DESIGNING FOR ACOUSTIC SATISFACTION IN OPEN PLAN OFFICES

Jack Harvie-Clark Apex Acoustics Ltd, Design Works, William St, Gateshead, UK
Nick Dobinson Apex Acoustics Ltd, Design Works, William St, Gateshead, UK
Richard Hinton Apex Acoustics Ltd, Design Works, William St, Gateshead, UK
Richard King Apex Acoustics Ltd, Design Works, William St, Gateshead, UK
Emily Forster Apex Acoustics Ltd, Design Works, William St, Gateshead, UK

1 ABSTRACT

This paper proposes a new approach for understanding and designing for acoustic satisfaction in open-plan offices using a soundscape framework. *Good acoustics* are not a property of the space: rather, acoustic satisfaction resides in the perception of occupants. There is little evidence linking room acoustic metrics with occupant satisfaction in general. Non-acoustic factors such as noise sensitivity, perceived control, personal need for privacy, expectations, and office culture strongly influence the experience of sound. Non-acoustic factors account for twice the variance in annoyance than acoustic factors in many branches of acoustics. To design for acoustic satisfaction, this paper advocates adopting human-centric and participatory design methods like surveys and focus groups. These methods can identify the range of spaces occupants need, and can also be used to continuously improve acoustic satisfaction after occupancy starts. Additionally, this paper discusses risk factors in acoustic design like incompatible team adjacencies. Incorporating human factors with a soundscape approach, not just technical acoustics, can be used to create offices tailored for comfort, health, and productivity. The paper calls for changing the narrative around “good acoustics” from the empty room to the occupants’ perceptual experience.

2 INTRODUCTION

2.1 Overview

The “noise problem” in open plan offices has persisted for many years; people’s homes have been shown to be better suited to most work activities than offices. There are many advantages for people to work together in offices, but these advantages cannot be realised if the office inhibits productivity. As many workplaces move to a hybrid environment with an emphasis on experience, avoiding barriers to office presence has never been so important.

Acoustic indicators may explain a part of noise annoyance, although emerging data raises questions over which acoustic indicators may be most appropriate. A soundscape approach can complement the room acoustics by focusing on people’s experiences and needs. A participatory approach implicitly takes account of the non-acoustic factors that are so important for acoustic satisfaction, and can reveal the range and type of spaces that the occupants need.

To design for acoustic satisfaction, we first have to accept that satisfaction resides primarily in the perception of the occupants, not in the room. We need to change the narrative around “acoustics”, from the empty room acoustic response to the occupants’ experience of the soundscape. If we fail to do this as acousticians, we leave the larger portion of acoustic satisfaction to others, or to chance.

2.2 Background

Firstly, it is useful to consider why acoustic satisfaction is important for occupants in an open plan office. Environmental satisfaction is closely associated with comfort and in turn with productivity and job satisfaction [1], which is the purpose of offices in the first place. There is a role for the physical environment in organisational well-being and effectiveness. However, an open plan office is far more than simply a physical environment, as Diane Hoskins, Co-CEO at Gensler indicates [2]:

The more the workplace is connected in a thoughtful way to the organizational strategies, leadership models, operational frameworks, and potential outcomes of a company, the stronger the workplace will emerge.

Acoustic satisfaction has proven to be highly elusive, in all types of open plan offices. Leesman, the world's largest employee workplace satisfaction survey, describes "the noise problem" as the most difficult for organisations to overcome [3, 4]. Leesman has been telling us for over a decade that in open plan offices:

- dissatisfaction with noise levels kills productivity (importance rated around 70 %);
- average satisfaction with noise is around 36%.

This is a huge opportunity for acousticians to improve the working conditions of many people.
Following the Covid-19 pandemic in 2020, many people speculated on the death of the office. Beth Humberd *et al* [5] maintained that the office would always be essential for building human relationships, trust and cooperation, as these have been shown to underpin effective information exchange, research collaboration, and innovation between colleagues. Flexibility in office attendance does appear to be here to stay, however, despite the benefits of presence in the office. Zoom has been reported as mandating at least two days a week in the office [6], recognizing the essential benefits of sharing physical space. The value of real estate has been re-evaluated through the networks and connections it can engender [7]. There is a lot of speculation about the nature of the office in a post-pandemic world. A significant question concerns the purpose and arrangement of the physical office: how will office design evolve to accommodate new modes of work, such as hybrid work, flexible work, or remote work, with potentially variable levels of occupancy?

Despite some significant apparent developments in the conception and framing of acoustics in open plan offices, emerging data suggests that simple associations between room acoustic response and the fraction of people classed as "highly annoyed" may continue to be elusive. This means that we cannot simply design or measure the room acoustic response and declare it to have "good acoustics". Clearly, the acoustic environment is a function not only of the room acoustic response, but also the pattern of sound sources within it. This is where open plan offices become immediately complex – people are both the sources of sound, and also the potential recipients of unwanted sounds. People need to talk in offices; sometimes, other people want to hear that speech, sometimes they don't. Hearing unwanted speech is frequently a significant "noise problem" in open plan offices [8, 9], while hearing speech is simultaneously a significant reason for being in the office in the first place. Resolving this paradox in a satisfactory manner requires much more than a specification for the room acoustic response.

In this paper, we set out the big challenge of reframing how we think about acoustics in open plan offices. This paper shows how we can understand acoustic satisfaction in open plan offices in ways that enable interventions to improve occupants' experience or acknowledge the constraints to that outcome. The questions for practitioners are around how we can understand the aspects of the design that affect the outcomes we are interested in. We propose that the "acoustic design" should include all aspects that might influence the occupants' experience of sound in the office. Conceptualising the problem like this, we are led to taking a soundscape approach.

