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Designing spaces and soundscapes. Integrating sonic previews in architectural modelling applications

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Abstract

Acoustics and architects are often engaged in design dialogues. While architects work on the definition of the spaces, acousticians deal with understanding in advance how these spaces will be sonically perceived by the future inhabitants. Sometimes, communication might be difficult, lacking a common vocabulary based on sound energy descriptors, frequency distribution, and perceptual dimensions. In this paper, we present the results of an online questionnaire answered by 15 professional architects asked to consider the possible integration of sonic anticipations in their design practice. The totality of the participants declared to be interested in working with a software environment enabling them to listen to (i) how changes in the geometry would affect the diffusion of sound, (ii) how changes in the materials would affect the diffusion of sound, (iii) simulate sound sources which are likely to be present in the space to be designed. Some of this percentage expressed the need to be further guided for such activity. A third of the respondents also completed an optional section which required them to test three interactive online examples, Playsound.space, Tranquil City pavement, and a javascript spatial sound demo. In discussing the results, we provide our design suggestions for the scenario depicted.

Keywords: Acoustic Education, Design Integration, Soundscapes, Real Time Auralization , Architecture

1 INTRODUCTION

In our daily activities, a comfortable sonic environment allows us to be productive and relax from stress when needed, improving our quality of life. However, sometimes this is not possible for a lack of design attention towards sonic matters, with the misconception that acoustic solutions might be expensive or too difficult to plan ahead. In urban design practices, it can be even harder to individuate design responsibilities and solutions, albeit steps have been recently taken to include modelling approaches deriving from virtual acoustics [3] among the strategies to identify and solve these problems in the urban fabric. Soundwalking has been largely used to investigate urban soundscapes to inform urban policies [1] or provide experiences and material to create artworks to be conveyed through sound and music [5]. Our previous research has shown how people reflect on soundscapes in situ through graphical templates [8, 7], highlighting how certain qualities of the spaces might not appear through other conventional procedures, thoroughly reviewed in [6]. Although promising results to bridge soundscape research and architectural practice have been brought forward by the field of Indoor Soundscaping [17], it seems that there is still a gap between research on soundscapes and architectural education [2], which this paper would like to address presenting the results from an online survey conducted with 15 architecture professionals.

2 AURALIZING ARCHITECTURAL MODELS

Auralization, "the creation of audible acoustic sceneries from computer-generated data" [14], has helped in the recent year to audition acoustic design solutions for architectural spaces and evaluate perceptually their acoustic signature, represented by a Room Impulse Response (RIR). A RIR corresponds to the response of the room to the excitation of a given signal, emitted by a source with a given set of coordinates, as recorded by a receiver placed in a different position. Acoustic simulation software has helped through years calculating, and recently hearing, how spaces might sound like, according to their volume, geometry, and materials. Acoustic simula-

tion methods can be split in two families, Geometrical Acoustics (GA) methods and Wave Models (WM) [15]. The latter can be exemplified by methods acting in the frequency domain, comprising of Boundary Elements Methods (BEM) and Finite Elements Methods (FEM), and those acting in the time domain, Finite Difference Time-Domain methods (FTDT), which might be considered similar to Digital Waveguide Mesh (DWM). GA methods include ray, cone, and pyramid tracing, Image Source (IS), and also all those hybrid models blending together these two techniques. These methods have been extensively discussed in literature and there are many software packages which adopt proprietary algorithms designed to solve specific conditions, such as CATT, EASE, ODEON, Ramsete, CadnaA, COMSOL, etc. In addition to these established packages, few more simulation frameworks recently arose seeking to answer the desire to walk around in a space and hear how it would sound like. We review next three of these frameworks (RAVEN, EVERTims, and Project Acoustics) whose potential could be further explored in educational settings, explaining briefly their underlying technical infrastructure.

