ACOUSTIC PERCEPTION EVALUATION IN BUILDINGS - THE APEAL METHOD

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1 ABSTRACT

Conventional acoustic performance criteria for buildings refer to the unoccupied state. In contrast, the APEAL method enables a shared acoustic evaluation of a building in use from the occupants' perspective. This method involves the production of an aurally-accurate video representing selected temporal and spatial elements of the environment. Binaural sound recording combined with a point-of-view video camera places emphasis on human perception.
The APEAL film systematically portrays the in-use acoustic conditions of a building. The common perception of an environment can enable a shared design aspiration for in-use acoustic conditions - something that has hitherto been without language to describe. The APEAL method is particularly useful for open plan, mixed use spaces, where the acoustic descriptors for the unoccupied building have only little influence on the in-situ acoustic environment. However, it is also a valuable resource to illustrate conventional acoustic design parameters.
The APEAL method overcomes the traditional difficulties of communicating acoustic performance, as it obviates the need for using technical descriptors such as sound pressure level and reverberation time that are often unfamiliar to the non-specialist. Rather, it enables non-specialists to participate and engage in forming acoustic design aspirations for all types of spaces.

2 INTRODUCTION

This new empirical method was inspired by the integration of three separate developments. On the one hand, a growing awareness of the soundscape approach: understanding the importance of the occupant's experience of the acoustic environment, in context. On the other hand, there is a global shift in the perception of real estate from asset to service. In this context, it is the performance in use that is important for the occupiers rather than compliance with benchmark design criteria. In-use evaluation may be focused on meeting the occupants' functional, operational and well-being needs. And lastly, by what has become a prototype video of a building in-use, created to illustrate the exemplary variations in acoustic environment within an open plan building. This has proven to be an invaluable communication tool in design team meetings, as architects and clients have declared:

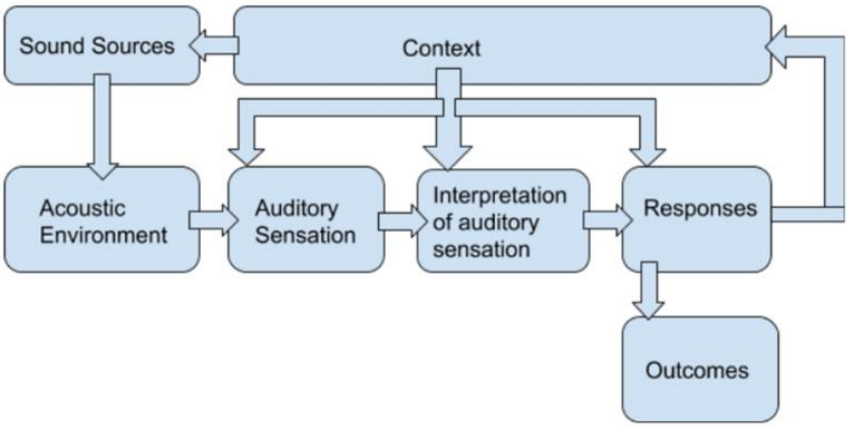
"we want our building to sound like that".

A film-based method, APEAL (Acoustic Performance EvaluAtion through Listening) expands on the recommendation that soundscape data should be 'visible' and communicable [1] by creating a sounding notation system, which can indeed be interpreted easily by professionals beyond acoustical engineering. As Schafer observes [2], *"No silent projection of a soundscape can be adequate".*

2.1 SOUNDSCAPE

Popularised by Canadian composer Raymond Murray Schafer, soundscape is defined by ISO 12913-1 [3] as *"the acoustic environment as perceived or experienced and/or understood by a person or people, in context".* It is thus a perceptual construct dependent upon several interrelated factors, whose assieme creates the context.

Fig.1 The Perceptual construct of Soundscape (schematic from ISO 12913-1)



Given the proven interaction between the acoustic and visual attributes of a place [4], soundscape research has emphasized the importance of visual cues, photographs and descriptions, the incorporation of multi-sensory observations of the soundscape [5]. The use of POV film represents a step change in providing context for the listener with the recording and reproduction of aural media.