2.3 Associations between room acoustics and occupant satisfaction

The “acoustics” or “noise” problem in open plan offices has been studied for many years, with many researchers looking for associations between environmental satisfaction and measurable quantities associated with the office. There are two distinct categories of acoustic indicators:

- Room acoustic indicators that describe the room acoustic response and conditions when it is unoccupied;
- Measurements of acoustic conditions when the office is occupied

The former category are the intended to be used as design targets, while the latter category may be used to explain the occupants’ experience, but are usually considered to be outside the designers’ remit. The introduction of room acoustic indicators in ISO 3382-3 [10], originally in 2012, was groundbreaking.

There is wide evidence that the most problematic sound in open plan offices is unwanted speech [8, 9]. Therefore the indicators in ISO 3382-3 are intuitively designed to describe the potential intelligibility of speech, by describing the distance at which speech starts to become less distracting (Distraction distance, r_D), the spatial rate of decay of speech ($D_{2,s}$), the speech level at 4 m ($L_{p,A,S,4m}$), and the background sound level in the unoccupied office ($L_{p,B}$). In the 2022 revision to ISO 3382-3 the notional distance at which the speech level falls below 45 dBA, the comfort distance (R_c) [11], was added, as this integrates both the speech level at 4 m and spatial decay of speech into one single number quantity (SNQ).
A review of the efficacy of the initial indicators was published by Haapakangas *et al* in 2017 [12]. This demonstrated that there were only statistically significant associations between Distraction distance, r_D, and the fraction of people who were “Highly annoyed”, taking the dataset of surveys and measurements as a whole. However, one subset of offices is represented with a different symbol – those with either a protected quiet space, where occupants could be confident of finding a place in which they would not suffer from acoustic distractions, or those offices that adopted an Activity-Based Working (ABW) strategy. An ABW strategy means that occupants do not have a permanently assigned workstation; they should find a setting that is suitable for the task in hand, which may differ throughout the period of work.

Subsequently, a large body of work has been undertaken, but not yet fully published, by Yadav *et al* [13]. This work investigated associations between noise annoyance and both room acoustic indicators and occupied acoustic indicators. The presentation of part of this work at Euronoise 2021 [14] concludes that both occupied and unoccupied metrics are necessary to characterize the complexity within occupants’ ratings of workplace satisfaction and acoustic disturbance; and that “good” physical acoustics as per ISO 3382-3 and ISO 22955 [15] may not necessarily translate into better experience for the occupants. Yadav’s presentation at Euronoise 2021 included some data from the work that has not yet been published elsewhere, as shown in Figure 1.

The data in Figure 1 shows the opposite trend in relationship between distraction distance, r_D, and % Highly Disturbed (HD) by noise, compared with the previous review [12]. These are very significant findings that have not yet been fully published, but they bring into question the whole notion that “good acoustics” can be assigned as a physical property of a space. Previously, these associations were relatively weak; there have been many suggestions of alternative approaches to addressing the noise problem in open plan offices – these are explored further below. Overall, the data strongly suggests that we need a conceptual model that accommodates all the factors that may affect occupants’ response to questions about “acoustic satisfaction” or “noise annoyance”.

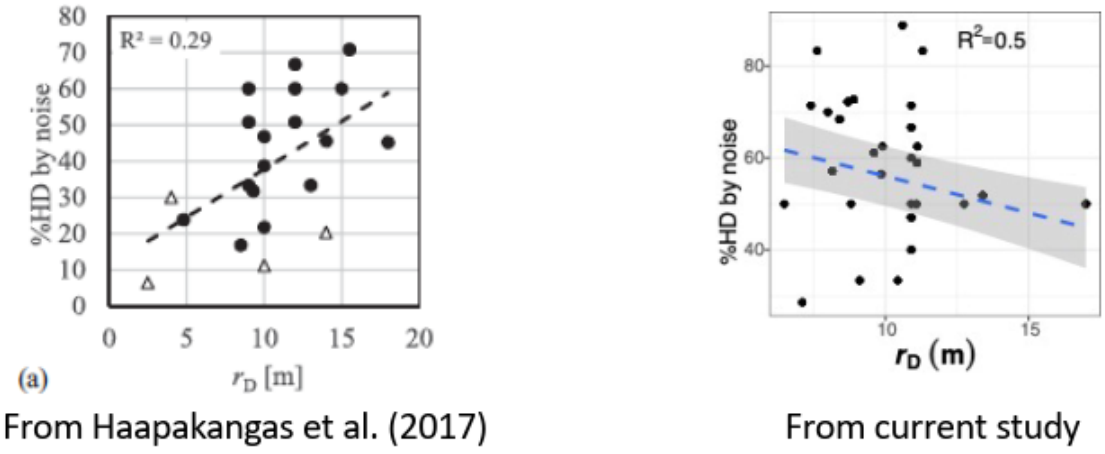

Figure 1: Extract from presentation by Yadav at Euronoise 2021 [12].

Measurements of acoustic conditions when the office is occupied have a longer pedigree; Yadav *et al* [13] provide a significant overview. While the simplest measure, the sound level in dBA, has failed to predict outcomes, more creative measures have been proposed for the specific context of sound in open plan offices. Vellenga *et al* [16] proposed the Liveliness Index, to characterize the sound environment in activity-based offices as Quiet, Tranquil, Lively, or Turbulent. There is no value judgement implied: different environments are suitable for different types of activities.

3 THE SOUNDSCAPE FRAMEWORK

The soundscape framework has been developed to describe people's experience of sound holistically, in context. ISO 12913-1 was published in 2014, with the conceptual framework as shown in Figure 2. Also on Figure 2 are annotations of where the room acoustics and acoustic space planning fit in. The room acoustics can be described by the indicators in ISO 3382-3 - this is the way that the empty room responds to sounds within it - the most notable indicator being the distraction distance, denoted r_D. Acoustic space planning refers to the process of planning the different occupancy locations or zones - to avoid acoustic conflicts; these typically occur between people who talk frequently - either because they are extrovert types, or their job requires it (eg a contact centre or IT help desk), and people who work mostly alone without conversing.

