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A soundscape approach to exploring design strategies for acoustic comfort in modern public libraries: a case study of the Library of Birmingham

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Abstract: Taking the soundscape approach to a study of the Library of Birmingham, this paper explored acoustic comfort in modern public libraries and measured the quality of the perceived sound environment, focusing on the appropriateness of the spatial organisation to facilitate users' activities of reading and writing. The research involved four groups of participants taking soundwalks which provided data at four main floors in the Library, identifying types of sounds, measuring sound pressure levels and evaluating the overall quality and appropriateness of perceived sound environment. A human sound dominated sound environment was found in the studied case. The overall soundscape quality varied among different levels and different functional spaces. However, the results showed that the overall soundscape quality of each floor varied and was not necessarily determined by the overall appropriateness and sound pressure level. The participants in the study were found influenced by their soundscape cognitions of spaces through visual and acoustic perceptions, as well as by their purposes of using the space. From these results, the layout of spaces is suggested as a determining factor of acoustic comfort, and design strategies were discussed to achieve acoustic comfort in modern public libraries.

Keywords: Acoustic comfort; open-plan spaces; modern public library; soundscape; soundwalk

1 Introduction

Libraries have been traditionally associated with quiet and silent spaces. In the past, this was due to the fact that they used to host a relatively limited number of functions (*e.g.* storage of books, reading and studying) that did not include any particular sound source, and the architecture itself was designed to inspire silence and self-control [1]. However, the concept and designs of modern public libraries seem to aim at more vibrant environments (*e.g.* audio-visual materials and media formats), which are beyond the simple reading-related functions of traditional libraries. Users of modern public libraries are also understood to have different needs and expectations of the acoustic environment, for instance, children, elderly people or university students (ibid). There has been a gradual shift from individual involvement to collaborative and even social activities (*e.g.* cafes, meeting areas), corresponding to different room setups and furniture elements, as well as acoustic treatments [2]. The proliferation of new activities in libraries has inevitably led to the emergence of different types of sounds and sound sources, which require architects and interior designers to reconsider how to improve the overall experience of such spaces by managing their acoustic environment in a proactive way rather than just achieving silence. With multifunctions and modern architectural forms of large open plan areas, in particular, sounds of various human activities and speech are difficult to control. In many cases, acoustic consultants have suggested solid separations between different functions to minimise these aural influences, but this often conflicts with the design purpose of creating open-plan spaces. People's purposes for using library spaces have expanded from only reading to visiting for exhibitions, children's activities, meeting friends and having lunch. Users now have different expectations and perceptions of library spaces and their acoustic environments which cannot be met through traditional acoustic

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design based on methods focused on objective acoustic features.

Current acoustic design approaches tend to focus on achieving certain sound pressure levels and reverberation times for target activities, using acoustic materials to absorb, diffuse and resonate sounds in spaces, but they do not take users' experiences into account. Such traditional ways of designing for acoustic comfort may not be able to deal with behavioural sounds, for instance, sounds from walking, chatting, turning pages, moving chairs, etc. and at the same time, meet changing requirements of users and the open-plan feature of modern public libraries. In contrast, a soundscape approach focussing on the human perceived acoustic environment of a place within its context [3] takes users' behaviours and perceptions as central to the experience of library space [1], and explores acoustic comfort both through objective acoustic features and through human perceptions [4].

In urban studies, soundscape is now a well-established approach to researching the acoustic qualities of built environments [4, 5], and is a recognised approach to managing sound environments and informs new urban planning themes [6, 7]. However, there are relatively few studies investigating the quality of acoustic environments of indoor public spaces through the soundscape approach which could make important contributions to design. A recent investigation of acoustic environments in university libraries taking a soundscape approach constructed a physical-psychological-acoustical framework for indoor acoustic environment studies [8]. The results suggested strong correlations between architectural features (*e.g.* function, floor and wall finishing, etc.) and human perceptions of loudness of sounds in the space. However, the functions and users of university libraries are much less diverse than public libraries, which means 'loudness' may not be as important as 'appropriateness' of the different types of acoustic environment in modern public libraries for different types of uses and users. In developing this idea, the paper explores the 'appropriateness' of the sonic composition in the context of modern public libraries.