RAVEN [11, 9] (Room Acoustics for Virtual Environments) is a real-time auralization tool based on a C++ library, designed as a plug-in for SketchUp. It comprises (i) the SketchUp plug-in, acting as a TCP/IP server for the simulation clients, (ii) the SketchUp Auralisation (SUA), Visualisation (SUV), and Controller (SUC) clients; (iii) the real-time convolution module. Changes in the SketchUp model are sent to the SUV and SUA, which updates the calculation only if needed. Since the SUA renders only one receiver at a time, it is possible to perform walkthroughs in the space interpolating between positions and operate modifications upon need. To calculate the sound propagation paths and detect changes to render, RAVEN adopts a hybrid combination of Spatial Hashing (SH) and Binary Space Partitioning (BSP), depending on the kind of recalculation needed. The RIR, calculated by composing direct sound, early reflections, and late reverberation, is auralised starting streaming the direct sound and immediately after the early reflections, the most important components to achieve a sense of space, leaving the calculation of the late reverberation at a lower priority. In SketchUp it is possible to assign material acoustic properties such as absorption and scattering, and position audience areas on which project the results of the simulation, which employs a combination of IS and RT.

EVERTims [10] [1] is an open-source tool for real-time auralisation, based on a C++ library which connects to a python add-on for Blender, an open-source 3D modelling tool. After receiving the room geometry and the listener and source positions, the room modeler unit, which differently from RAVEN works also with open geometries, constructs a beam tree for the current geometry. The highest simulated reflection order can be set in the controller and is passed as a parameter to the modeler. A list of computed image sources is generated and sent to the auralization unit which, through a Feedback Delay Netwok (FDN), computes the late reverberation and adds it to the IS and direct sound calculation, rendered as a binaural output. The auralisation module employs JUCE [2], a framework supporting the design of Digital Signal Processing (DSP) chains and User Interfaces (UIs), and allows to import specific Spatially Oriented Format for Acoustics (SOFA) files for source directivity or Head Related Impulse Responses (HRIR). The software is currently optimised to update the source and listener position without high computational load and potentially could support multi-sources and multi-listeners. Notably, it can auralise live sound on-the fly as if it was in the modeled space and export Ambisonics RIR. Updates on the geometry can be performed live within a short recalculation time.

Project Acoustics by Microsoft [4] [3], designed to achieve realistic and aesthetically pleasing auditory scenes in gaming environments, employs a two-steps approach. The first step consists of a precomputation (baking) which can be requested through a subscription system and received after running on a cloud computing systems, or alternatively run on high-performance local machines. This step generates a set of probe locations acting as both sources and receivers above the scene's navigation mesh. After adaptively pruning proble samples, depending on space characteristics, the system performs a 3D numerical wave simulation at each probe location and encodes impulse responses between source and listener locations in terms of four perceptual parameters. These are (i) the direct sound loudness (dB) of initial energy which arrives at the listener during the first 10ms;

[1] http://evertims.github.io/
[2] https://juce.com/
[3] https://docs.microsoft.com/en-us/azure/cognitive-services/acoustics/what-is-acoustics

(ii) the loudness of early reflections in the following 200ms; (iii) the decay time of reflections; (iv) the decay time of late reverberation. These represent 3D emitter fields sub-sampled uniformly at a spacing of around 1m and compressed by the encoder, with an optimal probe layout at 3-4 m. This precomputation (the bake), is unique for the model and its materials (which need to be assigned beforehand), allowing for the sources and the listeners to take any space in the navigation mesh. The real time listening experience is currently implemented in Unity (and Unreal), where the user just needs to import the software package as a plugin and the precomputed data before experiencing the auralised environment. At runtime an interpolation based on the reachable probes is applied to the decoded parameters to filter each source sound, achieving "smooth and realistic audio as sources and listeners move through the scene" [4]. With respect to other GA frameworks, this system may simulate diffraction more realistically and therefore provide innovative yet important perceptual aspects such as occlusion and portaling, once only domain of WM simulations, typically uncommon in the acoustic analysis of large and complex architectural models.