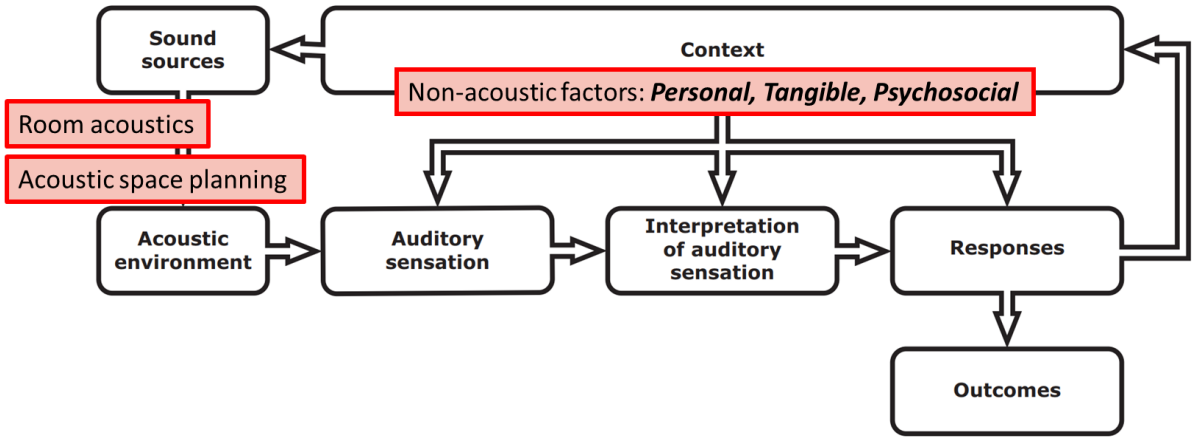

Figure 2: Soundscape conceptual framework, from ISO 12913-1, with red boxes overlaid

3.1 Non-acoustic factors

The larger part of this diagram is given over to “context” and this refers to the non acoustic factors. The non-acoustic factors are all the things apart from the sounds that affect people's experience, interpretation and response to sounds. The non-acoustic factors are starting to be documented and categorised by Fenech *et al* [17] as:

- Personal factors;
- Tangible factprs;
- Psycho-social factors

There is extensive work to describe and document non-acoustic factors for aviation noise [18]. In this field, researchers have determined that one-third of the variance in annoyance reactions is due to acoustic factors: another third of the variance in annoyance can be explained with non-acoustic factors, and the last third is currently unexplained. As it cannot be explained with the acoustic factors, this means that there are non-acoustic factors that are yet to be accounted for. Similarly, for road traffic noise, one third of the variation in the annoyance responses are caused by the sound level itself, as described in the FAMOS Study [19]. Moderators of annoyance include visibility of the road, views of vegetation / greenery, whether residents have a quiet side to the dwelling, and other neighbourhood noise amongst others, for example. The magnitude of the effects of each of these moderators on annoyance is described in the FAMOS study. Taken together, non-acoustic factors are being recognised as being more important than the physical sound level.

Personal factors are things like noise sensitivity, capacity to cope, perceived control and perceived fear. These are associated with an individual and are relatively stable over time. The FAMOS study lists examples such as noise expectations, and traffic safety expectations, which may be considered personal factors. Tangible factors (sometimes called environmental factors) are features of the environment rather than the individual, such as those listed above for road traffic noise. Psycho-social factors are described in the acoustics literature as factors which are shared between members of a community - qualities such as perceived fairness, perceived community benefit from the sounds, and attitudes towards the noise authorities. Examples cited in the FAMOS study include trust or acceptance of the decision makers and road administration. A new ISO Technical Specification (ISO/TS) on non-acoustic factors has been proposed to improve the interpretation and consistency of socio acoustic surveys [17].

3.2 Non-acoustic factors in open plan offices

It might seem like a whole new branch of science is required to investigate non-acoustic factors in open plan offices, but in fact much of this work has already been carried out in this area - just not described in this way. Oseland [20] has investigated the response to noise distraction by different personality types, demonstrating that extroverted people are more satisfied with noise in open plan offices in both allocated and unallocated settings; both introverted and extroverted people are less satisfied at allocated desks compared to unallocated desks. Personality and noise tolerance can be considered as personal non-acoustic factors.

Rather than considering comfort, an alternative approach is to consider the need / supply fitness concept, based on Person–Environment theory, described by Caplan [21], for example. Hoendervanger *et al* [22] look at the personal need for privacy and how that affects people's perception of how well an activity is perceived to fit in a particular work setting. The personal need for privacy affects both satisfaction with the work environment and task performance. This isn't restricted to a need for acoustic privacy - it's about people's personal needs and how well-suited people consider different tasks in different environments and settings. Similarly, Radun and Hongisto [23] have investigated the perceived fit approach to investigate how well different office types and indoor environments support different office activities. Dissatisfaction with noise explained by far the largest portion of the environmental factors, and indoor environmental quality (IEQ) factors explain fit better than office types (private offices / assigned workstations in shared offices / open plan offices, flex offices). Personal need for privacy can be considered as personal non-acoustic factor.

Other personal factors which are important in open plan offices include people's experience and their expectations. Oseland's study of personal office preferences [24] and other studies have demonstrated that people prefer the work setting that they are currently in. People in private offices rate private offices more highly than other types of work settings, whereas people in other types of work settings (open plan, ABW) rate private offices less highly. When people move from private offices to open plan offices and then to ABW offices they don't usually want to move back down that path.