The Library of Birmingham has been designed to achieve acoustic comfort for its users. The architects and environmental engineers of the Library of Birmingham, Buro Happold Engineering, have taken a traditional approach to reducing background noise, using sound absorption panels on ceilings, carpets on floors and acoustic insulation for vents on the façade to draw in fresh air [9]. This approach seems to be based on an assumption that the reduction of background noise level in the Library will make a good acoustic environment for the users. The absence of considerations of human perceptions and human activities from the acoustic design strategy for the Library of Birmingham makes it a good example through which to explore the difference between traditional approaches to acoustic design and a soundscape approach to design for acoustic comfort in library spaces. Meanwhile, this paper takes the perspective that reading and studying are still important purposes for libraries, even if they have to include all these other seemingly incompatible activities in order to survive. It is important to provide 'appropriate' soundscapes in those parts of the Library where reading and studying take place. This study, therefore, explores the quality of the acoustic environment in the Library of Birmingham from a soundscape perspective and discusses design strategies for achieving acoustic comfort for reading and studying in multi-function, open-plan modern public libraries.

2 Methods

2.1 Case study

A case study method was used in order to explore the complexity of real life situations contributing to soundscapes in a modern public library [10]. The Library of Birmingham is located in the city centre and designed as a landmark, reflecting the industrial history of Birmingham (see Figure 1). The striking appearance and the variety of activities at the Library of Birmingham attract a wide range of citizens, and this indicates that the building is likely to have a complex acoustic environment.

The Library of Birmingham is a typical example of a modern public library with large open-plan reading spaces and multiple functions, including a café, lecture rooms, a children's section, performance spaces, etc. The spaces are arranged around a large atrium in the middle of each floor which provides passive lighting, ventilation and escalator access (see Figure 1). The Library has ten floors: the top six floors include the Shakespeare Memorial Centre, staff offices and spaces for storing heritage artefacts of the city. For this study, soundscapes were explored in the main Library space for reading and studying activities located on the first four floors. The Ground Floor is the main reception space with a double-floor height, accommodating a café, an open exhibition area, and circulation and waiting spaces. The Lower Ground Floor has resources and activity spaces for children as well as access to the music and film collections. The main reading and studying spaces are located on the First and Second Floors.