These three platforms all seem to offer huge potential in support of design practices, in educational as well as professional settings. We imagine that introducing these tools as coursework resources would be the best strategy to see how they fit in the pedagogical development of the architect. It was noticed that although Building Information Modelling (BIM) approaches recently flourished, no plugins for acoustic simulation and auralisation were made available for REVIT or other platform. To our knowledge, there are only two attempts to integrate acoustic simulation in BIM practices [13, 16]. The survey we conducted, presented in the next section, aimed at capturing a general overview on how architects would receive the possibility of using software which would allow them to hear the effects of their design.

3 SURVEYING ARCHITECTURE PROFESSIONALS

We have previously investigated using graphic notation systems the perception of sonic environments and the conceptualisation related to design choices [7]. Nevertheless, we could not succeed in including architects or architecture students among our participants. Since the broader scope of this research was to investigate how Aural Design practices (including both Acoustic Ecology and Architectural Acoustics) could be integrated in architectural training, we took few further steps. A survey was launched in May 2018 to address how those involved in Aural and Acoustic Design practices, such as academics and professionals, would elaborate on a series of example teaching strategies, presented on a web page[4]. We received 14 responses and analysed the results. In a nutshell, respondents would encourage the teaching of acoustic subjects in architecture schools as part of design modules or technical modules and would encourage either listening experiences *in situ* as well as exercises employing simulation tools. The online survey[5] object of this article, targeting architecture professionals, was launched in December 2018 and advertised through social media platforms, with the result of being forwarded within few practices in London. The respondents could choose whether to answer the full survey lasting about 10 minutes, which involved a listening session[6], or a shorter version without this part, lasting less than 5 minutes. After the listening section, or directly after the introductory section, the respondents were asked to answer questions including in order: role in the practice, management of acoustic design within the practice, size of the practice, software mostly used, interest in workflow integration of sonic preview features, acoustic comfort in daily life, training on acoustic topics, use of virtual and augmented reality applications, age, gender identification, years of professional experience, musical listening habits, and answering platform. Differently from the other survey, we did not show demonstrative material related to existing auralisation platforms, but we rather aimed to provide coverage of the existing interest and education in sonic practices, to better understand the network of relationships among architects and acousticians. We further detailed this topic through a set of semi-structured interviews, discussed in another publication [7].

[4] http://eecs.qmul.ac.uk/~am320/resources/

[5] https://tinyurl.com/icasubmission

[6] We advised to avoid the mobile in this case for compatibility issues.

[7] Details of the Journal to be provided upon acceptance.

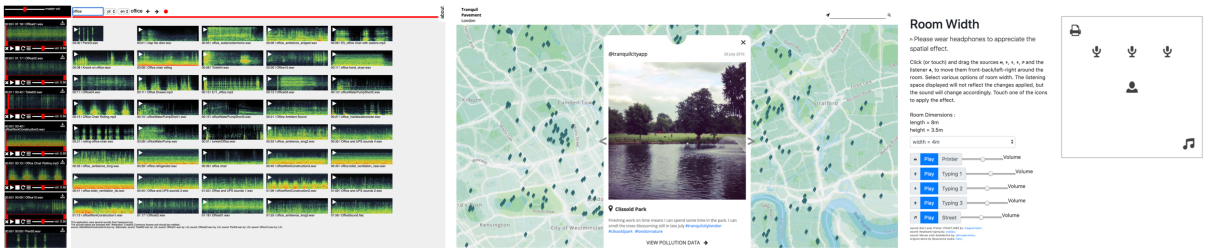

Figure 1. Playsound.space (left), Tranquil Pavement (middle) and spatialised demo (right)

3.1 Listening section: Results

One third of the respondents (5 on 15) took part in the listening activities, which involved using briefly three interactive online platforms which offered the possibility to experiment and reflect on soundscapes and architectural design in a light and effortless way. The first, employing the online platform Playsound.space [12] (left in Fig 1), required respondents to imagine an office space and select sounds to play accordingly, pasting the resulting link in the survey. All 5 respondents provided links similar to this sample result [8] (M n. of sounds: 6.4, STD: 2.3) and mostly clicked on what was available on the first page results after querying the word "office". The second question required to explore Tranquil Pavement [9], a crowdsourced platform which displays on a map of London, detailed with pollution and environmental noise data, images posted on Instragram with the hashtag #TranquilCity. Respondents were asked to find a tranquil route in London and then paste a link. We received 4 links showing some locations in London. In the third, a demo [10] employing the Web Audio library Resonance Audio by Google [11], an office space was simulated where the room width could be changed in a drop-down menu, sound sources and listener position could be moved around and mixed together using a slider. The question asked to "find your favourite combination of room width and sound sources positions".