Perceived control of one's environment is not just a nice-to-have benefit, but a fundamental essential for an individual's wellbeing, and a psychological and biological necessity according to Leotti *et al* [25]. Giving occupants control, by offering a range of workplace settings and letting them choose where to work, has been shown by Harvie-Clark *et al* [26] to have an enormous impact on environmental satisfaction – not just with acoustics, but also with the lighting and thermal comfort. The importance of control for occupant comfort and productivity has been well documented for other aspects of the building environment [27], where it has been described as a "killer variable", but there is less evidence in the literature of the value of control for acoustic satisfaction. A killer variable means it's a key indicator; it's well known that people's sense of comfort and self-rated productivity are strongly dependent on how much control they feel they have in the building. Lee and Brand [28] took a narrower concept of personal control, but this none the less proved instrumental in leading to higher perceived group cohesiveness and job satisfaction.

People don't like change - we are creatures of habit. Change invokes fear. People's expectations about a new office are very important, as are the way in which people's expectations are managed. Sirola *et al* [28] studied of a workplace change process and satisfaction with ABW. This demonstrated that the strongest predictor of the change in environmental satisfaction, a year after the move, was the degree of agreement with the management's reasons for the change. This can be understood as a psycho-social factor: people who believed their manager's reasons for the change felt more comfortable in the new office, and vice versa. The importance of change management and the way in which that process is carried out should not be underestimated. This study showed that where people thought they were going to have more impact on the design than they did, they felt disappointed with the new office and consequently felt less comfortable in it. Hongisto *et al* [30] also report that qualified change management was one of the reasons for increased environmental and job satisfaction following a refurbishment. Experience and expectations may be personal factors but they are also closely linked to psycho-social factors.

Psycho-social factors may form around expectations of behaviour in the office, and opportunities that occupants have to manage their environments – the extent of control that they enjoy, for example. Haapakangas *et al* [31] investigated the benefits of the opportunity to access quiet, protected spaces when organisations moved to open plan offices, finding it essential. Perceived control over the work environment is positively associated with social relations, environmental satisfaction and job satisfaction. Coping strategies [32] can only exist within a psycho-social context. Lenne *et al* [33] demonstrated that the subject of irrelevant speech had a significant effect on its impact – people talking socially had a greater mental fatigue than people talking about work. This illustrates how far the content of unwanted sounds – noise – affects people.

3.3 Soundscape approach to understanding open plan offices

Several researchers have started to take the formal soundscape framework and apply it to indoor spaces, and to open plan offices. Jo & Jeon [34] used virtual reality to investigate the effects of indoor soundscape perception on productivity and preferences for the work environment. They showed that indoor soundscape perception can be interpreted in the comfort–content dimensions and is significantly influenced by worker interactions such as conversation and laughter. Increased comfort improved the work environment preferences, and increased content significantly influenced the perceived productivity. They suggest the need to design a balanced OPO sound environment with preferred and productive zones by ensuring suitable comfort and content distributions. This is a significantly different approach from conventional OPO design. The experiments confirmed a need to

achieve an appropriate level of content in the indoor soundscape, contradicting the notion that OPOs should be quiet. However, as a VR experiment, this investigation lacks the real-world relationship between the person and place that has a strong influence on occupants' experience of acoustic conditions.

Acun and Yilmazer [35] undertook a soundscape survey and measurements of sound levels, with the aim of creating a conceptual framework for soundscape in open plan offices. The results showed how the task at hand was affected by the sound environment and personal factors. Sounds that were not expected or out of context and those that interfere with the concentration demanding tasks caused a negative interpretation of the soundscape. Occupants adopted coping methods such as accepting and habituating, intervening with the sound source, or putting on headphones to isolate themselves from the soundscape. It was noted that silence caused as much concern as the sounds of greater activity. Grounded theory was used to demonstrate that objective measurements alone are not sufficient to reflect occupants' perception of the soundscape, as there was no association between objective measures and outcomes.

The concept of indoor soundscape perception has been developed further by Torresin *et al* [36], who identify Comfort, Content, and Familiarity as the main perceptual dimensions in a residential setting. They propose a two-dimensional measurement system with Comfort and Content on the orthogonal axes.

Ben West *et al* [37] investigate the perceptual assessment of open-plan office environments using a soundscape approach. They report three main perceptual dimensions, found through principal component analysis of subjective attribute ratings: Pleasantness, Eventfulness, and Emptiness. The first two align with the pleasantness-eventfulness dimensions used for outdoor soundscape assessment. Scores for the Pleasantness dimension were positively correlated with overall soundscape assessment and appropriateness. Sounds from human activities like speech negatively affected Pleasantness but positively affected Eventfulness. Task type, gender, and aural sensitivity affected Pleasantness scores, suggesting the need to accommodate a variety of occupant characteristics and activities. Psychological wellbeing, work satisfaction, and perceived productivity correlated with Pleasantness, highlighting the link between acoustics and outcomes for occupants. Traditional acoustic metrics did not correlate with the perceptual dimensions, indicating a need for different indicators to quantify office soundscapes, or to use acoustic indicators with discretion. Overall, the results support using a soundscape approach to understand occupant perceptual response. This experiential perspective could lead to offices better tailored for comfort, health, and productivity. However, it is not yet clear how to apply these principles to guide the design of open plan offices.

3.4 Soundscape design of open plan offices

As ISO 12913-1 defines soundscape as "the acoustic environment as perceived or experienced and/or understood by a person or people, in context, it immediately raises the question: how can we design "perception", "experience" and/or understanding" of people in open plan offices? ISO 12913 Acoustics – soundscape Part 4: design and intervention [38], is new work that has only just started. This document will provide guidance on how to assess the soundscape data, collected and analysed by means of ISO/TS 12913-2 & 3, and how to determine the need for interventions to preserve and/ or improve a soundscape; it will provide advice on how to implement a soundscape design as an intervention. As the document aims to define a soundscape design process with relevant conceptual tools to involve different stakeholders, it is likely to be useful when it becomes available.

We can't necessarily even understand everybody's personal factors when people are getting a new office but we can design for a range of sensitivities and personal needs. Or we can be explicit about the fact that an office may be designed for a limited range of people's personal needs. We need to understand that two people doing the same task in the same environment will have a different experience of comfort in that place; they will have different needs even when they are performing the same activities, because of their personal factors.

