Parametric implementation of café acoustics

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ABSTRACT

This paper investigates how acoustic principles can be implemented within the architectural early design phase. The project work presented tested one parametric tool, Pachyderm, in a proof of concept, design of a café. Acoustic measurements were undertaken in six cafes and 30 café patrons completed a qualitative survey. In all cases measured ambient levels within the cafes exceeded the 50dBA L_{Aeq} criterion level suggested in the AS/NZS 2107 (2000). IRIS plots for each space showed a preponderance of late energy reflections (above 50 ms in most cases, with returns above 100 ms). Survey results suggested that the patron's ability to communicate decreased linearly as the café volume increased. In contrast, the patron's enjoyment of the café increased to a maximum then decreased quadratically as the volume increased. These qualitative and quantitative results formed acoustic design criteria that were implement into the design through a combination of Grasshopper and Pachyderm software.

1. INTRODUCTION

This research was undertaken following a pilot study that sought to qualitatively investigate the contention that inefficiencies within the architect and acoustician relationship lead to increased remedial action. The pilot study involved a survey of 51 employees of one acoustics firm. The results suggested that delays in engagement of acoustical expertise in the design process correlated with an increase in post-construction, remedial action being required for several building types (Wright et al., 2016).

The survey results also suggested that at least for the firm represented in the survey, New Zealand acousticians tended to be introduced later into building projects than seemed to be the case for acousticians with similar project types overseas. The exception to this was with office buildings in New Zealand where the indications were that the acoustical expertise was engaged earlier. The acousticians surveyed, reported significantly less remedial work in this area. In contrast building types were acousticians were typically introduced later in the design process tended to be associated with higher amounts of remedial work.

These implications were further explored through the design of a café, using acoustical simulation where possible to inform decisions in a concept informed by ideas presented in Schmidt and Kirkegaard, 2005.

To fulfil the architectural scale requirement of the project brief, this design was not restricted to the envelope of an existing structure. Instead, the design was proposed on an empty site with the context of the surrounding buildings. Through this design investigation the prospects and limitations of one parametric tool were assessed for its ability to incorporate acoustic design into early architectural design. Parametric design claims to be able to extract and optimise parameters to inform changes in the geometry (Schumacher, 2008). This project addressed the parametric design aspect through use of the Rhino/Grasshopper 3D modelling tool together with an acoustic simulation tool, Pachyderm.

2. DATA ACQUISITION PHASE

To assess Pachyderm's ability to simulate "real acoustics", acoustical measurements were undertaken in six cafes to provide the parametric baseline and assist in formulating acoustic design goals. In each of the six cafés t both qualitative acoustic measurements and quantitative patron survey analyses were undertaken.

2.1 Acoustic Measurements

Ambient Sound Pressure levels (L_{Aeq}) in the unoccupied spaces, unoccupied Reverberation Time (T20), Early Decay Time (EDT), Speech Transmission Index (STI) and Clarity (C50) were measured and analysed for each of the six cafes.

Figure 1 shows that each of the cafes tested had a higher ambient levels than the recommended given in in AS/NZS 2107 (2000). It is noted, AS/NZS 2107 (2000) sets a recommended L_{Aeq} of 45dBA for cafes and a maximum of 50dBA. Café 1 and 5 were more than 20dBA above this maximum.

