Pedagogical approaches to acoustics for architecture students

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Abstract

The impact of the architect's design on the acoustics of the environment is obvious. It becomes more specific when talking about room acoustics, building acoustics or soundscapes. However, the architecture pedagogic programs devote very little time to the study of acoustics. This work presents the results of an introduction course to research in architectural acoustics. With the focus in the perception of sound in built spaces, the students conduct their own research on a specific topic. The explanation will cover the results, difficulties, potential paths and limitations of these pedagogical practices.

Introduction: why this matters

The last stage of the architectural design process, according to several authors, is the *verification* phase. In the basic definition of this process by Herbert [1], the architectural design process is a recursive chain of stages. It starts on the detection of a *problem*, followed by the definition of a *programme* to work with, until the gestation of the design *core idea* draws the main features of the final definition, which will be defined by a *hypothesis*, *verified* by models. The process will start again changing the hypothesis definition, or even the idea before finally is *constructed*.

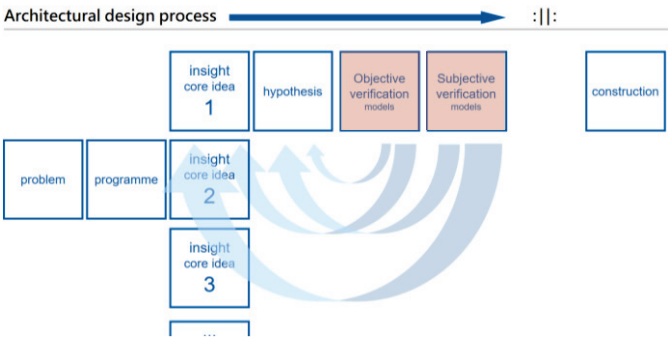

Image 1: Architectural design process, after Herbert [1]. In red, the *verification* phase divided into objective and subjective verifications, as it is implemented in the teaching course presented.

The *verification* phase contains the feedback for the architect's design. This can be easily seen in the design process of concert halls and conference rooms, in which the verification of the room acoustic parameters is crucial, but can be also extended to other architectural typologies. With the feedback received from the verification outputs, the designer can change the initial *hypothesis*, or even the *core idea*; change of materials of walls, ceilings and floor; the change of seating arrangements.

The discipline of architectural acoustics has developed diverse methods of evaluation of the built environments, which can be divided in two main groups: objective evaluation of sound and subjective evaluation of sound, defining objective and subjective parameters. They are tools that give feedback to the architect in the verification phase.

When addressing the education programmes in architectural education, the teaching of *verification models* –methods, criteria and praxis- is mandatory in order to close the loop of the architectural design process. Other experiences in education addressed the generation of the *core idea* from soundscapes [2, 3] and project based experiences [4] in the past. The present paper reports the pedagogical tasks closing the loop of the architectural design process, with the course *"Research on acoustic perception in architecture"*, taught at the Faculty of Architecture at RWTH Aachen University in the summer and winter semesters of the year 2019. In the following sections, a synthetic description of the pedagogical process is given. After this, a summary of the case studies of the course is explained with a conclusion.

Course description

35 students took the course, which were divided in 8 sub-groups of 3 to 5 people each. The main task of the course is to design and perform a test, which evaluates a specific "research" question in architectural acoustics in already existing rooms and, finally, generates feedback for the design in architecture. As a conclusion, the students compare their approach and the results with published research on the topic and compare that with validated studies.

Four main research topics are presented to the students. Two groups of students received the same main research topic, which means that eight research questions resulted, as it can be seen in the table 1.

All students received four lectures on the theoretical content of architectural acoustics. They were provided with the following content: Room Impulse Response (RIR), reverberation time (RT), music clarity (C), speech intelligibility (D), practical measurements of RT with dodecahedron speaker and microphones, practical measurements of RT with balloon and a mobile app for acoustic measurements.

Each group designed their test according to the research questions, selected the rooms in the city of Aachen which will be used for the test (between 4 and 7 rooms), and recruited their test participants (between 10 and 20 subjects).