4 CASE STUDY: “CAN YOU IMPROVE OUR ACOUSTICS?”

Our client asked us “how can we improve the acoustics in our office?”. We measured the ISO 3382-3 room acoustic indicators, and the ambient noise and Liveliness [16]; and we used a noise comfort questionnaire [9] to ask people about their experience. The data that was most useful to us were the observations of what was happening, which we made when we were taking the attended measurements and talking to people about their experiences in this office. The people that choose to sit at the middle table like to chat more than other people in this office. They are doing the same type of work as people in other parts of the office but they're more sociable or extrovert perhaps. The occupied measurements demonstrated this in the Liveliness results, as shown in Figure 3.

On the left hand side of the office, at measurement position P1, it was Tranquil most of the time whereas on the right hand side of the office, position P4, it was much more Lively for most of the time. The table of people who prefer to talk while they work impacts on the people sitting around them. These people need a protected area of the office, so that they can talk without disturbing others around them; some specific acoustic space planning.

Could this situation have been predicted during the planning of this office? We don't think so. This is a type of insight and intervention that can only be revealed in an operating office to improve the acoustic conditions. This demonstrates that the acoustic design should not be considered “complete” when an office is handed over; as people learn to use the office, there are always interventions and changes that can be made to improve the acoustic conditions.

The noise comfort questionnaire revealed that the sound of telephones ringing was a significant problem. Further investigation indicated that the six desks on the far right hand side are sometimes used as a contact centre. The telephones don't need to ring these days - the operators can use light indicators and turn the volume right down. The changes that were indicated to improve the acoustic conditions did not change the room acoustic indicators that could be measured with ISO 3382-3.

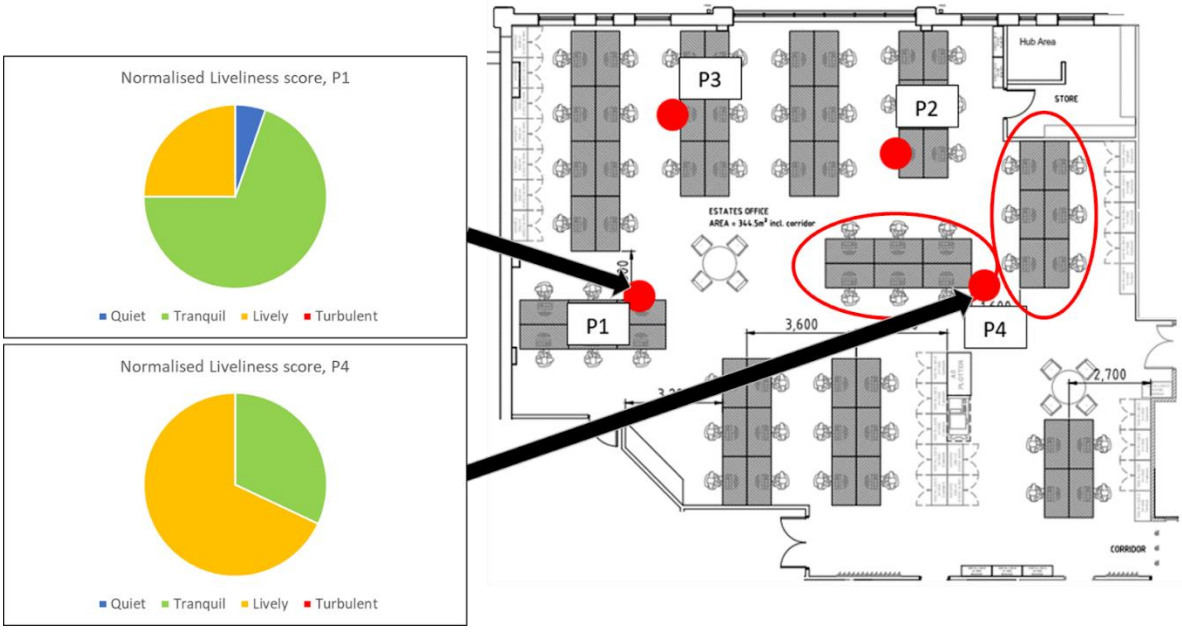

Figure 3: Measurements of Liveliness in an open plan office

5 RISK FACTORS IN ACOUSTIC DESIGN & OPERATION

Based on this new framework for understanding acoustic satisfaction, there are a range of potential factors that can be seen as risks for an organisation in failing to achieve acoustic satisfaction for the occupants. These can be considered in two groups: risk factors in the design of a new office, and risk factors affecting acoustic satisfaction in operation. This list should not be considered definitive, it is the beginning of taking a risk-based approach to open plan office design.

5.1 Organisation does not value occupant experience

Where an organisation does not want to consult its staff on their needs, it necessarily leaves the satisfaction of those needs to chance, and occupants to fend for themselves. A human-centric approach is, by definition, not possible. Many organisations are wary of asking occupants what they think, for fear of opening a can of worms. The process of engaging with staff and seeking their opinions and experience is genuinely risky – if staff believe that their opinions are going to have more impact than they end up having, they can be equally disillusioned and disappointed [28]. Hence while seeking to understand occupant needs is an essential process, it is not without risks if mishandled.

5.2 Inadequate acoustic space planning

A common problem in new offices is to locate incompatible teams adjacent to each other, without sufficient mitigation of sound transfer from one team to another. People that are typically quiet and more noise sensitive may be characterised as introverts. Introvert people tend to enjoy jobs that allow them to work independently, focus deeply on a task, and use their analytical and creative skills. They may also prefer jobs that offer a quiet and structured work environment, where they can minimise distractions and interruptions. Introvert people may find they are well suited to being accountants, lawyers, engineers, and software developers, for example.

