Chapter 8

The Sound of Inclusion: A Case Study on Acoustic Comfort for All

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8.1 Introduction

The past decade has witnessed a major shift in how human limitations are viewed (Froyen, 2006). Whereas disability used to be considered as a consequence of physical and/or mental limitations, it is increasingly recognised that the (built) environment holds responsibility for the exclusion of people as well, in other words that the environment can create handicap situations. This shift is complemented by a shift in professional attitudes: design for special needs, which focuses on a specific target group, gradually makes way for universal design, design for all or inclusive design. Inclusive design aims at objects and environments that are accessible, useable and comfortable for full range of people, independently of their capacities and limitations, and this throughout their entire lifespan.

While all people differ in terms of capacities and limitations, human functioning can be generally described by the ergonomic principle (Wijk *et al.*, 2003). This principle assumes that people perceive something in their environment, interpret what has been perceived, act on the basis of this interpretation and remain healthy while performing these three ‘ergonomic tasks’. Functioning in the built environment involves at least three modes of perception: seeing, touching and—the focus of this paper—hearing. Hearing provides us with auditory information about our environment, which is vital for human interaction and knowledge transfer, and essential for spatial orientation. Hearing well requires attention to the acoustic qualities of a space and sound amplification. It is especially important for people with a hearing or visual impairment, but also for the growing group of elderly people or for people who are not masters of the language of the speaker.

To our knowledge, however, studies on inclusive design in architecture have paid little attention to hearing so far. They tend to focus on accessibility of buildings and spaces, but rarely address their acoustic qualities. The same holds for accessibility regulations. Some prescribe or recommend the instalment of an induction loop, but since this serves only those users who wear a hearing aid, it does not guarantee access, usability and comfort for all. More generally, guidelines

exist for background noise level and reverberation time—two factors that considerably impact the acoustics in a space—yet their presence in codes and norms (and in building practice) varies considerably. In some countries, the guidelines are imperative, while others consider them as recommendations (Karabiber and Vallet, 2003). Across the board, however, little attention is paid to the diversity of people's hearing capacities and needs.

The scarcity of attention to acoustic comfort in designing inclusive environments is highly regrettable, because people who do not hear well quickly end up in social isolation as communication becomes difficult. The study reported on in this paper attempts to contribute to the knowledge base by exploring the notion of acoustic comfort for all. The term acoustic comfort is used here to denote a state of mind of satisfaction with the acoustics of the surrounding environment. Just like thermal comfort it differs from one space to another and depends on the activity taking place in that space. For instance, the preferred air temperature in a day care centre differs from that in a beer factory. Similarly, some places require speech privacy (*e.g.* open plan offices), whereas others need speech understanding (*e.g.* auditoria). Furthermore, music typically needs more reverberation than speech. In this paper, the notion of acoustic comfort for all is explored in the context of university education, a context where hearing well is vital to the core activity. After briefly introducing the context, focus and methodology of the study, the paper presents the major findings, followed by a summary and lessons learned.

8.2 Context, Aim and Methodology

8.2.1 A University as Universal Design Lab

The case study reported on in this paper was conducted within the context of the Katholieke Universiteit Leuven (K.U.Leuven). It is one of the initiatives that use the university as a laboratory for testing mechanisms to foster universal design (Heylighen and Michiels, 2007). Other initiatives include an assessment of the accessibility of the campus by architecture students in collaboration with users/experts; the development of a K.U.Leuven Code, which specifies accessibility norms and guidelines for new build and rebuild projects on campus; or the equipment of K.U.Leuven libraries with reading aids for people with visual impairments.