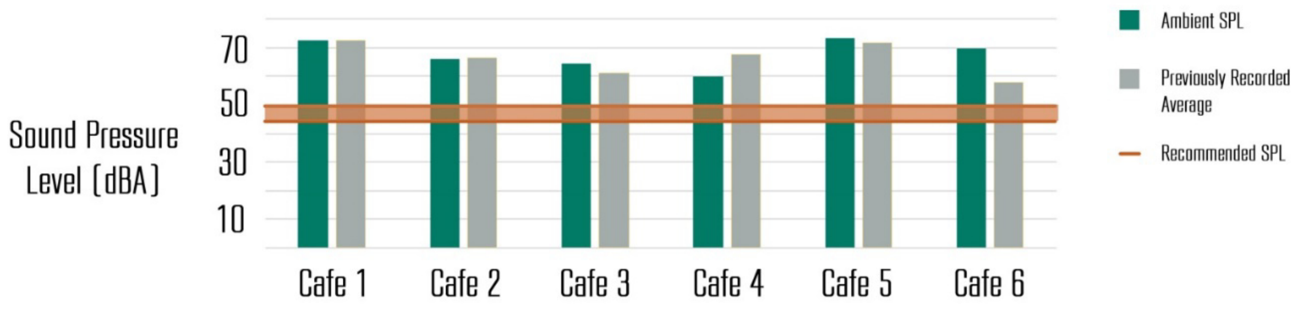

Figure 1 Comparison of SPL in the six cafes tested

T20 results showed a range of 0.35 seconds between the cafes (Fig. 2). Café 6 was the shortest result with 0.45 seconds, while the longest T20 was café 5 at 0.8 seconds. All T20s were within the recommended maximum RT of 1 second set by AS/NZS 2107 (2000). However, decreasing the RT was identified by Whitlock and Dodd as an effective approach for maintaining a high Speech Intelligibility and that café 5's longer T20 could be a contributing factor to its higher ambient levels (Whitlock and Dodd, 2006).

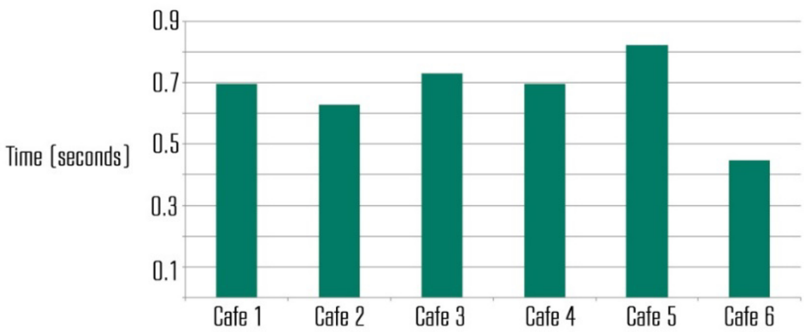

Figure 2 Comparison of T20 times for the six cafes tested

Another tool used to measure and analyse these cafes was IRIS. IRIS is a modern sound energy analysis program that measures a sweep produced by a speaker in an unoccupied room to form a three dimensional visual plot of the reflections received by the microphone (Protheroe, 2015). The plot shows the reflection direction, magnitude (ray length), and time received after the direct sound (ray colour). Through analysis of these plots within the café context, architecture's influence on the acoustics for each café can be established (Figure. 3).

As may be seen, the IRIS plots recorded in the cafes show significant similarities. Most are dominated by blue and light blue rays, representing late energy reflections (returns greater than 50 and 100 milliseconds for blue and light blue, respectively). Late acoustic returns are important as they decrease clarity, slurring articulated words and thus lowering the speech intelligibility (Bradley, 2002). In contrast to the other cafes, Café Six shows the largest number of green rays, suggesting a more directional room response.