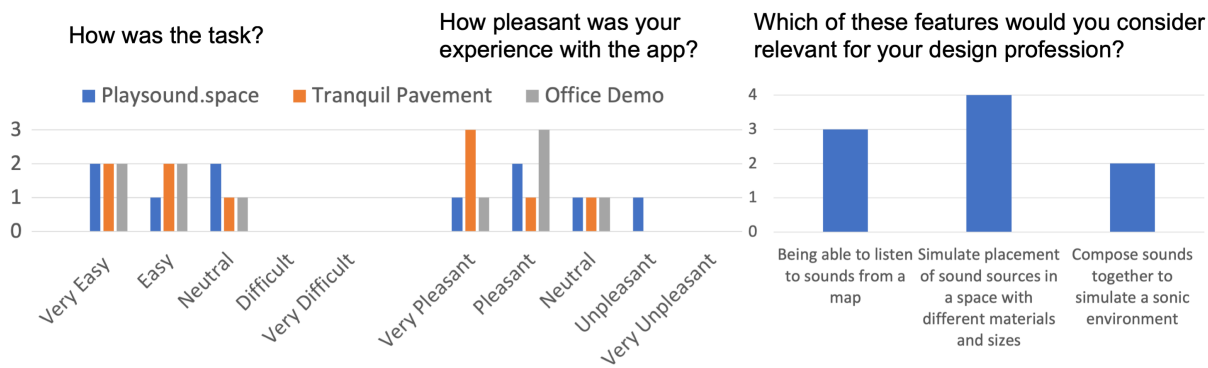

Figure 2. Listening section. Results for N = 5

After every experience, the respondents were asked to input on a 5 points Likert scale how difficult (very difficult to very easy) the tasks were and how pleasant the experience with the app was (very unpleasant to very pleasant). Results show how the most pleasant app to use was Tranquil Pavement and none of the exercises was found difficult (Fig. 2 left). Finally, and before going to the other part of the questionnaire, shared among all the respondents, participants were asked "Which of these features would you consider relevant for your design profession?" with three multiple choice options plus the open input "Other". On the right of Fig. 2 we see how 4 on the 5 respondents considered "Simulate placement of sound sources in a space with different materials and

[8] http://www.playsound.space/sounds=334980,168805,168596,414819,360496,149474
[9] https://tranquilpavement.com/
[10] http://eecs.qmul.ac.uk/~am320/demo/
[11] https://resonance-audio.github.io/resonance-audio/

sizes" the most relevant feature for their profession, followed by "Being able to listen to sounds from a map" (3), and "Compose sounds together to simulate a sonic environment" (2).

3.2 Shared questions: Results

Among the 15 respondents 60% identified as females, 40% as males; 80% aged 25-34, 13.3% aged 35-44, and 6.7% aged 18-24. 46.7% answered the survey from their phone, 40% from their desktop, 13.3% from their laptop. 40% of the respondents declared to listen to music more often at work, 26.7% at home, 26.7% while travelling, 6.7% as background; "at dancing events", "at live music events", "when making or playing music" were not selected. 60% of the participants had more than 5 years of professional experience as architects, 40% between 1 and 5 years; none selected "still studying", since the survey was targeting professionals. In the practice 60% of the respondents held the role of Project team / assistant, 40% of Project lead and 1 (6.7%) used the box "Other" to input "Architect". 80% of the participants worked in practices with more than 50 employees, 20% in practices with less than 10 employees. 86.7% declared that an external agency takes care of the acoustic comfort requirements of the project, while for 13.3% this is managed within their practice. In this last group, only one respondent worked in a 50+ employee practice, showing how relying on external acoustic consultants is the norm in large practices. In their design practice 73.3% uses mostly Autodesk Revit, which is a BIM based software, while 60% uses mostly Microstation, which is a Computer Aided Design (CAD) software. AutoCAD is mostly used by 26.7%, 3Dstudio Max and Rhinoceros3D by 20%, ArchiCAD (also based on BIM) by 6.7%. Unfortunately we did not include SketchUp among the options at this stage, although there was an additional field to add entries. Informal discussions held afterward with few architects suggest that SketchUp is in fact used in the practice but possibly not the one used mostly.