In an educational context such as a university, universal design has an important pedagogical aspect. Just as a multicultural curriculum is needed to create ethnic and cultural tolerance and diversity, universal design is needed to encourage inclusion and acceptance of all abilities (Tepfer, 2001). Since young people are educated as much by example as through teaching, environments that segregate teach acceptance of segregation and inclusive environments teach inclusion. Unfortunately, many educational environments are rife with examples of non-inclusive settings: “While this offers picturesque examples for UD instructors and powerful experiences of exclusion, it also subtly indicates to students that these characteristics are tolerable aspects of the built environment” (Welch and Jones, 2001).

8.2.2 The Grote Aula

Within the context of the K.U.Leuven, one auditorium was selected to explore the notion of acoustic comfort for all. The ‘Grote Aula’ (large auditorium) was chosen because of its frequent use for lectures and musical events, the complaints of experts/users about its poor acoustics, and the plans to renovate it in the near future.

The Grote Aula of the Maria-Theresia college is situated in the old city centre of Leuven. In 1778 Maria-Theresia accommodated the seminar of theology in this former Jesuit college. The right wing in the inner courtyard, which still accommodates the Faculty of Theology, was added in 1786-87. The Grote Aula and ‘Kleine Aula’ (small auditorium) followed in 1825-27. These neo-classicist auditoria, designed by Martin Hensmans, have a half-round ground plan and are on one floor. Since 1975, the Grote Aula is officially listed as a protected monument, together with the entire Maria-Theresia college and the neighbouring ‘Pauscollege’ (Pope’s College).

At the time of writing the 495 seats of the Grote Aula accommodate undergraduate and graduate students on a daily basis. Once a week, students of the University for the Elderly attend lectures here, and at night, or between semesters, the auditorium is available for musical activities. Both types of events – lectures and musical events – require different acoustic conditions: a speaker demands a much shorter reverberation time than an ensemble. Experts/users especially complain about the difficulty of clearly understanding the speaker during lectures. Comparison with other auditoria at the K.U.Leuven confirmed that the acoustic conditions in the Grote Aula show considerable room for improvement. The planned renovation in 2009 provided extra reasons to submit this auditorium to an in-depth analysis and to propose interventions that improve the acoustic comfort for all.

Figure 8.1a-b. The Grote Aula: exterior (photo: K. De Leye & E. Dooms) and interior (photo by M. Rychtáriková)

8.2.3 Methodology

Inclusive design confronts architects with a new challenge. If we are to design environments that are accessible, useable and comfortable for more people, a human-centred process should replace the design-centred process that characterizes

non-inclusive design (Paulsson, 2006). Thus, if we are to provide acoustic comfort for all, we have to give primary attention to the users and their diverse hearing capacities and needs.

To start with, a series of in-depth interviews were conducted with various experts/users – students and personnel with a hearing impairment, students with a visual impairment, and students who attend the University for the Elderly. These interviews provided us with a rough idea of the acoustic comfort in the K.U.Leuven auditoria – which motivated the selection of the Grote Aula for the case study. At the same time, they allowed us to start mapping the hearing needs and preferences of people with diverse capacities and limitations.

Subsequently, an attempt was made to address these needs and preferences in the context of the Grote Aula. The auditorium's present acoustic conditions were measured in situ. In order to improve these conditions, spatial interventions that respect the building's historic character were searched for and simulated. In addition, technical solutions that could further improve the acoustic comfort in the auditorium were inventoried so as to include people with and without a hearing impairment.

The following section will outline the findings of this study without going into too much technical detail.

8.3 Findings

8.3.1 Experts/Users Speaking

In order to get a view of diverse hearing needs and preferences in the context of university education, six students with a hearing or visual impairment were interviewed. These experts/users in the domain of acoustic comfort were contacted via the Working Group Students with Disabilities of the K.U.Leuven and participated voluntarily in the study. In addition, one interview was conducted with representatives of the University for the Elderly. All interviewees were asked to nominate the best and worst auditorium in terms of acoustic comfort, and to indicate problems they experience when attending lectures. The interviews were audio-taped, the tapes were transcribed, and the transcriptions were summarized.