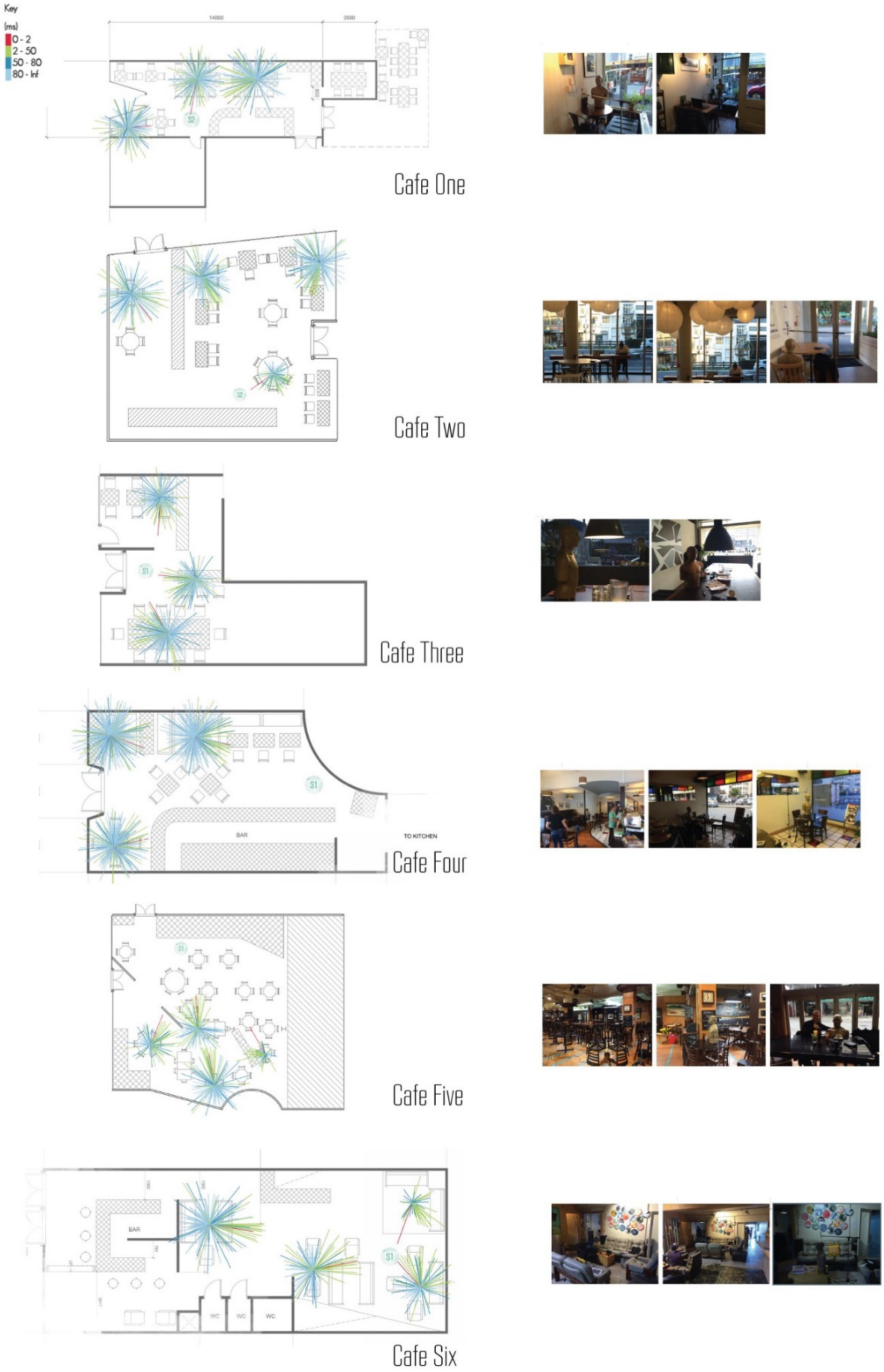

Figure 3 IRIS plot results of tested cafés with images of café interior

2.2 Survey Results

To accompany these quantitative measurements, 30 patrons from the six cafés were surveyed. A short survey was created to explore how acoustics affected their experience of the space. The results provided context to the measured acoustical data, informing a set of design criteria for acoustic influence on patron experience.

Figure 4 shows that the subjective ability of the patron to communicate decreased linearly as the experienced volume increased. The black circles on Figure 4 indicate the individual patron’s response. The frequency of a response is indicated by the circle size. “Holistic communication” is a measurement formed from three questions that tested the patron’s perceived ability to hear other, hear themselves and be heard by others.