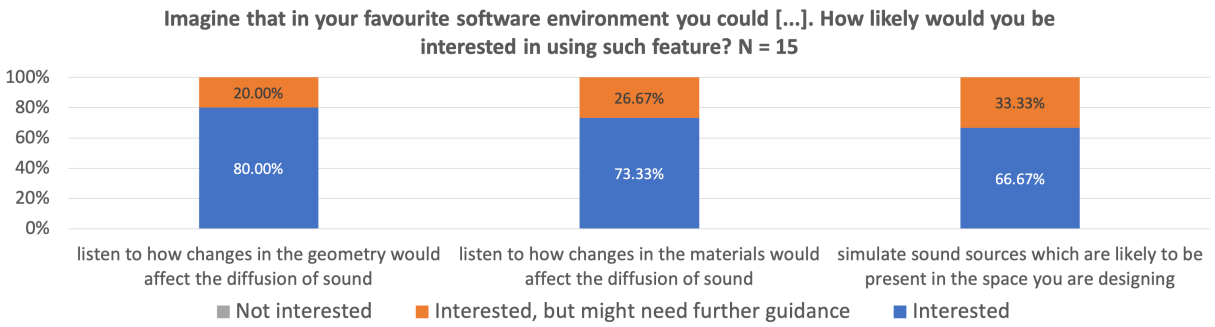

Figure 3. Results for the scenario question (N=15)

The following three questions presented a scenario starting with: "Imagine that in your favourite software environment you could " and then followed by these three cases: (A) "listen to how changes in the geometry would affect the diffusion of sound." ; (B) "listen to how changes in the materials would affect the diffusion of sound. "; (C) "simulate sound sources which are likely to be present in the space you are designing.". After every scenario, the final question was "How likely would you be interested in using such feature?". The answers to this question, presented in Fig, 3 show how all respondents (100% of the 15) were interested in these possibilities, although some think they might need further guidance. This perceived need for guidance is higher for sound sources simulation (33.34%), followed by changes in the materials (26.67%) and changes in the geometry (20%). A generic comment box was made available but no further observations were added. The next question was "In your daily life, in which context do you usually pay attention to acoustics?" with a multiple answer option. The results yielded in order working/productivity (66.7%), followed by conversation/-communication, reading/focused, and walking/travelling (all 60%), relaxation/leisure (53.3%), listening to live music and playing music (46.7%), spiritual/collected (26.7%), healing/restoration (13.3%). Then, it was asked "In your daily life, have you wished you could improve the acoustic comfort of a space?" yielding a 73.3% answering "Often", 13.3% answering "Rarely", 6.7% "Very Frequently", and 6.7% "Never". Until this ques-