While opinions on the best auditorium varied, several experts/users labelled the Grote Aula as the worst. The strong resonance and long reverberation especially are considered as negatively impacting the acoustic comfort of this auditorium.

Across the board, resonance and reverberation are cited most frequently by all interviewees as causing hearing problems during lectures. Students with a hearing impairment need a clear and high-quality signal in order to be able to understand the speaker, because their remaining sense of hearing is limited. Students with a hearing aid often use an FM listening system during lectures. The speaker speaks into the microphone, after which the speech signal, including the resonant sound, is sent to the hearing aid. According to one student, this is so difficult to understand that she must concentrate entirely on comprehending the speech and cannot make

notes. In other words, an FM system as such does not offer a solution; it requires good acoustic conditions to work properly.

Also students with a visual impairment complain about auditoria with long reverberation. In these spaces, they receive so many inputs that orientation becomes extremely difficult. Since they move relying on their sense of hearing (and touch), it becomes almost impossible for them to orient themselves. Moreover, audio-recording lectures is of little use in these auditoria, since the sound quality of the recordings is very low.

Besides reverberation, the experts/users mention several other factors that affect acoustic comfort. Background noise – caused by chatting students, for instance, or creaking wooden seats – is very disturbing, especially for students whose hearing aid does not filter the sounds it amplifies. Other elements include speakers' articulation, their (in)ability to deal with technology, or their tendency not to repeat questions asked in the audience.

8.3.2 Current Situation

As the Grote Aula was identified by several experts/users as worst auditorium in terms of acoustic comfort, we wanted to have a detailed view of its present acoustic conditions. To this end measurements were conducted in situ, which enabled us to derive several acoustic parameters. Based on the results of these measurements, we could assess the auditorium in more detail and propose interventions for improvement. The following paragraphs briefly introduce the reverberation time and the speech intelligibility – the most important acoustic parameters in the context of this paper – without the technical details, and summarize the major results of the measurements and their implications.

8.3.2.1 Reverberation Time

As mentioned above, long reverberation strongly affects acoustic comfort in a negative way. The acoustic parameter that models this phenomenon is the reverberation time (RT). A long RT (of several seconds) extends syllables so that they overlap, and thus negatively impacts speech intelligibility (DFES, 2003). This is the case in spaces with hard, reflecting walls and ceilings. A long RT causes the background noise level to rise, which further reduces speech intelligibility.

For people with a hearing impairment the allowed RT is shorter. A too long RT increases the background noise and makes listening very tiring and perhaps even impossible. For people with a visual impairment a short RT is crucial too. In a room with a long RT, these people have difficulty locating from which direction the sound is coming. However, the RT has also a minimum limit. Too much absorption in a space, especially in auditoria, diminishes the early sound reflections to such an extent that the sound level produced by the speaker quickly decreases and is too weak at the back (DFES, 2003).

According to our measurements the RT in the Grote Aula is 2.40 seconds, which was to be expected given its size (3,588 m³) and materials (hard surfaces and leather seats). This is too long – for lectures and for music – and should diminish drastically if we are to provide acoustic comfort for all. In a space of this size, one

second would be ideal for speech, while music demands 1.8 seconds. These values are based on experience, since no norm exists.

8.3.2.2 *Speech Intelligibility*

Speech intelligibility is an intrinsic characteristic of speech transmission for a certain position of source and receiver. The space (and its shape, finishes, ...) clearly affects the quality of the spoken signal during the transfer from speaker to listener. Reverberation, reflections and concentration of sound waves have a negative effect. Speech intelligibility also depends on the location of the speaker and listener, background noise and the loudness and quality of the spoken signal. Good speech intelligibility implies a strong and understandable signal. The level of occupation plays a role too, since the audience acts as an extra source of absorption, which diminishes the RT and thus improves speech intelligibility.