2.2 SOUNDSCAPE AND AUDIOVISION

"It is the business of the sound film to reveal for us our acoustic environment, the acoustic landscape in which we live, the speech of things and the intimate whisperings of nature [...] It is for the sound film to let them speak to us more directly from the screen."[6]

The relationship between vision and audition constitutes a whole body of literature in film studies. The APEAL method allows us to make meaningful connections across disciplines. If critical attention to the visual dimension of the acoustic environment is recent, so is that to the aural dimension of film. It is interesting to note that similarly to the role of photography within Soundscape studies, the role of sound in film has been mostly neglected from a critical point of view: even though the relationship between aural and visual should be central to both realms. As film sound theory pioneer Michel Chion notes, in audiovision, one perception influences the other and transforms it [7]:

"*we never see the same thing when we also hear; we don't hear the same thing when we see as well"*

The perception of sounds changes in accordance with the physiognomy or gesture of its visible source when seen together with the sound itself in a film; acoustic and optical impressions are linked together into a single experience [6]. It goes without saying that this important relationship in film derives from the way we perceive the world around us, i.e. with all our senses. The McGurk Effect, an interesting phenomenon that clearly demonstrates the interaction of hearing and vision, is explained in this video [8]. When an image is juxtaposed to a sound, it influences how we interpret that sound, sometimes overriding its meaning. As remarked by Professor Lawrence Rosenblum [8], being aware of this illusion does not make it vanish. In the context of the APEAL method, introducing the use of video for soundscape evaluation represents a more total approach to characterizing the acoustic environment.

3 THE APEAL METHOD FOR BUILDINGS' SOUNDSCAPES

The body of literature regarding the soundscape approach has mainly focused on sound outdoors, particularly in places where traditional acoustic consultancy has little to add to the understanding of their design. While it is true that acoustical design of buildings has been researched for a long time and buildings *"have to comply with criteria that are well related to the sound perceived by the user, in terms of function"* [9], the approach and methodologies for designing and evaluating buildings has not been systematically framed from a soundscape perspective; it tends to focus on meeting sound pressure level limits, sound insulation criteria and reverberation time limits. It rarely takes users' experience into account. Ever-changing requirements and expectations of building users and behavioural sounds such as walking, chatting, typing, clicking, etc. are left out of the equation. There are few studies that investigate acoustic environments of indoor spaces through a soundscape approach [10].

However, recent scholarship is focusing on how buildings mediate in the definition of the indoor aural experience; it calls for the integration of traditional noise-control engineering and building acoustics with soundscape techniques within a soundscape framework, to cultivate a human-centered acoustical design. The APEAL method offers a significant step forwards in enabling this process by adopting a multi-sensory perceptual perspective of how buildings sound, in use. The audiovisual recording captures the experience so that it can be shared more widely than simply amongst those present at the time. This method entails the production of a short film with a binaural, aurally accurate sound recording; shots and scenes are selected to characterise the acoustic environment of the building or location within it, under one or more typical operating conditions, to create a representative rendition as perceived by the APEAL film maker. Preliminary observations are required to observe the environment, along with temporal and spatial variations. Time is taken to listen to and observe the acoustic environment in different locations, noting sound sources and the behaviour and responses of other people. The same acoustic environment will invoke different concepts of soundscape in different people.

The aim of the APEAL method is to provide the most accurate reproduction of the acoustic environment with as much context as possible, so that the response of the viewer comes as close as possible to the response that the same individual would have in the real environment. This means that the recording and editing must be done by a person who was present and retains the experiential memory of the real environment. Nonetheless, it is likely that there will be variation between the footage captured, edited and presented between two different operators. The potential for both repeatability and reproducibility requires further work.

3.1 ACCESSING BUILDINGS

The use of in-situ film with binaural sound poses new challenges in terms of access and permission. Whether public or private, permission to film on the premises must be obtained from the building management. Depending on the nature of the building occupancy and their GDPR policy, we have found that obtaining permission can be straightforward, complex or impossible. At the filming stage, there are "on-set" challenges. Permission to film from the building management might be granted under the assurance that building users will not be personally identifiable. In order to achieve this, long shots can be prioritised for the capture of a general impression of the space. This photographic clause can however interfere with the soundscape investigation, as sometimes significant sound sources are located in crowded areas. When featuring someone's face cannot be avoided, post-production utility effects such as blurring or pixelating are required.