If yes, could you provide at least one example of the problem with the acoustic comfort? N=11	If yes, have you ever thought of specific design solutions to mitigate the problem? N=11
Open space offices regarding calls, conversations versus concentration	*Hierarchy, rooms to talk and discuss combinated with open spaces areas*
Lack of sound insulation, lack of attention to create an appropriate environment, urban sound pollution	*More attention to acoustics/sound aspects when designing, new software solutions*
skype conversations at your desk	*move that person to a different room*
People loud	*better insulation*
Too loud sounds	*Better acoustically insulate the environment*
Our home could be better insulated from noise coming from trains outside. Our office is an open space and it often gets distracting when people near you talk.	yes in the first case (adding acoustic insulation to external walls and changing windows) but too expensive.
Reduce reverberation in certain environments, without sacrificing the choice of materials.	Yes, acoustic panels or baffles.
The sounds of people working would echo throughout the space, creating a constant and slightly distracting bustle	I have never really taken a solution into consideration
Converted cinemas as gig venues often frustrate me acoustically.	Material upgrade to the development
Acoustics affecting conversations ie in public areas/cafes/restaurants. Working Environments where noise is a distraction ie open plan offices	Material choice, spatial planning of space
Too noisy	No

Figure 4. Problems and design solutions N=11. In italic the responses of those who answered also the listening section

tion, all the respondents answered the questions proposed. The next three questions wanted to detail in which situations acoustic comfort was found to be problematic, which for one was not the case. The most critical activity was found to be working/productivity with an almost unanimous response of 92.9% on 14 respondents, followed by 71.4% for conversation/communication, 50% reading/focused, 35.7% relaxation/leisure, 28.6% for listening to live music and walking/travelling, 14.3% for playing music, and 7.1% for spiritual collected. The respondents were further invited to provide answers to: "If yes, could you provide at least one example of the problem with the acoustic comfort?" and "If yes, have you ever thought of specific design solutions to mitigate the problem?". 11 respondents answered as shown in Fig. 4 with recurrent problems such as conversations at work, worsened by open spaces (4 mentions) causing distraction and having impact on concentration, loudness (2), lack of appropriate insulation (2). Single mentions reported acoustic frustration from converted cinemas, reduce reverberation, acoustics affecting conversations, "too noisy". The suggested recurrent solutions included insulation (3), materials (2), spatial planning (2), with single mentions of: more attention to acoustics/sound when designing; new software solutions; acoustic panels or baffles.

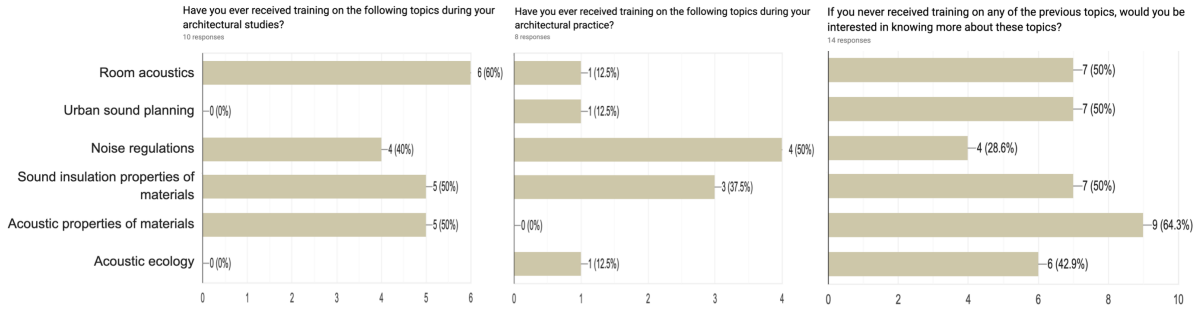

Figure 5. Training during architectural studies (left), architectural practice (middle), and interest (right)

The next two questions asked whether the participants received training on certain topics during their architectural studies and practice, providing multiple choices options. The results highlight first that not everyone answered, suggesting that for some these topics were never treated. During the architectural studies of 10 respondents, 60% received training on room acoustics, 50% on sound insulation properties of materials, 50% on acoustic properties of materials, 40% on noise regulations, none on urban sound planning nor acoustic ecology (Fig. 5 left). During their architectural practice, out of 8 respondents (Fig. 5 middle), 50% received training on noise regulations, 37.5% on sound insulation properties of materials, 12.5% on room acoustics, urban sound planning, and acoustic ecology, none on acoustic properties of materials. Finally, when asked "If you never received training on any of the previous topics, would you be interested in knowing more about these topics?", out of 14, 64.3% selected acoustic properties of materials, 50% room acoustics, urban sound planning, sound

insulation properties of materials, 42.9% acoustic ecology, 28.6% noise regulations (Fig. 5 right).