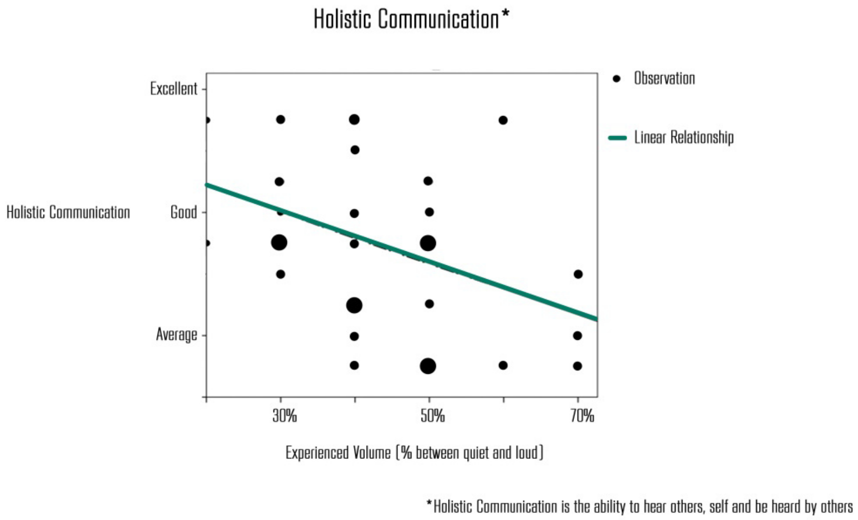

Figure 4 linear regression of the relationship between the ability to communicate and the café volume

Overall patron enjoyment increased and then decreased quadratically as the volume increased (Figure 5). This result suggests that there is a peak enjoyment sound level, before which patrons are not as completely satisfied, despite an easy of communication. Afterward the enjoyment maximum enjoyment levels decreased, potentially due to the decrease in holistic communication.

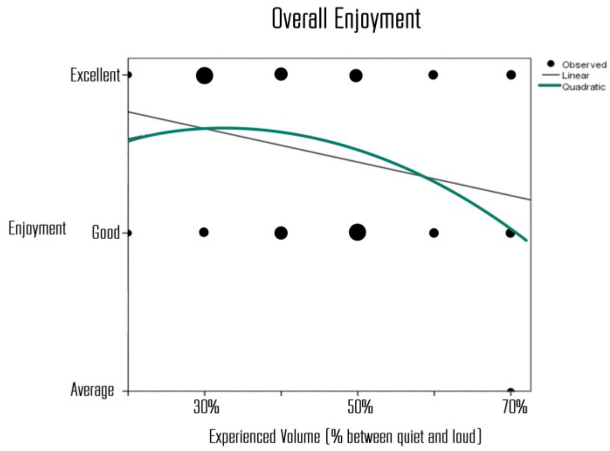

Figure 5 Quadratic regression of the relationship between Patron Enjoyment and the café volume

3. CONCEPT PHASE

Pachyderm, a ray tracing and image source plug in for Rhinoceros/ Grasshopper, simulated acoustic readings within a room. Ray Tracing and Image Source methods are two methods for simulating the reflection of energy within a digital model. Galapagos, an evolutionary solver in Grasshopper produced multiple design iterations by optimising the acoustic parameter to match a specified goal, or “fitness” (Harten, 2015).

A fitness of a 0.6 second T30 was selected as 0.6 seconds was the lower limit of the range suggested by AS/NZS 2107 (2000) and was comparable to results measured in the “acoustically better” cafes. An algorithm was written to allow Galapagos to alter the eight vertices of a box to find different forms that produce the targeted fitness of a 0.6 second T30 (Figure 6).

The seven iterations shown in Figure 7 each have a simulated T30 of 0.6 seconds, yet different architectural outcomes. (As noted, the model was not designed within an envelope of another building, instead the design was proposed on an empty site with the context of the surrounding buildings). Geometric constraints were created for the physical extents of the corner points to represent the neighbouring buildings. As the cafes tested had largely timber interiors the surfaces were modelled with absorption and scattering properties typical of such construction.