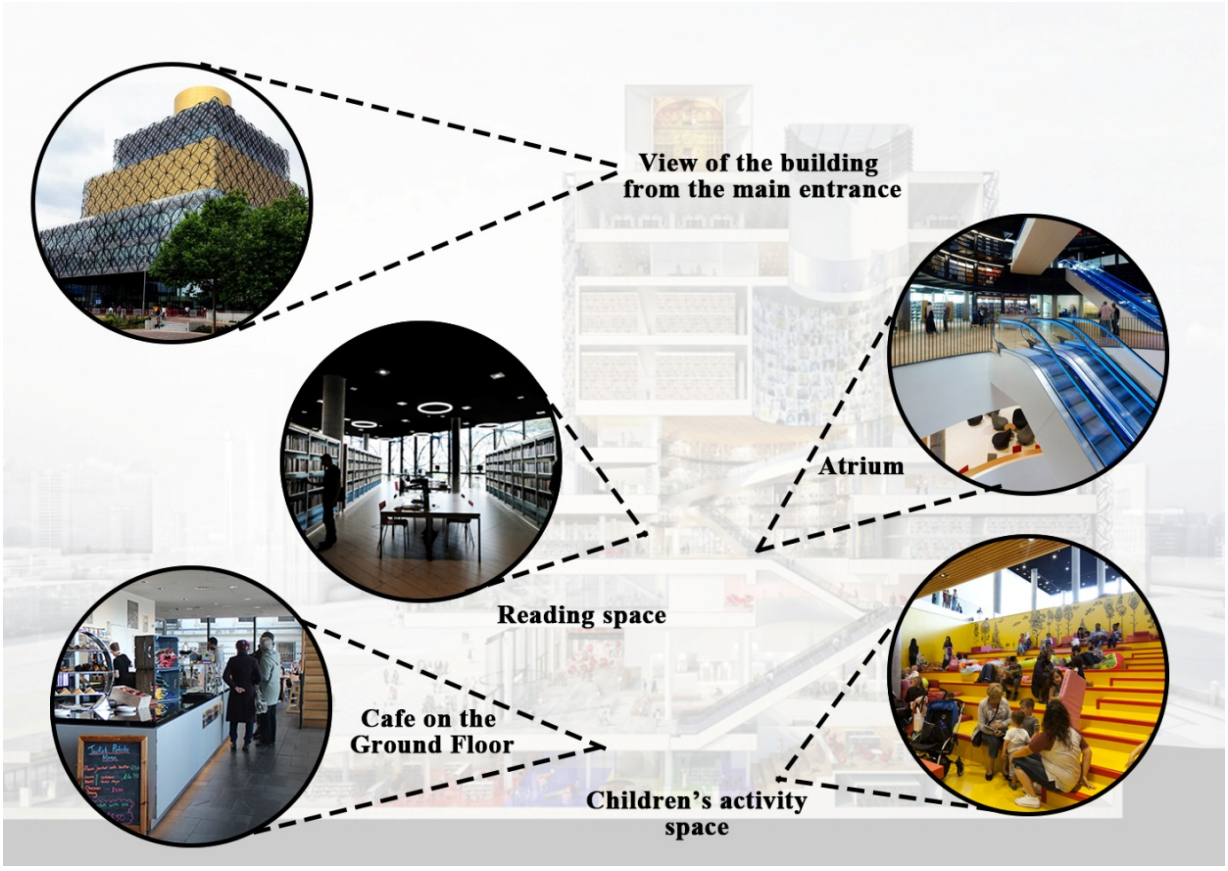


Figure 1: Examples of the architectural characteristics of the Library of Birmingham.

2.2 Soundwalk

This research adapted the 'soundwalk' method to explore the characters of soundscapes in the Library of Birmingham. The soundwalk is an established method in soundscape studies for collecting perceptual data about the acoustic environment [11–14]. Participants are normally guided through a pre-planned route and asked to give feedback on their immediate reactions to the surrounding acoustic environment. Meanwhile, current studies have suggested using audio recordings and objective measurements such as sound levels during the soundwalk to support analysis of subjective data collected from questionnaires or interviews [7, 15, 16]. Informed by existing studies, for the Library soundwalks, a route was designed for each floor based on preliminary onsite observations, which was then tested and finalised after a pilot walk. Each route had several stopping points, which were selected in relation to the different functions of spaces and surroundings (see Figure 2). All routes were designed to be accessible to participants, and followed the main circulation routes on each floor.

2.3 Participants

Twelve undergraduate architecture students participated in the soundwalks and recorded data as part of their course work. These participants are not representative of the ordinary public but have a special interest in this topic. They are not just providing their immediate reactions like ordinary users would, but are giving design-influenced responses, as well as using 'technical' expertise. Participants had a discussion on what they consider as appropriate in the beginning of the study and agreed that the appropriateness of library soundscape should allow for reading and studying activities not disturbed by surrounding noise. Participants were aged between 20 and 23, including 5 males and 7 females: they were divided into four groups of three people – Groups A, B, C, and D – and allocated to the Lower Ground Floor, Ground Floor and First Floor and Second Floor respectively.

