Acoustics 2019
Sound Decisions: Moving forward with Acoustics

Improving Shape Design of Auditoriums with Real-Time Feedback Based on Parametric Modelling, Simulation and Machine Learning

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ABSTRACT

Auditoriums require both acoustic performance and aesthetic values, while the efficiency of current design process should be improved for architects to better realize these two goals. In this paper, a new design process of auditoriums integrating parametric modelling, acoustic simulation and Support Vector Machine is proposed, implemented and verified to provide architects with real-time architectural and acoustic feedback in the early design stage. This paper contains three parts: 1) a parametric model of auditoriums that can generate various auditorium designs automatically; 2) an interface connecting modelling and acoustic simulation software, which facilitate architects' acoustic evaluations on auditorium designs; 3) an acoustic aiding tool that provides architects with suggestions on design revision. The results indicate that the new design process and relevant design tools can provide reliable outcomes within 1 min in most cases. Moreover, it enables architects to revise an acoustically unacceptable shape into a desirable one independently. Thus architects' efforts in attempting infeasible design ideas could be largely saved, and desirable designs are more likely to be achieved.

1 INTRODUCTION

An auditorium is a container of performing arts, and also serves as a landmark of a city or even state, therefore, an auditorium should not only provide a perfect acoustic environment for performances, but also express the aesthetic value by its form and space. In practice, however, to acquire both these two virtues in the same time is not easy. The difficulties of auditorium design include: 1) Architects need a lot of time and efforts to achieve or modify designs. 2) The design by architects needs to be tested by acousticians and the feedback loop causes delays and discontinuity. 3) Architects and acousticians have divergent ways of thinking and judgments. These factors could affect the efficiency and thinking continuity of architects, which reduce the possibility of novel and acoustically appreciated designs to occur.

The objective of this research includes: 1) To raise and implement a new computer-aided interactive design process of auditoriums in the schematic stage with the help of computers. 2) To provide architects with real-time architectural and acoustic feedback to improve work efficiency and design quality. 3) To enable architects be more concentrated on the creative part of design, and let acousticians be released from testing different designs and can focus on pre-selected ones.

2 ARCHITECTURAL FEEDBACK

The architectural feedback is provided by a parametric model of auditoriums. The idea of parametric modelling is to model buildings by defining essential rules instead of actual geometries. It can automatically provide a family of designs that meet requirements quickly.

Here the parametric model is built by the "Component Based" Method, which is a method that includes different types of building components (walls, doors, stage, etc.) and their inter-connections.

A parametric model of shoe-box concert halls is implemented based on Rhinoceros, a 3D modelling software (Fugier, 2018), with its Python Editor. The result shows that a large variety of designs can be generated. Any concert hall with vertical walls and no curvy components can be generated (Figure 1). Meanwhile, Architects' ideas can be turned into designs simply by drawing drafts or modifying components. Every component can be modified directly, in accordance with architects' design customs. Therefore, this parametric model is effective and could be used in design practice.

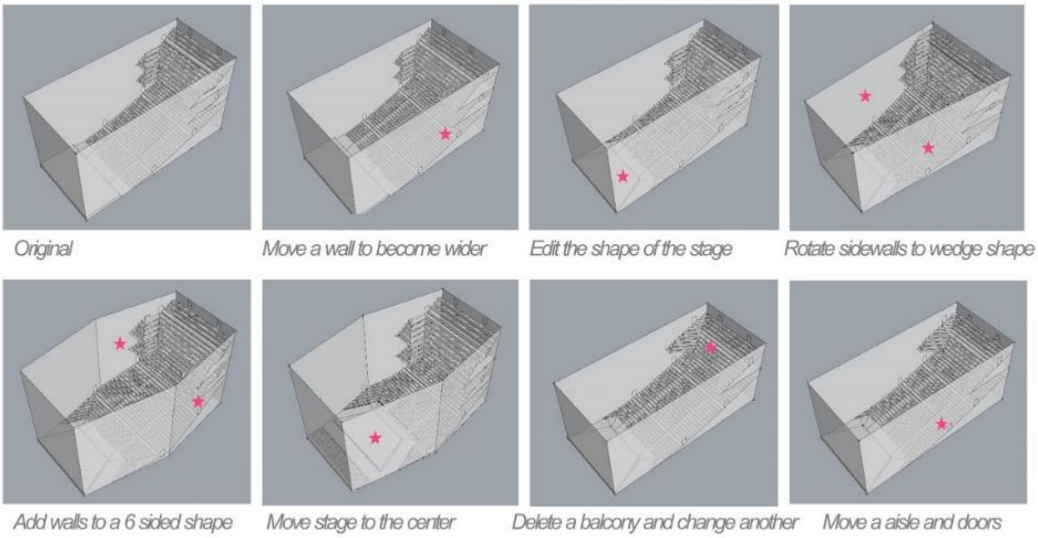

Figure 1: Designs generated by the parametric model (star indicates changed component)

3 ACOUSTIC EVALUATION

The method to implement acoustic evaluation is to build an interface bridging Rhino, the 3D modeler (Fugier, 2018), and CATT, the room acoustic simulation software (Dalenbäck, 2012), in order to improve architects' utilization of acoustic simulation in the input, manipulation and output.