In contrast, extrovert people tend to enjoy jobs that involve a lot of social interaction, collaboration, and communication with others. They may also prefer jobs that offer variety, excitement, and opportunities to influence or persuade others. Examples of jobs that may suit extrovert people are in sales, marketing, and public relations. Other jobs can also involve significant and frequent interaction with others, such as in contact centres or IT help desks. As these are broad stereotypes of personality and job types, there are always plenty of exceptions; the extrovert data analysts may prefer each others' company, for example; it may be difficult or impossible to anticipate these outcomes in the design of a new office, but issues can be addressed when an office is functional.

As a baseline, if areas of the office are designated to different teams, there is a basic requirement for sufficient acoustic mitigation between incompatible teams. This may be in the form of distance between them or physical separation with furniture, partitions or screens. Locating people next to each other whose natural inclination is to behave very differently is likely to cause dissatisfaction for the more noise sensitive group.

5.3 Insufficient opportunity to find a suitable place

The importance for occupants of having access to a protected quiet space for individual work has been highlighted and discussed by Haapakangas *et al* [31]. Hoendervanger *et al* [22] confirm that different people's personal need for privacy affects this requirement. If people cannot find a quiet place to undertake individual concentrative tasks, they may opt to work from home, where that option exists, for example. A personal need for privacy in other ways – for example, to make a private or difficult phone call, participate in a video call without disturbing other people, for 1-2-1- meetings – may also affect occupants willingness to come to the office.

This is an aspect of the need for perceived control over one's environment or conditions [26]; however, the extent to which people's preferences for a type of workspace can be immediately satisfied it is not well evidenced. For example, if someone wants to access a quiet space or a private space, but has to wait for some time for a suitable space to become available, does this undermine the perceived

control? At some point, this could contribute to a perceived lack of control. The method to identify the appropriate proportion of workstations with particular acoustic characteristics is vital.

5.4 Client project manager has their own ideas

It is common that the project manager has their own ideas about what type of acoustic environment is suitable for everyone. Many people find it difficult to empathise with others who have a very different acoustic tolerance or preferences to their own – think of the difference between some people who like to be in vibrant environment such as a busy coffee shop to undertake their individual work, and others who find it inconceivable to work in vibrant environments. There is an emerging narrative around neuro-diversity and variation in needs; a heightened sensitivity to sound may be common amongst people who consider themselves neuro-diverse. However, it is not necessary to conflate acoustic diversity and neuro-diversity more generally; there is a risk that doing so may represent a barrier for some people in bringing greater meaning to the discussion.

5.5 Coping strategies and office etiquette

Not many offices have an etiquette, or explicitly express expectations for behaviour in the office. If the office culture can embrace the sonic conflicts that inevitably arise, then it may not be necessary. Occupants rate “approach strategies” to resolving conflicts more highly than avoidance strategies, but avoidance strategies are more commonly adopted [32]. Even the process of developing an office etiquette can give occupants a greater sense of control over their environment, and thereby increase their environmental satisfaction. There is an example etiquette as an Annex in ISO 22955.

5.6 “Our office is too noisy”

This is a commonly reported problem, which when investigated reveals an office that is objectively quiet. When an office is objectively quiet, then speech may be clearly intelligible over larger distances, leading to distraction from more people.

5.7 Insufficient sound absorption

There are many anecdotal examples of offices designed without any sound absorption, that are unsuitable for most occupants for a large range of activities. However, there are also some offices with very little sound absorption that do not achieve any greater acoustic satisfaction, within the same organisation, than other offices that have much larger quantities of sound absorption. Although there does not appear to be a clear relationship between sound absorption and satisfaction, a complete lack of sound absorption oftens leads to high levels of dissatisfaction. The exceptions often have high soffits – e.g. 5 m. It is tempting to speculate why this may be so – as a soffit at this height will provide much less reinforcement to a nearby voice than a much lower soffit, and the soundscape is likely to be composed of a higher level of babble sounds, which may provide beneficial masking of nearby talkers who would otherwise be intelligible. On the other hand, a low plasterboard ceiling can easily lead to intolerable conditions. These aspects warrant further investigation.

6 CHANGE THE NARRATIVE

We need to change the narrative – “good acoustics” are not a property of the room, it is the perception of the occupants. To design for acoustic satisfaction we need to take room acoustics out of the box and we need to address the people who are using the office. We need to understand their range of needs, and design the accommodation so that they have choice and control, to find the type of spaces that suit their needs. We need participatory design processes.

Acoustic design should not stop when the building is handed over. An office is a tool for the business to achieve its outcomes; it is a tool that can always be improved and honed with maintenance; it also takes time to learn how to use it effectively. In many of these situations, the outcome of acoustic satisfaction – and perhaps the greater environmental satisfaction – is left to chance, and for staff to cope despite the organisation, rather than thrive with the support of the organisation. If we don't do this we will be obsolete as acousticians, because currently the acoustic problem is being solved by workplace strategists, not by acousticians. In acoustics, we are struggling to even explain improvements in acoustic satisfaction that users can clearly perceive.

Taking a soundscape approach to the question of open plan office design leads to consideration of acoustic ecology, the study of the relationship between humans and their soundscapes. Acoustic ecology can help with the design of open plan offices by providing insights into how people perceive, experience, and understand sounds in different contexts, and how sounds can affect their well-being, productivity, and creativity.

Soundscapes are not only composed of physical sounds, but also of the meanings and associations that people attach to them. Soundscapes can evoke emotions, memories, and identities in the listeners. For example, some people may find natural sounds such as birdsong or water soothing and relaxing, while others may find them distracting or annoying. Similarly, some people may prefer music or speech as background noise, while others may find them intrusive or irrelevant. Therefore, the design should consider the diversity of sound preferences and expectations among the occupants, and provide them with options and choices to customize their soundscapes according to their needs and moods.