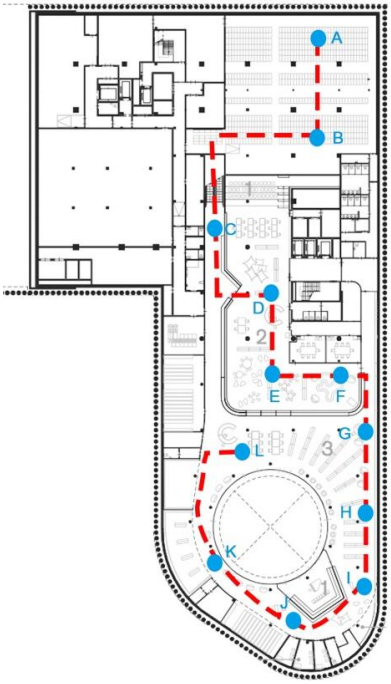
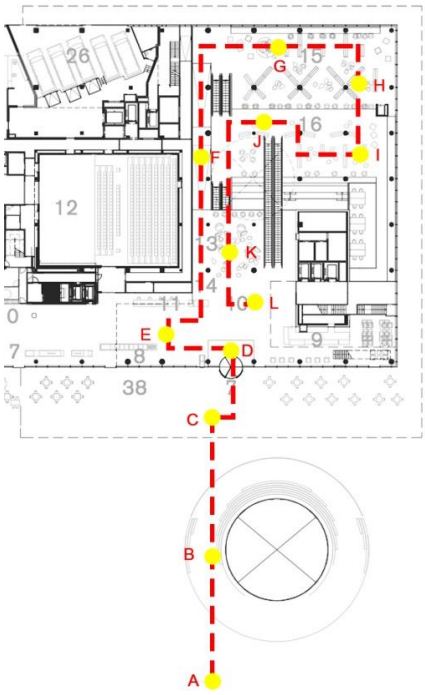
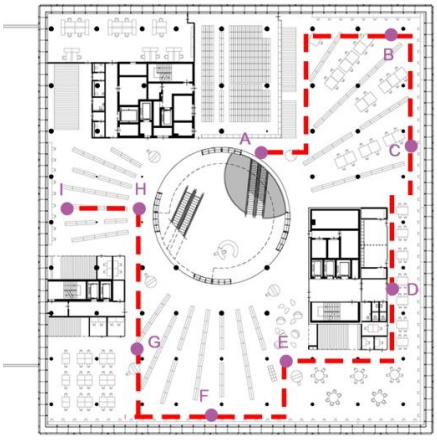
Group A: Lower Ground Floor	Group B: Ground Floor
	
Main Functions: Open lending and reading space (A/B), Music library (G/H/I/L), Children library (C/D/E/F), Performance space (K) and a small theatre (J)	**Main Functions:** Front open space (A/B/C), Foyer (D), Reception (E), Café (L), Open lending and reading area (G/H/I/J), Meeting point (F/K)
Group C: First Floor	**Group D: Second Floor**
	
Main Functions: Entrance (A), Supported leaning space (F/G), Group study area (B/D), Quiet study area (E/H), Inquiry Desk (C/D)	**Main Functions:** Entrance (A), Reading space (B/C/G), Group study area (D/E), Viewing seats (F/I), Meeting point (H)

Figure 2: Route descriptions of soundwalks taken at four levels in the Library of Birmingham.

Figure 3: Group D soundwalk (left) and Group B soundwalk (right).

2.4 Data collection

A series of soundwalks was conducted with the selected four groups of students in October 2015. Each group conducted three soundwalks at 11.00 am, 1.30 pm and 4.00 pm, to cover different user flows during peak and off peak times. Before conducting fieldwork, participants were trained to understand the soundscape concept, design the soundwalks and measure sound pressure levels on their handsets. Participants followed the designed soundwalk route with an average time of 45 mins per walk, and were asked to walk in silence in order to listen to the acoustic environment. Figure 3 illustrates participants collecting data onsite.

At each point, each individual group member detected the sound pressure level with a calibrated sound level meter, listened to the acoustic environment for two minutes and completed a questionnaire to record the dominance of different sounds and sound sources, as well as the perceived overall quality and appropriateness of the sound environment [17, 18] (see Table 1). The questionnaire was adapted from protocols available in existing literature [*e.g.* 19, 20] and after preliminary observations onsite was revised to match the context of the indoor acoustic environment of a library. After the walk, all participants were gathered in a small lecture room to discuss what they thought would be appropriate in particular spaces and then correlate their replies with their evaluation of the soundscape during the walks. Notes were made by the researchers and used to help analyse the data.

3 Results

3.1 The sonic composition of the Library

The detection and identification of sound sources are important in the soundscape approach to understanding the acoustic environment. The sonic composition of a library includes the types of sounds perceived and how dominant they are in the space. Figure 4 illustrates the composition of sound sources perceived at each spot on the soundwalks through the Library of Birmingham. The types of sounds detected at all stops across all explored floors were similar with verbal and non-verbal sounds being detected most frequently, indicating a human sound dominated sound environment. Figure 5 summarises the sound source profiles on each floor by averaging the sound source dominance scores of the different stopping places (*e.g.*, A to L).