There is a risk that by introducing recording apparatus and personnel into a space that is in use, people may change their behaviour. The act of seeking to record the environment could alter that environment. Our equipment is selected to be low-key and as non-intrusive as possible, to reduce this risk. Experience to date suggests that people may notice the recording, may be curious for a short time, and then resume the activities that were observed prior to our intervention.

3.2 TYPE OF RECORDING

A real sound documentary

"Cinema has created codes of "truth" – in fact what feels true – that have nothing to do with what is true. Cinema prefers the symbol, the emblematic sound, over the sound of reality." [12]

It is useful to frame the APEAL method from a cinematographic standpoint. At first glance, APEAL appears to fall within the realm of documentary film: there is no fantasy narrative content. Indeed, we are documenting the soundscape of a building. However, even in the language of conventional documentary filmmaking, the soundtrack is only a rendition of the actual soundscape. As Michel Chion notes [12], film can only provide an approximation of the cluster of human perceptions, which are complex and intertwined. To recompose and render this cluster *in black and white, monocularly, and monoaurally*, it manipulates the simulacrum via exaggeration, montage, contrast, etc.; instead of opting for the sound that most accurately corresponds to the auditory reality, film "creates" sound that only gives the idea or the feeling of the sound event. For example, a cinematic punch has a conventional sound that is far from real, however it has the ability to transpose the *physical, psychological, even metaphysical* effect of the punch on its sender or receiver.
Viewers (listeners) have become habituated – through a century-long process of acculturation – to these conventions, which have gone beyond the silver screen and are immanent across different creative multimedia. Consequently, when presented with APEAL films, which are "unconventionally" seeking the sound of reality, viewers can find the film's realism to be confronting; by the democratization of sound events: the humming of the building utilities, the slamming of doors, the unscripted and uncontrolled chatter of the occupants, etc. As they all combine to create the building's soundscape, one is not privileged over the other through audio manipulation. This is a hugely different audio-visual experience to the one that has become ubiquitous.

Point of view, point of audition: soundwalk recording vs stationary recording

An established method for outdoors soundscape investigation is the "soundwalk", *"an excursion whose main purpose is listening to the environment"* [5]. However outdoor sounds are culturally different from indoor sounds [2], and the activities through which we experience the acoustic environment when we are in a building are different; they are typically static for a period of time at any one place, for a particular purpose. Outdoors it is less common to remain in one position for an extended period of time. As the APEAL method was developed, it became evident that continuous movement through a building was not able to convey the more common user experience. So, we researched alternative camera techniques, and adopted a sedentary posture at times.

3.3 BINAURAL TECHNOLOGY

Recent developments in Soundscape studies have seen the rise of binaural technology as the standard recording medium. ISO TS 12913-2 [13] dedicates a section of the Data collection chapter to binaural measurements, stressing the importance of *"acoustical measurements related to a soundscape [that] consider the way human beings perceive the acoustic environment".*
Binaural technology allows the recording of auditory events so that they can be reproduced as would be heard by a listener. One method for doing this is by capturing the input signals at the position of the ears of the person making the recording [14]. The recording at the position of the ears emulates the way we hear; the level, time, and spectral differences between Left and Right channels create the stereo image [15] containing spatial information that our brains can decipher. This is informed by the direction-dependent filtering of the sound signal caused by our outer ear; *"the filter impact results from a modification of the sound waves diffusion through attenuation, deflection, reflection and resonance of the sound waves."* [16]. The sound at each ear is also affected by the size and shape of the head – the Head-Related Transfer Function (HRTF) describes how incoming sounds are heard at the two ears for individual people. This is standardised in the dummy head as an "average".

Fig.2 HEAD HMS IV – Head Measurement System [16]

Dummy head recording devices achieve aural accuracy by taking into account the acoustic filter characteristics of our auditory apparatus, as well as the decisive role played by the geometry and anatomy of our head. Likewise, playback devices can apply an equalization that considers, amongst other factors, the distance between the headset microphones and the entrance to the ear, and the unique frequency response of headphones.
This type of technology has been developed particularly the automotive and telecommunications industries, where there is competitiveness to be gained through sound quality improvement. Nevertheless, it is widely accepted that binaural audio is more useful than mono or stereo because it recreates the spatial characteristics of the sonic environment [18]. Listening experiments have shown that the aurally accurate playback of spatially distributed sources causes stronger physiological reactions than the same soundscape recorded with a conventional monaural microphone [19].