Soundscapes are dynamic and change over time and space. Soundscapes can influence the rhythm, pace, and flow of activities and interactions in the office. For example, some sounds may signal the start or end of a workday, a break, or a meeting. Some sounds may indicate the presence or absence of colleagues, clients, or visitors. Sound may create a sense of continuity or separation between different spaces or zones in the office. The open plan office design can consider the temporal and spatial aspects of soundscapes, and create sound environments that support the transitions and movements of the occupants throughout the day and across the office. This is especially important with a high level of flexible working, and the office has very different occupancy levels on different days.

Soundscapes are social and cultural constructs that reflect the values and norms of a community or organization. Soundscapes can communicate messages and meanings to the listeners about the identity, culture, and atmosphere of the office. Some sounds may convey a sense of professionalism, creativity, or collaboration, while others may express a sense of hierarchy, authority, or equality. Some sounds may create a sense of belonging, inclusion, or exclusion. The open plan office design can consider the symbolic and communicative functions of soundscapes, and create sound environments that align with the vision, mission, and values of the organization.

7 HUMAN CENTRIC DESIGN METHODS

Diane Hoskins explains [2] that human centric design means to:

Optimize for business outcomes by optimizing for people… It is designing with the intent of enabling people. It is not about putting the design before the human, but rather the design is for the human.

Human centric design can be used to redefine the role and purpose of the workplace in the post-pandemic era and create spaces that enable choice, connection, and culture. It is a process that focuses on the needs, preferences, and experiences of the people who use a space, rather than on the technical or aesthetic aspects of the space itself. The principles and methods of human centric design align with the soundscape interpretation and assessment. These principles include:

- **Understanding the users**: the first step is to engage with the occupants to understand their roles, tasks, goals, challenges, expectations, and preferences. This can be done by using methods such as surveys, interviews, observations, focus groups, personas, and journey maps, for example.
- **Defining the problem**: the second step is to define the problem or opportunity that needs to be addressed by the design of the office. This can be addressed using problem statements, value propositions, and user needs, for example.
- **Generating ideas**: the third step is to generate possible solutions that can meet the user needs and solve the problem. Methods include brainstorming, sketching, and prototyping to co-create solutions.
- **Evaluating solutions**: the fourth step is to evaluate the feasibility, desirability, and viability of the solutions. Prototype testing with feedback can be trialled, with design iterations. This step may be skipped, depending on the magnitude of the changes proposed.
- **Implementing solutions**: the final step is to implement the chosen solution and monitor its impact and outcomes. In practice, many designers bemoan the lack of Post-Occupancy Evaluation (POE).

This is a very different approach from conventional acoustic design, and is not necessarily what clients have in mind when they seek acoustic consultancy. It may be necessary to change the narrative before this type of approach is possible for the acoustic design. We are currently trialling this approach to improving acoustic conditions, with the aim of developing a streamlined process to identify the most significant risks and opportunities within the various workplace strategies that different companies adopt.

7.1 Evidence for a human-centric approach

There is wide evidence for the benefits of this type of approach. Candido *et al* [39] analysed a data set of 8,827 post-occupancy evaluation surveys conducted in 61 offices in Australia and found that occupants who were more satisfied with their environments were also more satisfied with their jobs, as well as perceiving themselves as more productive. They also identified some key features of high-performance, open-plan offices, such as:

- A human-centred approach to interior design.
- A variety of spaces to support different work-related tasks, such as focus work, collaboration, socialisation, and relaxation.
- A biophilic design that incorporates natural elements, such as plants, daylight, views, and natural materials.

This process and features are consistent with the statement that environmental satisfaction is closely associated with comfort and productivity in open-plan offices.

8 SUSTAINABILITY CRISIS

Everything we do must be in the context of our sustainability crisis. We can't afford to keep designing workplaces that don't work for people: it's a huge waste of our resources. We need to be honest about the full range of factors that affect acoustic satisfaction - otherwise people won't ask acousticians about the acoustics.

9 CONCLUSION

The science of acoustics in open plan offices has made great advances with the room acoustic indicators in ISO 3382-3, and the guidance of ISO 22955. However, these guides are necessary but not sufficient to explain occupants' acoustic satisfaction. There is little evidence for the traditional room acoustic indicators linking with the desired outcome – acoustic satisfaction. On the other hand, there is a wealth of evidence supporting a human-centric approach to open plan office design to achieve the same target outcome.

We need to take account of the diversity of the particular people who will use an open plan office, and the activities that they will perform. We need to take their experience and expectations seriously if we want them to be comfortable, in their existing or new office. We need to give occupants a genuine sense of control over their environment, so that they can be confident of finding suitable places for the variety of tasks that they perform on any given day.

If the office design is simply directed by management, based on their ideas of what occupants need, there is already a barrier to acceptance and hence comfort, whatever the physical manifestation. The suitability of the office is left to chance, people may attend the office reluctantly; both the organisation and the individuals will lose the benefits that can be gained by working closely together with colleagues. Human centric design already exists, we don't need to reinvent it; we need to include sound in those processes as a human factor as well as a technical factor.

10 REFERENCES

1. Jennifer A. Veitch, Kate E. Charles, Kelly M.J. Farley, Guy R. Newsham. A model of satisfaction with open-plan office conditions: COPE field findings, J. Env. Psychology, Vol 27, Issue 3, 2007.
2. https://www.mckinsey.com/industries/real-estate/our-insights/the-rebirth-of-workspace-design-an-interview-with-gensler-co-ceo-diane-hoskins
3. The Next 250k, Leesman, 2017. https://www.leesmanindex.com/the-next-250k/
4. A decade of change, Leesman, 2023. https://www.leesmanindex.com/a-decade-of-change/
5. The office is dead! Long live the office in a post-pandemic world, The Conversation, July 2020.
6. Zoom tells staff to come into the office at least two days a week, Tom Ambrose in The Guardian, 7th August 2023.
7. Rachel Casanova, Sophie Schuller. Does space matter? A new measurement for the effectiveness of workplaces: using Organisational Network Analysis (ONA) to measure connectedness, networks and strength of relationships. Workplace Trends, April 2022; and Using Organisational Network Analysis to measure connectedness, networks and strength of relationships, 2023
8. Valtteri Hongisto. A model predicting the effect of speech of varying intelligibility on work performance. Indoor Air, October 2005.
9. M. Pierrette, E. Parizet, P. Chevret & J. Chatillon (2014): Noise effect on comfort in open-space offices: development of an assessment questionnaire, Ergonomics, 2014