3.2 Overall soundscape quality and appropriateness

Figure 6 illustrates the ratings of overall quality, the appropriateness of perceived acoustic environments and mean values of sound pressure level (SPL) readings at each stop along the soundwalks. The average SPL values were similar, at around 57 dB at all stops and on each floor studied, but there were variations in the overall quality and appropriateness of sounds. Overall quality and appropriateness were not correlated with the sound pressure level readings

Table 1: The Sound Walk Questionnaire. For each question, participants could express their preference on a ten-point ordinal scale.

Question	Items	Extremes of the scale (0-10)
To what extent do you presently hear the following five types of sounds?		Do not hear at all - Dominates completely
	Verbal individual sounds (*e.g.* conversation, laughter)	
	Non-verbal individual sounds (*e.g.* coughing, footsteps, browsing pages)	
	Crowds of people (*e.g.* passers, children at play)	
	Mechanical sounds (*e.g.*, elevators, air-conditioning systems)	
	Environmental noise (*e.g.* road traffic noise, loud music)	
Overall, how would you describe the present surrounding sound environment?		Very bad - Very good
Overall to what extent is the present surrounding sound environment appropriate to the present place?		Not at all - Perfectly

in the studied library. The overall quality was rated acceptable at the Lower Ground Level and Second Floor, which generally matched functions of spaces on both floors. However, the overall quality of sound on the First Floor and Ground Floor varied between different stops. In particular, the overall quality and appropriateness were mostly negatively correlated, meaning that the acoustic environment did not match the context, *i.e.* the open lending and reading area on the ground floor. Participants gave lower evaluations of the overall sound quality where stops were in spaces with no specific functions, such as the meeting point at Ground Floor, and easily distracted by the mechanical noise, such as entrance area at First and Second Floor. The participants found the viewing and meeting spaces around the escalators to be a generally poor acoustic environment. Another space where acoustic quality was perceived as poor was the Silent Study Area on the First Floor, since it was surrounded by noise-generating uses such as a supported learning space and group study areas.

Comparing the different ratings of overall quality and appropriateness, participants' expectations of spaces for 'interacting and communicating' or 'reading and thinking' are also important to their assessment of the overall quality of acoustic environment. Comparing ratings of overall qualities of stops where more verbal sounds were perceived with stops where more non-verbal sounds were noticed (see Figure 6), it appears that people in spaces for reading and thinking are more bothered by verbal sounds than by non-verbal sounds, while people in spaces for interacting and communicating are not significantly annoyed by either verbal or non-verbal sounds. Thus, in open lending and reading areas, people enjoyed a 'chatting' environment rather than being silent, such as Stop H on the Ground Level. This fact suggests there is no direct correlation between actual sound levels and people's expectations of how different spaces should be used.

4 Discussion: design strategies to achieve acoustic comfort in modern public libraries with large open-plan spaces

The layout of space is critical for influencing people's behaviours and separating different user groups to improve acoustic comfort, particularly in large open-plan library spaces where solid separations are minimised. Hierarchizing sonic spaces is a way of organising spaces in libraries to achieve a good sound environment [1]. From results in this study, it is difficult to identify sonic spaces by types of sounds or sound pressure levels in large open-plan pub-