For the input of simulation, this interface can collect information automatically. It can convert all geometries of Rhino into a .txt file following CATT rules. It automatically selects 2 sources on the stage, and 1 receiver in every 6 rows and 12 columns all over the audience area (Figure 2). It provides two possibilities to choose material, the 1st one is to choose from a material list for each kind of components; the 2nd is to use the materials of an existing successful auditorium (Figure 3).

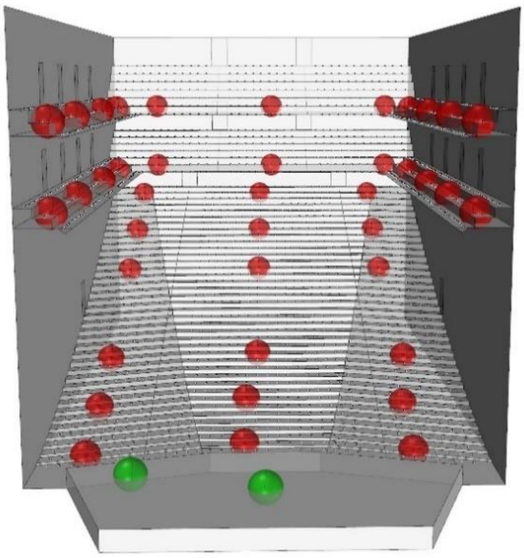

Figure 2: Distribution of the sources (green) and receivers (red)

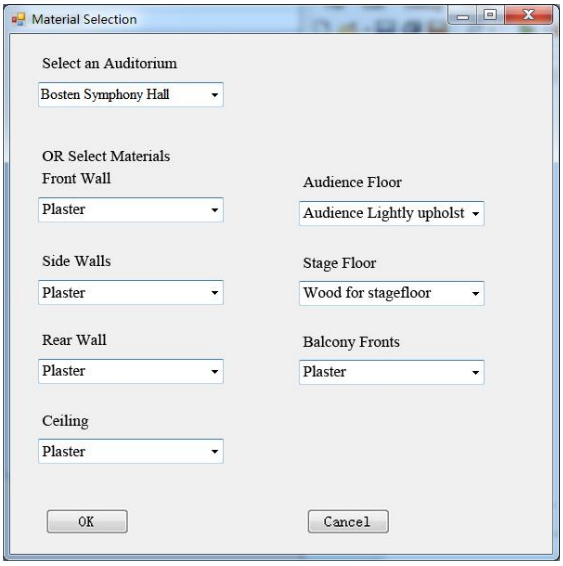

Figure 3: User interface to input material information (select materials for each kind of components or select an auditorium)

For manipulation, the interface automates and standardizes the process of simulation. It automatically manipulates CATT in the background using scripting. 2 simulations are conducted for one design with different sources. Simulation parameters are fixed as recommended by the CATT manual for a quick test (10000rays, 2000ms echogram).

For output, the interface simplifies and visualizes the results. For concert halls, Reverberation time (RT), Early Decay Time (EDT), Binaural Quality Index (BQI), Strength Factor (G), Initial-Time-Delay Gap (ITDG), and Clarity (C80) are selected as the acoustic indices according to the recommendations of (Beranek 2004). Lateral Fraction (LF) is not used for its relevance to BQI, while Bass Ratio (BR) and Surface Diffusivity Index (SDI) are not used because they are mainly determined by material design and not closely related to shape design. The recommended ranges of the indices are also from (Beranek, 2014). The results are visualized by two graphs, a radar chart and a distribution map. The radar chart shows the mean value, standard deviation, and the acoustically "worst point" of the design. And the distribution map shows the acoustic qualities of different receivers, and the position of the worst point (Figure 4).