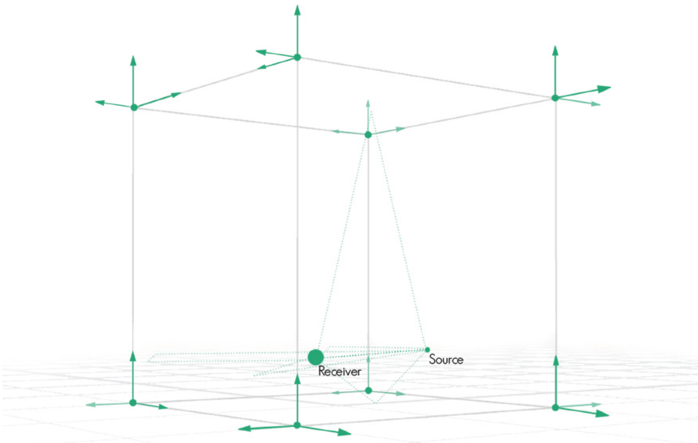

Figure 6 Diagram showing Galapagos’ ability to alter each corner in three dimensions to produce a fitness

Figure 7 Iterations of designs with simulated T20 of 0.6 seconds

4. VALIDATION PHASE

The concept phase of this project suggested that Pachyderm can iterate architectural forms with the same simulated T20 suggesting that acoustics can be included as an effective architectural driver. However, for this result to be useful and support the hypothesis, i.e “that early acoustic intervention helps” the simulated measurement must be reliable.

To validate Pachyderm, Café 5 was modelled in Rhino and its T30 was simulated using in Pachyderm. The simulated T30 result at 1000Hz of 0.85 seconds was compared to the original T20 reading of 0.87 seconds recorded on site. Pachyderm simulated results within 0.02 seconds of the measured result, suggesting that the acoustic qualities of the newly-generated building geometry can be predicted with some confidence.

5. SUMMARY AND CONCLUSIONS

All cafes included in this project recorded ambient sound levels over the 50dBA L_{Aeq} design sound level suggested in the AS/NZS 2107 (2000). IRIS plots within the cafes showed predominantly late energy reflections, as would be expected of these typically live and reverberant spaces. T20 results showed a range of 0.35 seconds between the cafes, but all six cafes were within the recommendations set by AS/NZS 2107 (2000). Survey results suggested that the patron's ability to communicate decreased linearly as the café volume increased. In contrast, the patron's enjoyment of the café increased to a maximum then decreased quadratically as volume increased. The above qualitative and quantitative results formed acoustic design criteria that were implemented in a Café design through a combination of Grasshopper and Pachyderm software. A T30 of 0.6 seconds was selected as the acoustic goal for the generation of the design shell. Multiple solutions were designed within the geometric restraints that achieved a simulated T30 of 0.6 seconds. One cafe was digitally modelled within Grasshopper as a validation study. The simulated T30 was compared to the measured data with good agreement.

In conclusion, the ability to develop architectural form from given acoustic performances suggests the potential importance of parametric software like Pachyderm, however it is recommended that further study be completed to understand the limitations to the software and the parametric design concepts considered.

6. FUTURE PLANS

The continuation of this research project will explore Pachyderm's limitations through a comparison of different levels of model detail and the acoustic results they simulate. It is hypothesised that ray tracing software has the potential to produce misleading information if the model is created in fine detail, as important details of the building geometry can be missed by the finite number of rays. Further research will investigate the level of detail required to provide guidance in the use of these concepts in further projects. The project will continue to explore Pachyderm's ability to simulate different acoustical measurements, such as STI. Lastly it is intended that the project will investigate means by which Pachyderm (and parametric design tools more generally) can be made more user friendly and accessible for architects.

ACKNOWLEDGEMENTS

The project reported here was undertaken in partial fulfilment of a Master of Architecture. The author is grateful for discussions and guidance from Natasha Perkins, Michael Donn and Christina Mackay - supervisors at the Victoria University of Wellington School of Architecture and Design. This project would not have been possible without the continuing support of Miklin Halstead and the team at Marshall Day Acoustics.

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