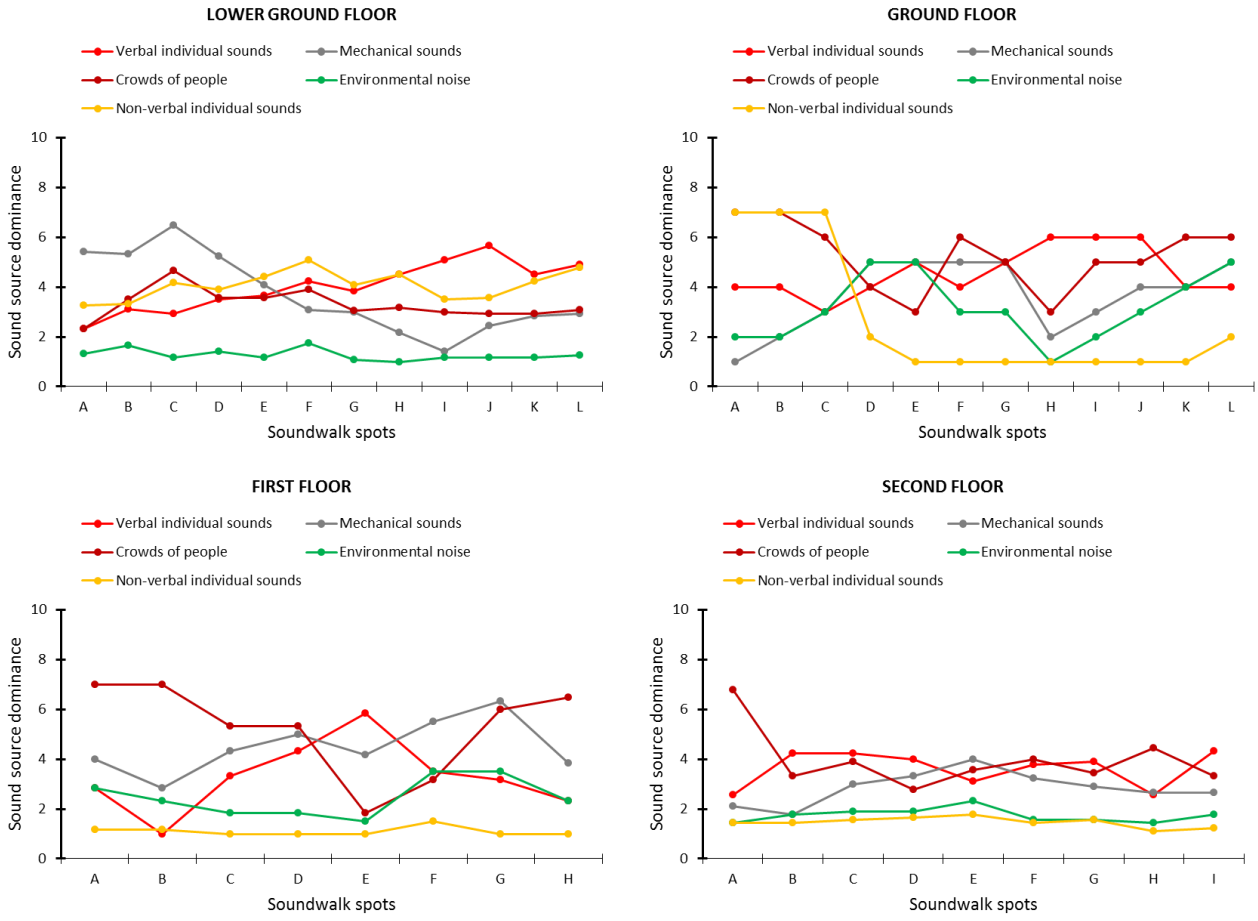


Figure 4: Dominance of sound sources detected during the soundwalk on each.

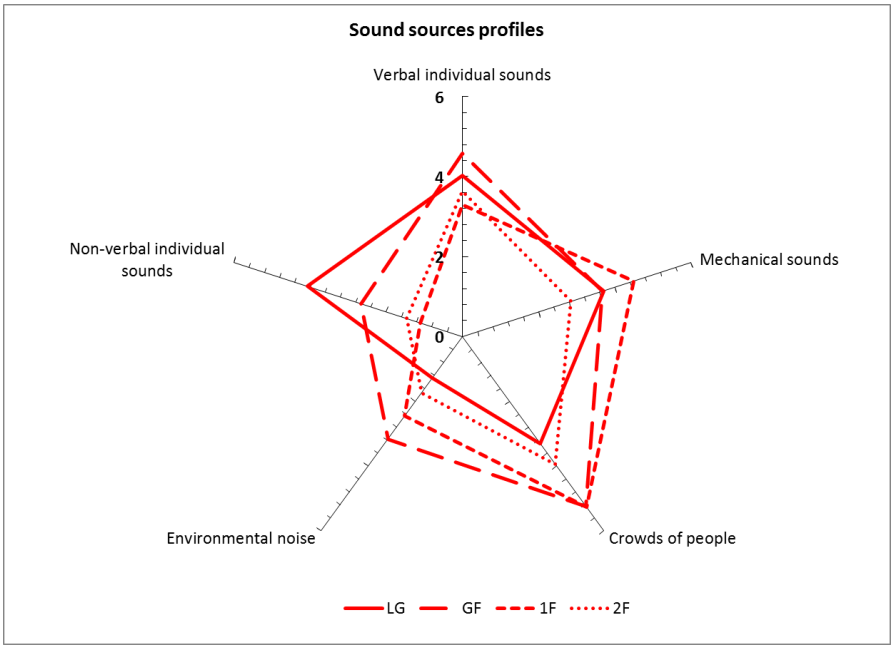


Figure 5: Aggregated Sound source profiles for each floor.