10. ISO 3382-3: 2022 Acoustics - Measurement of room acoustic parameters - Part 3: Open plan offices
11. Hongisto V, Keränen J. Comfort Distance—A Single-Number Quantity Describing Spatial Attenuation in Open-Plan Offices. Applied Sciences. 2021; 11(10):4596.
12. Annu Haapakangas, Valtteri Hongisto. Distraction distance and perceived disturbance by noise—An analysis of 21 open-plan offices. JASA, 2017
13. Manuj Yadav, Densil Cabrera, Jungsoo Kim, Janina Fels, Richard de Dear. Sound in occupied open-plan offices: Objective metrics with a review of historical perspectives. Applied Acoustics, Volume 177, 2021
14. Manuj Yadav, Densil Cabrera, Jungsoo Kim, James Love, Jonothan Holmes, Janina Fels, Richard de Dear. Investigating noise disturbance in open-plan offices using measurements of the room acoustics, and of the sound environment during occupancy. Proc. Euronoise 2021, Portugal.
15. ISO 22955:2021. Acoustics - Acoustic quality of open office spaces
16. Proposed Method For Measuring 'liveliness' In Open Plan Offices. Sara Vellenga, Tom Bouwhuis, Theodoor Höngens. ICSV24, 2017.
17. Development of a new ISO Technical Specification on non-acoustic factors to improve the interpretation of socio-acoustic surveys Benjamin Fenech, Lisa Lavia, Georgia Rodgers, Hilary Notley. ICBEN 2021.
18. Coping with Aviation Noise: Non-Acoustic Factors Influencing Annoyance and Sleep Disturbance from Noise. Susanne Bartels et al. (2022) Aviation Noise Impact Management.
19. FAMOS - FActors MOderating people's Subjective reactions to noise. Deliverable D4.5 Guidebook on how to reduce noise annoyance. CEDR Transnational Road Research Programme Call 2018: Noise and Nuisance. https://famos-study.eu/
20. The response to noise distraction by different personality types: An extended psychoacoustics study. Nigel Oseland, Paige Hodsman. Corporate Real Estate J., 2020
21. R.D. Caplan. Person-environment fit theory and organizations: Commensurate dimensions, time perspectives, and mechanisms. Journal of Vocational Behavior, 31 (3) (1987)
22. Perceived fit in activity-based work environments and its impact on satisfaction and performance, Hoendervanger et al, J. Environmental Psychology 2019
23. Jenni Radun, Valtteri Hongisto. Perceived fit of different office activities – The contribution of office type and indoor environment. J. of Env. Psychology, Vol 89, 2023
24. Personal office preferences, Nigel Oseland, 2019
25. Born to choose: the origins and value of the need for control, Lauren A. Leotti et al, Trends in Cognitive Sciences, 2010.
26. The value of control for acoustic satisfaction in open plan offices: a case study. Jack Harvie-Clark, Richard Hinton. ICBEN 2021.
27. Productivity in buildings: the 'killer' variables. Adrian Leaman & Bill Bordass, Building Research & Information, 1999.
28. Lee, S. Y., & Brand, J. L. (2005). Effects of control over office workspace on perceptions of the work environment and work outcomes. Journal of Environmental Psychology, 25(3), 323–333.
29. Pia Sirola *et al.* Workplace change process and satisfaction with activity-based office., Facilities, 2020
30. Valtteri Hongisto, Annu Haapakangas, Johanna Varjo, Riikka Helenius, Hannu Koskela. Refurbishment of an open-plan office – Environmental and job satisfaction. Journal of Environmental Psychology, Vol 45,2016

31. Annu Haapakangas, Valtteri Hongisto, Johanna Varjo, Marjaana Lahtinen. Benefits of quiet workspaces in open-plan offices – Evidence from two office relocations. J. of Env Psychology, Vol 56, 2018.
32. Rianne Appel-Meulenbroek, Sven Steps, Remy Wenmaekers, Theo Arentze. Coping strategies and perceived productivity in open-plan offices with noise problems. Journal of Managerial Psychology, 2021.
33. Lucas Lenne, Etienne Parizet, Patrick Chevret. Assessment of annoyance and cognitive fatigue of open-plan office occupants subjected to noise from two different activities. Proc Inter-noise 2022.
34. Hyun In Jo, Jin Yong Jeon. Influence of indoor soundscape perception based on audiovisual contents on work-related quality with preference and perceived productivity in open-plan offices. Building and Environment, Volume 208, 2022.
35. Volkan Acun, Semiha Yilmazer. A grounded theory approach to investigate the perceived soundscape of open-plan offices. Applied Acoustics 131 (2018) 28–37.
36. Simone Torresin, Rossano Albatici, Francesco Aletta, Francesco Babich, Tin Oberman, Stefano Siboni, Jian Kang. Indoor soundscape assessment: A principal components model of acoustic perception in residential buildings. Building and Environment 182, 2020.
37. BJ West, I Ali-MacLachlan, AM Deuchars. An in-situ investigation of office soundscape perceptual evaluation methodologies. Proc IOA Vol 45 Pt 3 2023
38. ISO/AWI TS 12913-4 Acoustics — Soundscape — Part 4: Design and intervention
39. Christhina Candido, Prithwi Chakraborty, Dian Tjondronegoro. The Rise of Office Design in High-Performance, Open-Plan Environments. Buildings 2019, 9(4), 100;