Finally, we investigated the participants' experience with immersive media platforms, since they can be used to render sonic scenes in a compelling way. Out of 15 respondents, 60% never tried augmented reality applications, 26.7% used these outside work, 13.3% used them at work, with content made by others. 33.3% never used virtual reality applications, 33.3% used them at work, with content made by others, 26.7% used them outside work, 6.7% (1 person), used them with self-made content.

4 DISCUSSION AND FUTURE WORK

We are aware that the sample is small and we should extend the inquiry forwarded to a larger number of practice, if we aim to generalise the scenario depicted. From the small sample presented here, it emerged how large studios rely mainly on external consultants to take care of the acoustic requirements of the project. This suggests that it is not up to the architect to deal with acoustic requirements in the practice. However, from the interviews we recently conducted, it seems that the acoustic consultant provides the requirements and the architect designs accordingly, in a responsibility model which we can assume to be shared. The results obtained in this study show that the idea of integrating into typical design tools the possibility of listening to how spaces propagate sound is generally welcomed. Either in the listening section and in the rest of the survey, changes in the geometry of the spaces and the materials appear more relevant to the architect than the positioning of the sound sources. In fact, the design and analysis of potential sound sources in spaces often takes a back seat in the architectural project, with a deeper focus on the response of the space to sound than on sound sources themselves. We believe that if we want to improve the acoustic comfort of spaces this sonic imagination should be further researched. From a broad educational point of view, our suggestion is to strengthen the presence of disciplines related to acoustic design in architecture schools. Upon the results obtained, these could include and combine: (i) the study of simulation techniques, requiring some understanding of physics and the application of problem modelling and solving skills to practical architectural examples; (ii) the study of the social and cultural dimension of the soundscape, supported by on site measuring and surveying practices which could also help inform students on noise regulation policies and mediation strategies. From a purely technical point of view (or listening), we note that the platforms reviewed in 2 seem to not fully exploit the potential offered by the BIM system. This system, which includes all the essential information to communicate the project in a single model, allows the insertion of materials and technical solutions with precise acoustic information previously measured, necessary for a good simulation. On the other hand, the integration of RAVEN with SketchUP makes it a tool suitable to teach how sound propagates in different geometries with acoustically different materials. EVERTims, modular and open-source, may flourish at best projects employing immersive media technologies. Project acoustics is a large step towards the possibility to export models with high level of detail, including exteriors, filter spaces, corridors, as geometries with many different acoustic properties, encouraging to study and have audible experience of places previously considered not important enough to require a simulation. We hope for it to better integrate with software packages currently used in design practices, first of all REVIT, whose functionalities are already extended with plugins that can be written in C#. Among these, DYNAMO [12] employs visual programming and allows to connect through generative algorithms series of operations on the elements of the model, therefore offering valuable design potential to explore acoustic properties of spaces. To our knowledge, not many publications cover the response from architecture students to the auralization platforms described in 2. Future research should therefore look on the one hand at integrating auralisation platforms into widely adopted BIM packages such as REVIT, without diminishing the importance of specialized figures such as acoustic consultants. On the other hand, it should look at the use of non-commercial products within educational contexts and at their value as tools for acoustic exploration and design, as the idea of listening to the effects of design choices seems to be welcome by the architecture professionals we surveyed.

[12] https://dynamobim.org/

5 CONCLUSIONS

The work shows a first step towards engaging architects in a positive dialogue on acoustic design practices through future software products which may leverage their creativity and help them imagining how future spaces may sound like, supporting their collaborative design partnership with acoustic consultants. It was also noticed a possibly uneven breadth of training on acoustic design topics and the desire to know more. As two thirds of the respondents often wished to improve the acoustic comfort of spaces, there seems worthwhile to strengthen education in architectural acoustics and soundscape surveying practices among architecture schools.

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