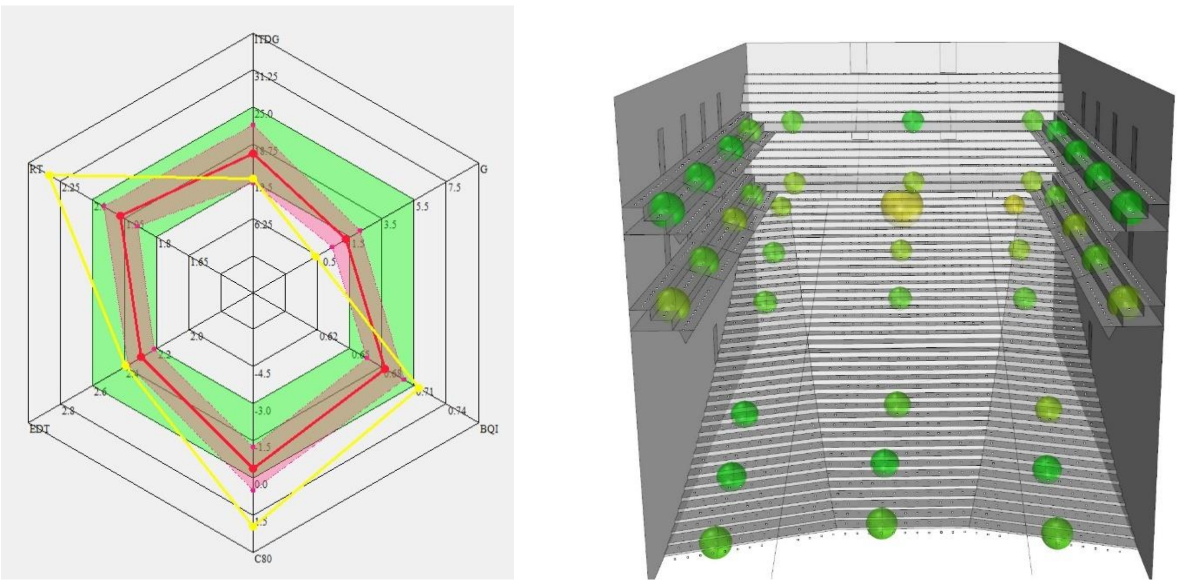

Figure 4: The radar chart and the distribution map that show architects the simulation results

4 ACOUSTIC FEEDBACK

The goal of the acoustic feedback part is to provide design suggestions based on acoustics, which specifically includes: 1) quick prediction of current design; 2) performance potential of shape (when materials have not been decided yet); 3) modification suggestion, including performance variation trend, similar designs with better performance, local optimization; 4) acceptable range analysis.

The methodology is shown in Figure 5. First all information in a design problem (including formal, environmental, materials, construction, etc.) needs to be converted into a set of parameters. It needs to be ensured that all main characteristics of possible designs are covered in the set of parameters. At the same time, evaluation indices of performance need to be selected. The second step is to obtain a sufficient number of designs and their performance information as the samples, while the designs and their performance need to be described by parameters and indices chosen in Step 1. The third step is to use regression splines algorithm (Multivariate Adaptive Regression Splines, an effective method to build nonlinear statistical methods for a set of variables by dividing them into segments and connecting them using smooth splines) to build statistical model using these samples (Friedman, 1991; Hastie, 2004). The fourth step is to achieve the basic functions of the system: to use statistical models to do single prediction, which is to predict the performance quality of a certain design. The fifth step is to realize other functions based on single prediction, including evaluation of the performance potential of a form, modification suggestion based on the current design, analysis of feasible range, etc.

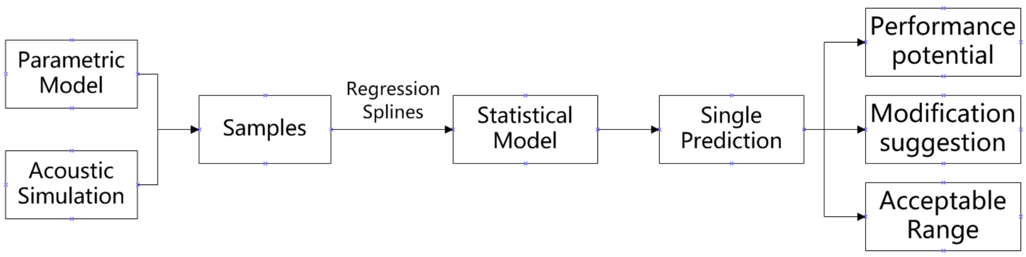

Figure 5: Methodology of the acoustic feedback part

A performance aiding system of shoebox concert halls is developed following the methodology described above as an implementation example. The parametric model used here is a shoe-box concert hall with 7 variables (4 form parameters: width, height, length, area of balconies; 3 material parameters: side wall, back wall, ceiling. Stage house and audience are usually similar thus are not chosen as variables). The acoustic indices used here are RT, G, LF, C80 (only 500Hz included, others can be adjusted by materials). 1000 samples are generated automatically (800 for regression and another 200 for testing). The regression is implemented by the CRS package of R software (Racine, 2014). The statistical indices of the regression models are good and acceptable to do prediction (Table 1).