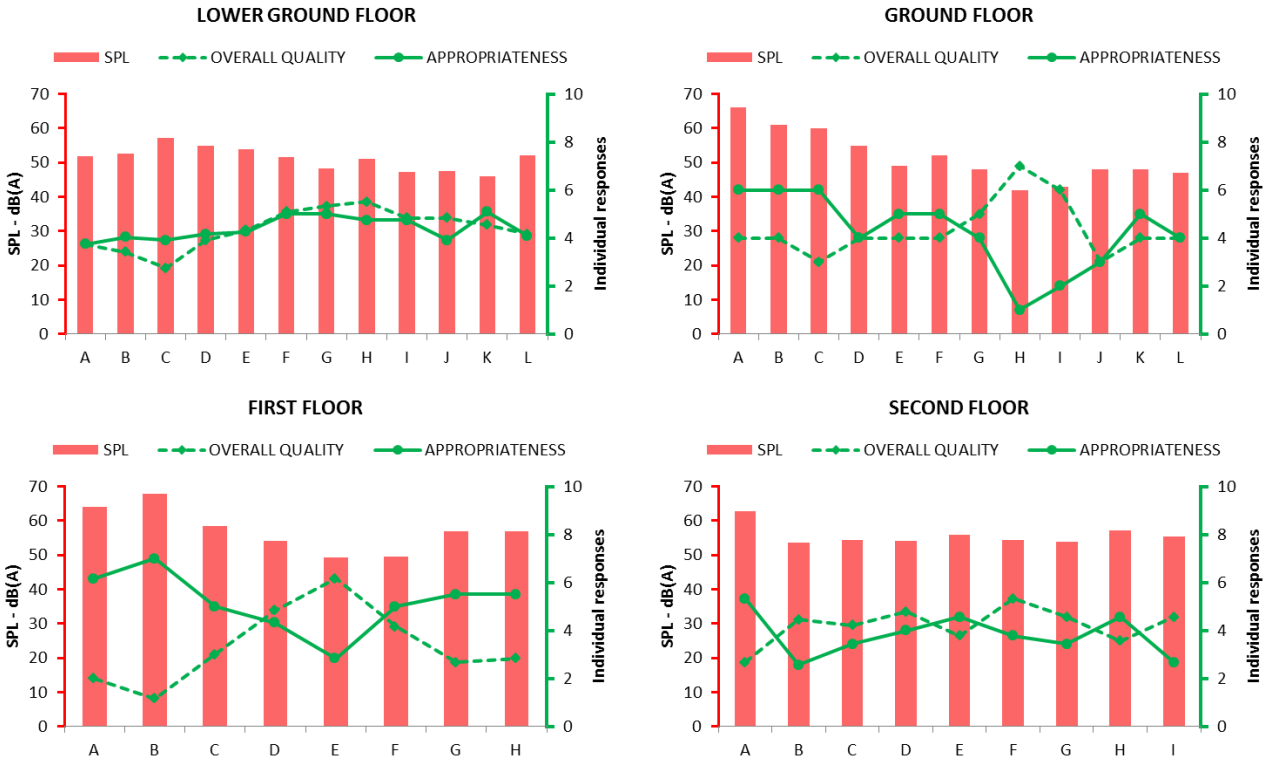


Figure 6: Ratings of the overall quality and appropriateness of soundscapes along the soundwalks on each floor with Mean values of SPL readings.

lic libraries, since they were found similar across all stops and levels. The participants in this study evaluated the overall quality of the acoustic environment depending on their cognitions of spaces rather than the appropriateness of contexts. Participants seem to have higher acoustic requirements of spaces for 'reading and thinking' than for 'interacting and communicating'. In the case of the Library of Birmingham, meeting points, the reception area, foyer, guided study area and café are definitely spaces for 'interacting and communicating', while the quiet study area and reading space are for 'reading and thinking'. There are other types of 'in-between' spaces without fixed functions, such as the viewing seats, circulation spaces and open lending and reading areas. It can be indicated that users' acoustic requirements in such 'adaptive' spaces are influenced by the surroundings. For example, users' requirements of the acoustic environment in the open lending and reading area would be different if they were located next to the café or a quiet study area. It would be good to have a sequence in the layout from the main circulation space to the spaces of 'interacting and communicating' to 'adaptive' spaces and then to spaces for 'reading and thinking'.