3.4 RECORDING TECHNIQUES

Our listening and filming techniques have evolved to favour the portrayal of the building user's experience - point of view and point of audition - which is typically stationary and prolonged, such as working at a desk.
We found that the quieter the station, the longer permanence is required to capture the subtle nuances of the soundscape. It is interesting, in the case of open-plan spaces to showcase the diversity of the acoustic environment by recording in areas of different intended use, e.g. collaborative areas, individual work areas, quiet/silent work areas, which can co-exist in an open plan environment.

Fig.3 HEAD acoustics SQobold with binaural headset BHS II [20]

Fig.4 GoPro HERO 8 Black [21]

The above figures represent the equipment we use for our APEAL films. BHS-II built-in omnidirectional microphones are extremely sensitive; being body-worn will be prone to noise from our clothing or accidental cable clanking. Extremely close to our nose and mouth, they can detect our breathing. Noise from the operator is distracting for the viewer and is best avoided. It is important to be still during stationary recordings and be smooth during transitions between areas.

With regards to the protection of the building users' privacy, recording in areas with little to no background noise might constitute a risk if somebody starts a conversation that includes identifying information. Although SQobold allows for synchronized video recording through a USB connected webcam, we concluded that a higher quality image is beneficial for immersive portrayal of the acoustic environment. As APEAL films are rooted in the listener's point of view, we decided to use GoPro (i.e. a POV camera), experimenting with different mounts, including a headstrap, handgrip, and tripod. The use of a head strap was initially motivated by the desire to walk through the space and still obtain smooth footage; when we concentrated on the single stationary positions, more traditional mounts (tripod and handgrip) proved easier to manage and are less intrusive for the users of the space.
We have encountered two main issues with filming indoors. The first is the common low-light condition which we cannot solve by "lighting the scene". So, we are obliged to experiment with the settings on the camera; a few other solutions are also available in the post-production process, e.g. controlling exposure and contrast, antigrain plugins. The second issue is related to maintaining building users' privacy and has to do with the field of view. Due to architectural and design limitations, it is not always possible to move far from the area that we want to film, e.g. when we want to get a general impression of a space, without including recognizable facial features. GoPro's SuperView option allows it to include more of the surroundings and is suitable when shooting in tight spaces, such as a library or an office floor.

