most concerned factor was safety in the stage 1 and 2 studies, whereas in the stage 3 study the top concern was property price in the UK and convenient transportation in Taiwan. In the mean time, the factor 'quiet' was also perceived as an important factor in both countries. The correlations between various demographic factors, such as education and age, and current living environments were examined, although no clear tendency was found. The annoyance levels of various sources in the living environment were examined. It was shown that the most noticeable noisy sources were various vehicles as well as those from neighbours and own home.

The comparative study in the UK and Taiwan reveals the importance of considering cultural factors. This is reflected by the significant differences between the two cultures in a number of aspects, including choosing the living environment, effects of social and demographic factors, perception/evaluation of current living environment, main activities, noise annoyance and sleep disturbance, and sound preferences. These cultural differences generally correspond to the differences found in stages 1 and 2 of this overall study [2, 5- 7].

Table 1. Importance ranking of various factors when choosing a living environment.

	Stage 1		Stage 2		Stage 3	
	Sheffield	Taipei	Sheffield	Taipei	UK	Taiwan
Convenient to work	**3**	**2**	**4**	**2**	**2**	**2**
Convenient transport	**5**	**2**	**7**	**3**	**3**	**1**
Convenient school shopping	3	5	5	5	6	3
Recreational space	6	7	9	9	7	10
Social with neighbours/friends	7	9	8	11	5	10
Safety	**1**	**1**	**1**	**1**	**4**	**4**
Property price	**2**	**4**	**2**	**6**	**1**	**6**
Quiet	**4**	**3**	**6**	**4**	**8**	**5**
Views	8	7	10	8	8	7
Size of the house	**3**	**6**	**3**	**7**	**4**	**8**
Interior decoration	9	8	11	10	8	9

4. Buildings: life cycle analysis and acoustic sustainability

The results of this study demonstrated the importance of considering environmental sustainability of various materials which could have similar acoustic performance. An example is shown in Table 2, where for each house types the Ecopoints for brick and stone external walls are compared. Overall, the results in this part of study showed that although individual components may not affect the total Ecopoints greatly, when every acoustics-related component/material in a building is taken into account, significant differences in Ecopoint could be made with a better selection of those components/materials from the viewpoint of environmental sustainability. It is noted that the ratio between embodied and operational Ecopoint is about 1:9 in average, showing the significance of considering operational sustainability [3-4, 8-9].

Creating/developing sustainable living environments is a rather complex system, and it is important to consider various relevant factors and achieve a good balance. Whilst this study has examined the effects of various building elements, the effects of other factors such as land use, which affects noise source distribution; and quality of open public spaces including soundscape and acoustic comfort, must also be taken into account. With those factors considered, the sustainability rankings/comparisons derived from this study may change considerably [3].

Table 2. Difference (%) in Ecopoints between brick and stone external walls.

	Bungalow		Detached		Semi detached		Terraced		Apartment	
	Embodied	Operational	Embodied	Operational	Embodied	Operational	Embodied	Operational	Embodied	Operational
Climate Change	6.11	-1.81	23.84	1.94	4.05	-1.58	13.75	-1.33	36.37	-1.46
Acid Deposition	-9.76	-0.42	-2.70	0.00	-24.68	-0.54	-5.64	-30.39	4.65	-0.15
Ozone Depletion	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	90.00	0.00
Human Toxicity Air	-25.00	-0.40	-28.26	0.40	-23.94	-0.51	-21.92	-0.19	-12.55	-0.17
Ozone Creation	0.00	0.00	0.00	0.00	-4.76	0.00	-0.79	-2.94	27.14	-2.56
Human Toxicity Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	40.91	0.00
Eco Toxicity Water	-80.00	0.00	-82.86	0.00	-85.19	0.00	-85.46	0.00	-79.39	0.00
Eutrophication	-35.00	-1.69	-36.84	1.72	-34.48	-1.05	-31.54	-0.93	-20.20	-0.93
Fossil Fuel Depletion	6.90	-2.77	29.79	3.13	11.24	-2.05	13.36	-1.91	25.17	-2.08
Minerals Extraction	-16.75	0.00	-11.83	0.00	-4.73	0.00	-7.70	0.00	-1.13	0.00
Water Extraction	0.00	0.00	0.00	0.00	16.67	0.00	5.56	0.00	38.46	0.00
Waste Disposal	-1.77	0.00	-9.28	0.00	8.82	0.00	-1.59	0.00	18.34	0.00
Subtotal	-9.44	-1.59	-4.88	1.66	-6.71	-1.36	-3.48	-4.73	11.05	-1.21
Embodied + Operational	-3.69		0.04		-2.70		-4.50		1.20	

5. Resources: acoustic effects of wind farm to surrounding areas

The results with hypothetic cases, such as those illustrated in Figure 3, showed that a wind farm could have significant noise effects in a large area. The effect of land form is insignificant in terms of the differences caused by the source-receiver distance, but various land forms can bring considerable sound pressure level (SPL) differences in terms of noise barrier effects of buildings and ground profile. With a typical configuration, the buildings within 200m from the source bring a considerable extra SPL attenuation, typically over 5-15dB, especially in the region of about 80-200m from the source. In terms of turbine height, when it is increased from 10m to 46m, the SPL increase could be 10-20dB in far field [10].

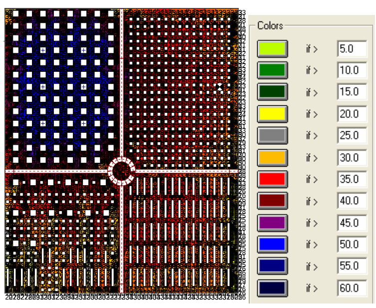

Figure 3: SPL (dBA) distribution with different building arrangements. ▭, terraced house, 6m by 44m, 12m high; □ , detached house, 8m by 8m, 12m high; □ , flat, 15m by 15m, 36m high.

The survey results in the Royd Moor wind farm showed that the SPL at low frequencies was significantly higher than that at high frequencies, which was as expected. This again demonstrated that great attention should be paid to the low frequency effects around a wind farm. With the derived sound power level of wind turbines by comparing measured and calculated noise distribution, further parametric studies showed that the effects of land forms are generally insignificant, while changed source number could typically caused about 7dB difference in far regions.

6. Conclusions

This systematic study in the three major aspects of sustainability, namely people, buildings and resources, has demonstrated that acoustics should be an essential consideration in sustainable development, in particularly in urban residential areas. It is also important to integrate these three aspects as well as other related factors into the overall planning and design process. This is the topic of the current study, in which some case study sites are selected to achieve the best design considering the above three main facets.

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