The speech transition index (STI) of a space varies between zero and one; the higher the value, the better the speech intelligibility. An STI of 0.6 is considered as desirable, yet complete intelligibility of sentences requires 0.75. Research on speech intelligibility with elderly (suffering from reasonable hearing loss) and non-native listeners and speakers, shows an increase in STI of minimum 0.10 to be desirable, yet in many cases 0.15 or 0.20 is necessary.

Judging from the measurements, the STI in the Grote Aula varies between 0.36 and 0.50. Across all positions, the average is 0.44, which is usually experienced as poor. The value diminishes at the back, since the sound level reduces with the distance from the source. The more absorption in the space, the greater this reduction. Moreover, the farther from the speaker, the more reflections (with walls, ceiling) have taken place. If these reflections arrive at the listener with a considerable delay (more than 50 ms), they are disturbing and reduce speech intelligibility.

When using the current audio system in the Grote Aula, the measured STI varies between 0.37 and 0.69, with an average of 0.48. This suggests that the system does not perform properly. A better installation that divides the sound across the entire auditorium would considerably improve the speech intelligibility. The current system makes speech sound louder but not better. The amplified sound, which is broadcast at the front, is strongly reflected by the surrounding walls and ceiling, and causes disturbing echoes. Thus, the audio system does not improve the RT or speech intelligibility.

8.3.3 Improvements

Judging from the measurements in situ, providing acoustic comfort for all in the Grote Aula will require major improvements. A first set of improvements come down to adding absorption so as to reduce reverberation and increase the speech intelligibility. As the auditorium is a protected monument, discrete solutions are needed that can provide extra absorption. In the case of a new building, many more possibilities exist to create a favourable acoustic climate. Given the double function of the Grote Aula – lectures and music – we explored the possibility of applying movable interventions, which can be adapted to the activity taking place.

The following interventions were considered:

1. replacing the leather-covered seats by lightly padded seats covered with cloth
2. replacing the linoleum floor by carpet (suggested by the technical services)
3. applying an acoustic plaster on an acoustic absorption layer to the wall
4. placing removable sound-absorbing wall panels covered with cloth
5. hanging curtains along the wall
6. applying an acoustic plaster to the ceiling above the gallery
7. applying a thin acoustic plaster to the cupola and vault above the podium

Combinations of the interventions proposed for seats, floor, wall and ceiling were tested in an acoustic simulation program with regard to their impact on the spatial acoustics of the auditorium. Table 8.1 schematically presents how they perform on different criteria:

- speech: RT of ca. 1 second and speech intelligibility > 0,6
- music: RT of ca. 1.8 seconds
- maintenance: how easily materials can be cleaned and how fast they get dirty
- flexibility: adaptability to change in use (music/speech)
- replacement: how easily solutions can be removed or replaced

Note that the score for the latter three applies to the intervention in bold only.

Table 8.1. Performance of interventions. Key: -- = weak, ± = moderate, ++ = optimal

	Present	Interventions								
		1	1,2	1,2,3	1,2,4	1,2,5	1,2,3,6	1,2,3,6,7	1,3	1,6
RT	2.48	2.44	1.72	1.18	1.10	1.26	1.17	1.01	1.90	2.22
STI	0.45	0.46	0.51	0.58	0.58	0.59	0.59	0.62	0.52	0.48
Speech	--	--	--	±	±	±	±	++	--	--
Music	±	±	+	±	±	±	±	±	+	±
Maintenance	++	±	-	++	±	±	++	++	++	++
Flexibility	--	--	--	--	±	++	--	--	--	--
Replacement	±	±	±	--	++	++	--	--	--	--

The RT clearly decreases as absorption increases. Solutions that are labelled as moderate for speech do not meet the requirement for RT and STI, but may come close. Solutions marked as weak are to be avoided, as the RT is way too long and the STI too low. Solutions that do not meet the requirements for music are marked

as moderate, because the echo in the space is either too strong or insufficient for music to sound optimally. Cloth materials or covers are moderate solutions with regard to maintenance; they easily absorb dirt that is difficult to remove. Carpet is even worse, as it quickly becomes dirty when walked over. Moreover, it is less comfortable for wheelchair users or people with allergy. Curtains are considered flexible because they can easily be opened or closed depending on the activity taking place (lecture/music). Wall panels can be removed, but this is much more laborious. Plasterwork cannot be removed or replaced without damaging the underlying structure, and is therefore marked as weak with respect to flexibility and replacement. Curtains and wall panels are easily removable, while the moderate solutions require more effort.