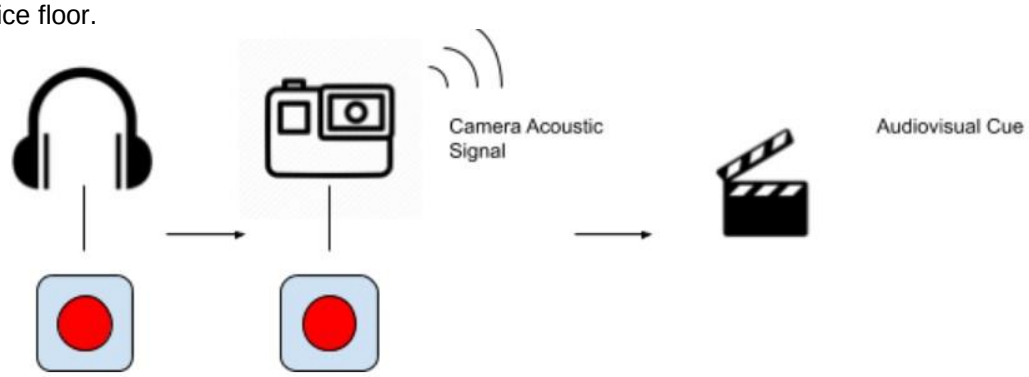


Fig.5 Audio Visual workflow – Start Recording

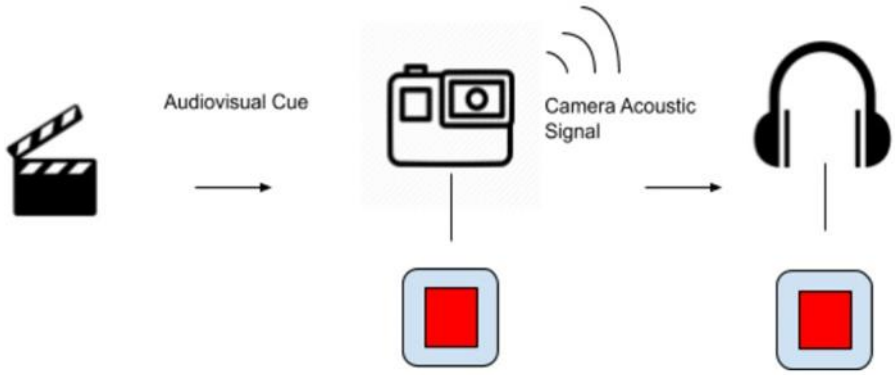


Fig.6 Audiovisual workflow – Stop Recording

3.5 POST-PRODUCTION AND PRESENTATION

Recording audio and video separately, the first, most critical aspect of post-production of the sound films is their synchronization. To speed up this process, the correct workflow must be followed during filming. Since GoPro can record audio with the same sampling rate of SQobold (48kHz), the ultimate way to check that audio and video are synchronized is playing the audio track from the camera and the audio track from SQobold simultaneously, shifting the second until constructive interference is achieved.

The montage represents the more creative part of our method and is in fact the key to the APEAL film's appeal. It is also the only manipulation we use to draw listeners' attention to particular aspects of the soundscape. For example, if the acoustic diversity within the floor of an open-plan office is of interest, simply crossfading between clips can emphasize the variation in loudness e.g. from the collaborative work to the individual work areas. If transitions to and from these areas are to be included for orientation purposes, speeding up and silencing the footage helps maintain the hierarchy of aural experiences (stationary vs mobile) we want to portray. Absence of montage can also be very effective. When examining acoustic privacy between e.g. meeting rooms, a continuous shot starting from the source room, going through the circulation zone into the receiving room can demonstrate the degree of sound insulation in a simple but graceful manner [22].

3.6 APEAL STAKEHOLDER FEEDBACK

Feedback on APEAL films was sought from building designers, managers and users through semi-guided interviews. We presented APEAL films through different playback systems, and asked participants to consider their reaction to different presentations of the media. We used variously the laptop speaker, a quality speakerphone, and high-quality studio monitor headphones. Clearly the first two representations lose the binaural information. Different reproduction systems were calibrated to reproduce the films at the same level. According to the feedback received, listening through headphones can really enhance the subtle variations in the soundscape, which is perceived in a more positive way compared to the same soundscape reproduced on the laptop speaker or speakerphone. Feedback from architects and designers was considered essential from the outset of developing APEAL, as these are the specialists whose engagement and collaboration with acousticians we hope to improve.

Positive observations were made regarding how APEAL could help decision making during the design process. As well as helping to crystallise aspirations and expectations around open plan mixed use spaces, it was suggested that it would be highly beneficial to be able to communicate the meaning of other traditional acoustic criteria. Demonstrations of sound insulation could help clients and designers determine suitable performance targets, for example, without having to understand the meaning of acoustic indicators for sound insulation. This could in turn help the client and design team identify appropriate budgets to meet those acoustic aspirations.

… it would be very useful to architects to have such a universal medium (a film) that allows for an immediate A-B comparison of the differences e.g. for party wall sound insulation, or absorption and reverberation in rooms…

It was also discussed that such an empirical method could spark a reform not only in the way buildings are designed but also in the way they are regulated in regard to sound.

4 RESULTS AND DISCUSSION

The early feedback from our pre-emptive recording was *"we want our building to sound like that*". This was one of the motivating factors to develop this method, as the value in having easily accessible recordings to evaluate and share an acoustic environment was clearly demonstrated. You can watch and listen to APEAL films on our website [22].