Rooms tested

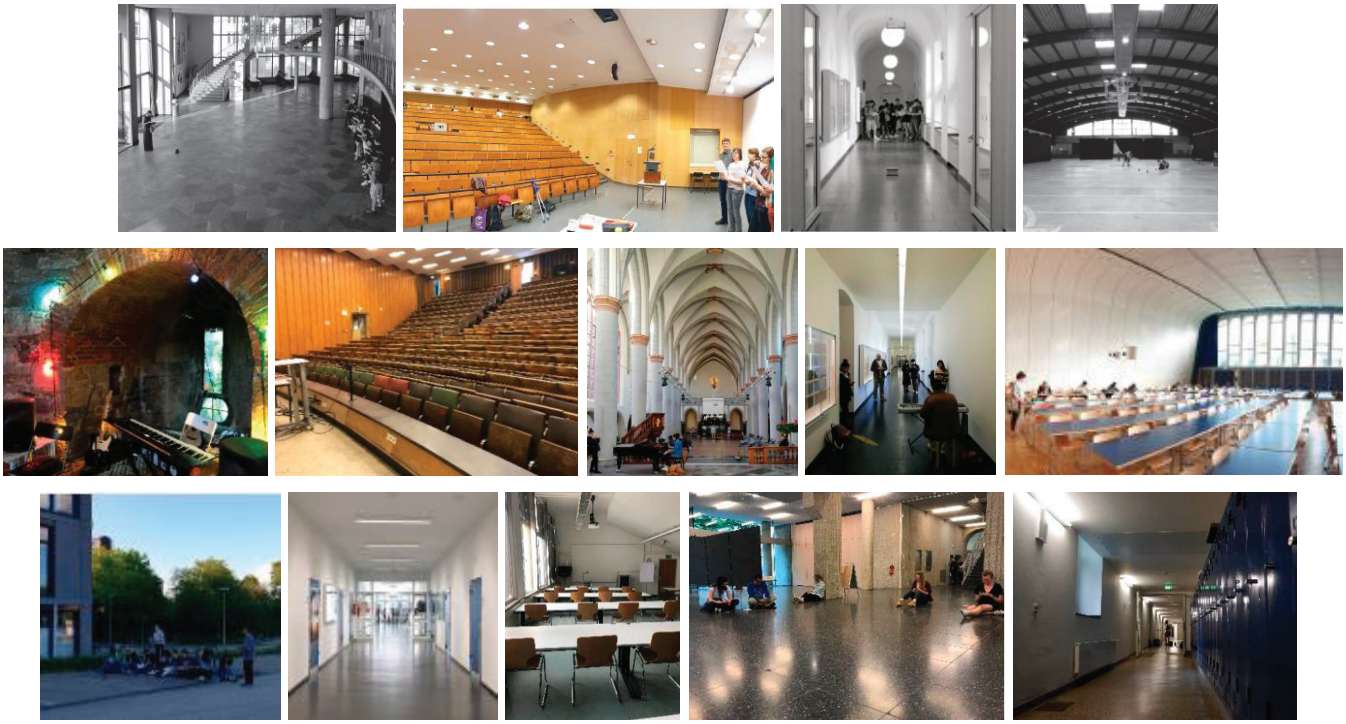

Image 2: All rooms are located in the city of Aachen. From left to right, and top to bottom: I) Audimax foyer. II) Hörsal Mensa. III) Reiff-museum corridor. IV) Sports 100.5 arena. V) Grüner Hörsaal Audimax. VI) St. Nikolaus Kirche. VII) 2nd floor Reiff-museum corridor. VIII) Aula 2. IX) Outdoor Mensa Ahorhnstr. X) Mensa corridor Ahornstr. XI) Seminarraum Z6. XII) Reiff-museum foyer. XIV). Reiff- museum basement.

The reverberation time of every room was measured with a balloon as impulse source, and the Android App *RT* as receiver and calculator. The measurement points corresponded to the test subject's location. The balloon position was always located to the sound source location. All subjects were located to the same distance to the sound source.

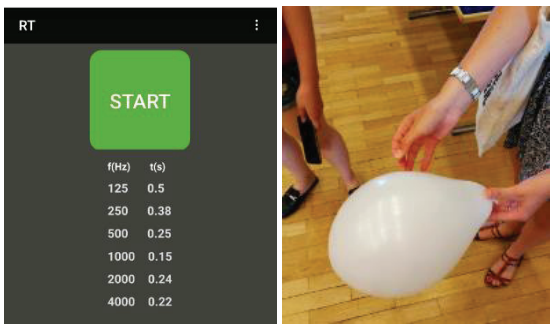

Image 3: *RT* App and balloon sound source method used for RT measurements.