One way of zoning for soundscape cognitions is to create enclosures and different levels of openness. The enclosure and openness of space are suggested as influencing users' cognitions of spaces for public activities (interacting and communicating) or private study (reading and thinking) [1]. However, in large open-plan library spaces, architects usually do not want to include solid partitions to create many enclosed spaces or semi-closed spaces. But as essential library facilities, book shelves could be used as partitions to create different levels of enclosure and openness to form different cognitive spaces and separate users groups. However, the layout of bookshelves could block daylight and create large shadows on desks. This limits the ways of laying out book shelves to create preferred enclosure and separations. Meanwhile, books have to be catalogued and sequenced in particular ways that may conflict with a layout designed to provide functional areas.

Another way of zoning is visual differentiation, by using different patterns and coloured acoustic materials on surfaces to indicate different cognitions of spaces, such as screens, walls, floors and ceilings. Visual aesthetics of the physical environment influences people's preferences both towards specific sounds and the overall soundscape [21]. In particular, research has shown that colours influence different psychological reactions, acoustic expectations and perceptions: red indicates a noisy environ-

ment while blue indicates a calmer and quieter environment [22]. Good acoustic environments in libraries can be created by the use of carpets to reduce noise of footsteps, patterned acoustic foams on walls, acoustic wood slat panels, metal decks, tiles and baffles on ceilings to absorb sounds and reduce reverberations [23]. The appearances of these acoustic materials inform different acoustic cognitions. For example, treated wood slat panels give a warm colour and homely atmosphere, aluminium acoustic tiles give a white neutral colour and modern finish, and colourful suspended acoustic baffles give a creative and exciting feeling. Shapes and colours of carpets on floors also need to match the colours and patterns of the ceilings to reinforce the perception of zoning and to direct people's routes in large open-plan spaces.

A soundscape approach would allow architects and interior designers to explore users' experiences and design for a high-quality acoustic environment in modern public libraries, for both reading and other public activities. However, people's cognitions of acoustic spaces may vary in different contexts and change with new design concepts and built forms of libraries. It would be essential to identify types of users and cognitions of acoustic spaces to proceed to the layout strategies discussed in this paper.

5 Conclusion

The architectural form of the Library of Birmingham challenges the achievement of acoustic comfort. The large open plans of the public access floors do not prevent sound transmission between different functional spaces and types of users. In order to ensure good lighting and ventilation, the designers created a central Atrium, but this allows sounds from the Ground Floor foyer to spread through each floor. The Atrium also forms the main circulation space for the building, generating more noise in the middle of each floor, and making the acoustic environment even worse. However, the most negative influences on the acoustic environment arise from the layout of different functional spaces, which does not take acoustic requirements into account. Sounds generated by different types of users penetrate surrounding areas: for instance, group study areas from which the verbal discussion is audible in the quiet study space which requires silence for concentration.

The study indicates that people's judgement of the appropriateness and comfort of soundscapes in multifunctional public libraries might depend more on their soundscape cognitions and the purposes for using the space, rather than actual measured sound levels. Three types of soundscape cognitions were found in the study: interacting and communicating, adaptive, reading and thinking. Layout of spaces is critical to acoustic comfort in large open-plan libraries. Separations of spaces in the layout of a plan can be achieved by hierarchizing acoustic spaces with types of users and their soundscape cognitions. In addition, different coloured and patterned acoustic materials with relevant shapes, and coloured carpets creating different zonings for identified soundscape cognitions, can be helpful to guide users' activities and to separate different human sounds. Overall, this case study suggests that it is worth investigating the acoustic environment of public libraries from a soundscape perspective by which architectural strategies might be implemented to enhance users' acoustic comfort in such spaces.

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