4.1 APEAL METHOD AS A COMMUNICATION TOOL

Acoustics is regularly described as a "dark art" by other design team professionals or clients. The language of acoustics is technical, and by its nature is inaccessible to people who do not have extensive background and training in this area. Acoustic indicators such as the A-weighted sound pressure level are used to quantify descriptors, such as the ambient noise level. Often the descriptors do not correlate with the acoustic environment or soundscape that is important for the users. At the same time that the technical acoustic tools and narrative can be clumsy or unhelpful, almost everyone can listen to an APEAL film and comment on the subject under discussion. Acoustic concepts, meanings, intentions and achievements can be communicated directly with sound, presented in context. Although the interpretation of those sounds will vary between people, by communicating in the medium that we are seeking to describe, the barriers to engagement are significantly reduced. Suddenly, everyone can have an opinion on what is desirable or unacceptable. The APEAL method overcomes the traditional barriers to communication over acoustic issues, and makes significant advances in enabling participatory design. Participatory design is an approach to design attempting to actively involve all stakeholders in the design process to help ensure the result meets their needs and is usable. It is an approach which is focused on processes and procedures of design and is not a design style; it can contribute to buildings which more effectively meet the users' needs, and hence achieve greater efficacy and sustainability as an outcome.

4.2 APEAL METHOD AS EVALUATION TOOL

Currently, the acoustic performance evaluation of buildings may traditionally be based on compliance measurements of ambient noise, sound insulation and reverberation times. Thus, a building may be deemed to meet the criteria that were set out by the acoustician at the design stage. However, the real question, of course, is does the acoustic environment meet the functional, operational and well-being needs of the occupants? Traditionally, acousticians may be cautious about even asking this question, as many of the reasons for the potential "failure" of a building may be considered by the acoustician to be outside of their control. Occupant behaviour may lead to acoustic conditions that give rise to complaints in scenarios that were never conceived by the acoustician who considered their job to advise on compliance type criteria. Thus, the very idea of evaluating the acoustic performance of the building in use implies a human-centred approach to the acoustic design. An evaluation tool is essential to accommodate this occupant-centred design approach.

4.3 APEAL METHOD AS A DESIGN TOOL

The acoustic design process currently relies on the acoustician to interpret the acoustic needs or aspirations of the client or design team and infer acoustic performance criteria as design targets. This is conventionally achieved by reference to legacy design standards. The acoustician then advises the design team on the design features and finishes that may achieve the inferred performance. There is an emerging field in acoustics consultancy of "virtual acoustic reality", in which models of potential design solutions are created that may be viewed with VR headsets, along with modelled acoustic conditions. However, these models take time to build, are costly, and take many resources to reproduce for reviewers. The time, expense and detail required is rarely available in the early stages of the project when key decisions are made about the potential acoustic environment. With simple auralisation of different designs, the sound alone without the realistic visual immersion can be conceived by listeners to be very different compared to the real experience.

During the early stages of a project, particularly for a new type of building, the client and key advisors typically visit other premises that may illustrate facilities in use that the client may wish to emulate. The APEAL film enables members of the design team to experience, as closely as possible, a much larger array of environments than is physically possible to visit in practice. The immersive nature of the recordings means that the viewer gets as close as possible to "being in the room" acoustically without actually having to travel there at a set time. Acoustic experience is encapsulated through APEAL films as a new reference point for clients and designers. Acoustic aspirations can be agreed as experiences are common.

4.4 APEAL METHOD AS BUILDING USER ENGAGEMENT TOOL

Another potential use of APEAL films is for the potential occupants or users of a building. The media can be used to assist in engagement, to inform people about the acoustic experience of the building. For example, is there a suitable place to work in a public or university library? Is a cafe likely to be noisy at a certain time, or just the right amount of "lively"? Will a restaurant be too noisy? Are the offices of a particular company an appealing place to work? In these and many other scenarios, the APEAL method can add another dimension to visual illustration by conveying the experience in an immersive manner compared to traditional recording and footage.

4.5 CHALLENGES WITH THE APEAL METHOD

We have encountered various challenges when reproducing recorded environments In some cases, the aural impression that was noted in-situ does not correspond to the impression we get from the APEAL film. This led to further questions about listening modes and variance in perceptual attributes between the real and recorded acoustic environment.

In the context of indoor soundscapes, there is emerging evidence that auditory perception of the real acoustic environment and of its reproduction may differ: in a case study conducted at Bilkent University [23] the real acoustic environment of an open plan office was overall perceived as *calm* and *pleasant*, whilst the recording of that same environment was perceived as *annoying* and *chaotic.* This comparison was made in accordance with the Axelsson *et al.* circumplex model [24]. The reasons for this variance in perception require further investigation. One could be related to the technicalities of recreating an acoustic environment with simply POV video and binaural audio.