Research questions

The research questions were developed according to the four given research topics and the capabilities of each group. The definition of the research question was also in accordance to the type of sound stimulus they could generate and the type of questionnaire they could develop.

Table 1: Relation between groups and research questions.

	Given research topic	Final research question
	How does the RT of a room influence the…	
Group A	music clarity	clarity in different musical instruments
Group B	music clarity	clarity in different velocity performances
Group C	music performance	velocity in a piano performance
Group D	music performance	velocity performance in different musical styles
Group E	speech intelligibility	text recognition in sentence and numbers
Group F	speech intelligibility	lyrics intelligibility from a choir
Group G	speech performance	reading velocity from a live reader
Group H	speech performance	lyrics performance from a recorded choir

Test methods used

The following list includes the collection of the methods and sound stimulus used by the groups in their tests:

- Written questionnaires
- Online questionnaires
- 5-point Likert's scale
- WRR (Word Recognition Rate)

- Singing articulation methods for choir: loudly, quietly, articulated.
- Fill-in the gaps of lack parts of text.
- Velocity modification of music reproduction with VLC
- Anechoic recordings of musical instruments
- Chronometer measurements of piano interpretation
- Live text readers
- Live piano player
- Record and playback of sentences and number sequences.
- Record and playback instrument melodies.

In the following, three groups are given as examples:

Group A:

- **Research question**: how does the RT of a room influence the clarity in different musical instruments?
- **Sound stimulus:** anechoic recordings of three instruments (double bass, piano and ukulele). Three melodies recorded for each instrument (slow, medium and fast).
- **Questionnaire:** note-counting for each instrument and each melody in different rooms.
- **Hypothesis:** instruments with low frequencies are less clear in higher reverberant spaces. Subjects will not be able to count all notes of the fast melody played by a double bass in those spaces.

Group C:

- **Research question**: how does the RT of a room influence the velocity in a piano performance?
- **Sound stimulus:** pianist playing the same songs in different rooms. Four songs: Beethoven-*Für Elise*; Einaudi-*Nuvole Bianceh*; Hou-*A breathtaking piano piece*; Tiersen-*Comptine d-un Autre Éte*.
- **Questionnaire:** velocity of interpretation measured with a chronometer tapping each bar.
- **Hypothesis:** the same pianist performs faster when he is in a low-reverberant space, and he performs slower when he is in a high-reverberant space.

Group F:

- **Research question**: how does the RT of a room influence the lyrics intelligibility of a choir?
- **Sound stimulus:** SATB choir performing in different rooms the same melody with slightly changed lyrics. Three choir articulation methods are used: loudly, quietly, articulated
- **Questionnaire:** fill-in the blanks with lyrics you hear from the choir. WRR metric is performed with the results.
- **Hypothesis:** lyrics are better understood in lower reverberant spaces and which the articulated method of singing.

Conclusions

The course had a good acceptance from the students. It introduced the verification methods of the architectural spaces regarding the basic room acoustic parameters. However, they could not finally perform the comparison of their own results with the published studies on those topics. This point will be relevant for further focusing and developing the course.

Biography

[1] Herbert, Gilbert. (1966). *The architectural design process*. British Journal of Aesthetics. 6, 152. Doi: https://doi.org/10.1093/bjaesthetics/6.2.152

[2] Llorca-Bofí, Josep; Llorca-Bofí, Vicent and Redondo, Ernest. (2019). *Representation of the soundscape in the architectural design process* . EGA Revista de Expresion Gráfica Arquitectónica. 24 (37) : 192. Doi: https://doi.org/10.4995/ega.2019.11780

[3] Llorca-Bofí, Josep; Engel, Margret; Kohnen, Michael; Fels, Janina; Vorländer, Michael. (2019). Generation of architectural designs using soundscapes: an educational case study. In *Fortschritte der Akustik – DAGA 2019 Rostock*, March, 2019. https://www.dega-akustik.de/publikationen/online-proceedings/

[4] Llorca-Bofí, Josep; Redondo, Ernest; Vorländer, Michael. (2019). *Learning room acoustics by design: a project-based experience.* International Journal of Engineering Education. 35 (1B): 417-423. Doi: https://doi.org/10.5281/zenodo.2579130