Depending on the priorities set, one can select the most appropriate solution from the scheme above. Obviously, the fact that the Grote Aula is protected as historic monument does play a role in this selection. However, whatever solution is selected, increasing absorption alone will not automatically lead to acoustic comfort for all. As the table indicates, none of the solutions perform optimally for reverberation and speech intelligibility – even less so when taking into account the more stringent acoustic conditions posed by people with a hearing or visual impairment. Since these are not attainable in the context of the Grote Aula, the acoustic comfort needs to be further improved in a technical way.

Several technical interventions may improve speech intelligibility in an echoing space. Within the gamut of loudspeakers alone, multiple types and possibilities exist. In this study, we have only considered interventions that can bring the sound signal to the listener with better quality. An induction loop and the use of headsets avoid sound waves having to cover a path through free space before reaching the listener. As a result, the poor acoustic qualities of the space have less impact on the quality of the signal transmitted. Loudspeaker installations solve this problem by directing the sound so that it avoids the reflecting surfaces in the space as much as possible. Moreover, the loudspeakers should be oriented so that the sound level no longer diminishes with the distance to the source, as is currently the case in the Grote Aula. Applying extra absorption will further reduce the sound level in all positions and thus make well-oriented loudspeakers even more important. Unlike the interventions to increase absorption, the proposed technical solutions have not been tested with simulation software because of the laborious and very specific character of the subject matter. If specific performance requirements are formulated in advance, these calculations or simulations can be performed by the suppliers of these installations.

8.4 Summary and Lessons Learned

In architecture, inclusive design aims at environments that are accessible, useable and comfortable for all people. This aim is usually associated with accessibility, yet acoustic qualities may considerably impact usability and comfort as well. By way of first step, the study reported on in this paper explored the notion of acoustic

comfort for all in university education, a context where hearing well is vital to the core activity.

The experiences of diverse experts/users revealed that the Grote Aula performs very weakly in terms of acoustic comfort. Measurements in situ confirmed the need for radical improvements. Several interventions regarding material use were proposed—taking into account the auditorium’s historic character and double use—and tested in terms of effectiveness via a simulation model. Analysis shows that the ideal solution does not exist; what is most appropriate depends on the priorities set (lectures versus music, maintenance, flexibility, replacement). Since none of these interventions guarantees acoustic comfort for all, including people with a hearing or visual impairment, additional technical interventions are proposed: a better audio system, a headset connection and an induction loop. In addition, speakers’ awareness should be raised regarding the importance of articulation, correct technology use, and repeating questions asked in the audience.

The Grote Aula is a historically protected monument and since every monument is protected in a specific way, general guidelines are difficult to derive. Nevertheless, the outcome of the case study largely transcends the planned renovation of this specific auditorium. The issues inventoried and addressed in this study may serve as points to consider when (re)designing other auditoria in the future. Moreover, the solutions explored in the context of the Grote Aula may be useable in other renovation projects. The same holds for the approach of looking for flexible changes by using acoustic predictions. Judging from our experience, room-acoustic simulations provide a convenient method to evaluate particular alternatives in the context of historical buildings. As such, the study contributes to sensitization and knowledge transfer, in that it makes students and professionals in the building sector aware of the importance of acoustic comfort for all, and offers a first view of which solutions are possible and desirable, and how these can be obtained.

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8.6 References

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