As noted by OOI et al. [25] regular binaural recordings have been deemed unable to recreate acoustic environments in a holistic manner, maintaining attributes such as "Spatialness" and other directional cues. OOI et al. hypothesized the superiority of ambisonic recordings coupled with head tracking in VR simulations to regular binaural or stereo recordings. The validation of this soundscape evaluation method was based on the similarity of responses as compared to the real in-situ environment. VR does indeed allow for a more immersive experience that mimics how we perceive our surroundings; the head-tracking system can spatialize HRTF in real-time by taking into account listener head orientation.

As mentioned in 3.2, whether we are watching a two-dimensional or a 360 video, we have specific acoustic expectations that have been conventionally set throughout the last century, during the development of the cinematic language. These conventions, once dictated by technical limitations, have become an integral part of how meaning is constructed in film and shaped its language. Human voice (dialogue) is always placed at the centre and above everything else; "background noise" is added in Post-Production and is usually artificial, e.g. composed with separate sonic objects that can be mixed together to resemble the real acoustic environment.

For example, the real acoustic environment of a busy Café, eventful, vibrant, even chaotic, with a lot of chatter, the roar of the coffee machine, the roughness of the coffee grinder, the loud hums of the fridge-counter - here, speech intelligibility is at risk. While we are inhabiting this space, we accept these acoustic conditions as part of our sonic world. However, if we are looking at that same café through a screen and a pair of headphones, our acoustic expectations change. We are used to the "cinematic" soundscape of a Café as calm, pleasant, uneventful for the most part, the voices of our protagonists will be perfectly intelligible, with little to no reverberation, and yes, maybe a subtle layer of typical crockery sounds will keep us anchored to the recreated experience. That is how cafés have been sonically portrayed in cinema since the birth of the talkies.

At the same time, when we are asked to listen actively to the soundscape, whether in situ or virtually, we will hear differently. Some elements of the soundscape will inevitably be privileged over others. The hierarchy of sounds in a recorded or virtual environment, such as our APEAL films, is much stricter due to what we have just mentioned. It is also important that we acknowledge the lack of control we have over the playback of the APEAL films. While we utilize calibrated recording and playback systems, it is very unlikely that our audience can do so. Playback conditions are even more unpredictable when the videos are embedded in video presentations e.g. during online webinars.
We have created a short easy-calibration tutorial to help listeners setting their playback systems to the correct level so that they get an accurate impression of the soundscape presented in the APEAL film. The other aspect of control that is emerging as a significant modifier of soundscape experience is the level of control the user has of their experience. We know how important the sense of control is for users of real buildings – how can users of APEAL films also achieve a sense of control over their engagement with the media?

4.6 FURTHER RESEARCH AND PRODUCT DEVELOPMENT

Indoor soundscape evaluation is a relatively new field of acoustic enquiry, to which the APEAL method can make a significant contribution. We are in the process of recording in a variety of contexts, public and private buildings, including offices, libraries, universities, museums, galleries, residential buildings, etc. The feedback from stakeholders and clients will shape the process and product going forwards. As a synthesis of filmmaking with new sound recording techniques, there are many skills to assimilate to improve APEAL films. It is necessary to re-evaluate the visual framing to assist the aural experience. Hence the APEAL method will also benefit from advanced filmmaking skills for improving their visual effectiveness. Further work is required to consider accuracy - repeatability and reproducibility have not been systematically assessed. There are questions about the time we must spend in different parts of a building in order to characterize its soundscape - how it varies throughout the day, or according to the building's own scansion of time, e.g. academic terms. Initial feedback indicates a significant appetite for this medium.

5 CONCLUSION

When acoustic conditions can be evaluated from a human perspective, they can be designed from a human perspective. The APEAL method helps enable a paradigm shift in acoustic design, by enabling participatory design. By helping to shape a common understanding for the in-use experience intended for a building, it can reduce abortive design work, the risk for clients of an unsuitable building, and reduce the need for remedial work on site. This leads to a more sustainable outcome while adding value for the client.

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