Table 1: Statistical indices of the regression models

Acoustic Indices	R^2	Standard Deviation
RT	0.9653	0.068
G	0.9844	0.1485
LF	0.8333	1.936
C80	0.9778	0.1791

The functions of the acoustic feedback system include:

1) Single prediction, which is to predict the performance indices of the current design very quickly. In this case architects only need to enter all design parameters correspondingly in the blanks of the first column and then click "Prediction" button, thus they can get the performance indices of current designs in real-time. For easy understanding, prediction results are shown in radar chart, where red dots correspond to the prediction results of different indices, while green area corresponds to the recommended ranges of the indices, and thus

architects can intuitively understand whether their current design has an acceptable performance quality (as in Figure 6, where C80 is beyond the green area and suggests architects to revise the design).

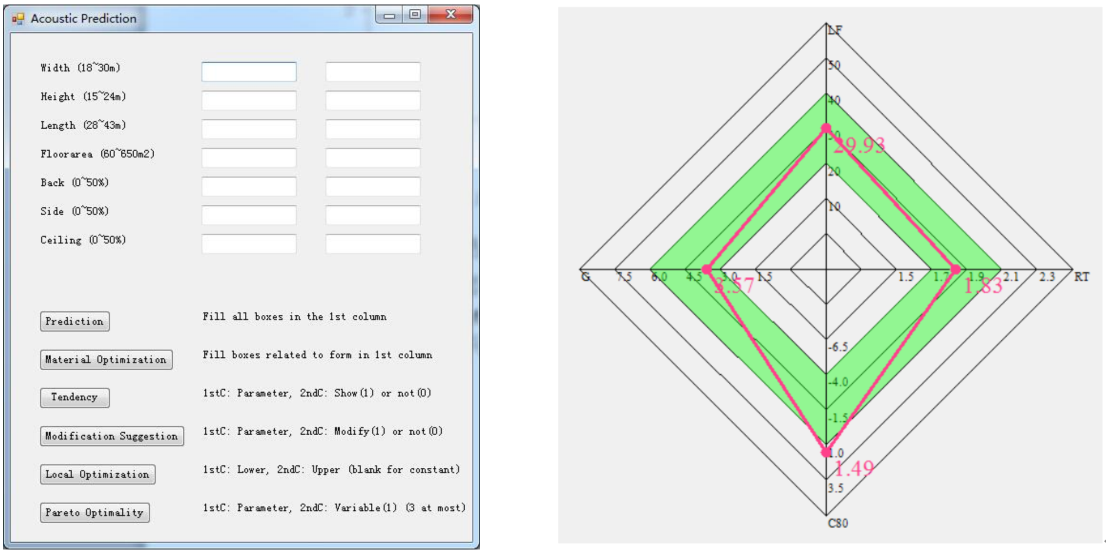

Figure 6: The input of a single prediction and the visualization result

2) Material optimization, which is to find the most appropriate configurations of materials for the current design by trying all possible configurations. And then the software calculates the optimum performance indices as the performance potential of the shape of the current design. In this case architect need to input all parameters regarding forms (i.e. width, height, length, area of balcony, not including the absorption coefficients) correspondingly in the blanks of the first column and then click " Material Optimization " button. After that the software will show most appropriate configurations of materials, as well as the performance potential of current.

3) Variation trend analysis of performance, which is to show the variation trend of performance indices with design parameters, so that architects can get advices on how to modify the design to pursue better performance. To use this function, architects need to input all parameters of current designs correspondingly to the blanks of the first column and input “1” to corresponding blanks of the second column to choose design parameters for analysis. After a click on the "Tendency" button, visualized results will be displayed: different design parameters are represented by curves of different colors, the y-axis represents a certain performance index, while the x-axis represents the variation ratio of design parameters. The red dot represents the current design, while the green area indicates the acceptable range of performance index.

4) Modification suggestions, which is to provide similar designs with better performance for architects as a reference by comparing all similar designs of the current design. To use this function, architects need to input all parameters of current designs correspondingly to the blanks of the first column and input “1” to corresponding blanks of the second column to choose design parameters that can be changed (other design parameters will stay as the current design). After a click on the “Modification Suggestion" button, a list of similar designs that have better performance will be shown. The more similar to the current design, the upper position the suggested design will be.

5) Optimal design in a local range, which is to search the design with the best performance within a range of design parameters given by architects. In this case, architects need to input the lower limits and upper limit of design parameters to be optimized in the first and second blanks of corresponding rows, and also input the values of fixed design parameters in the first blanks of corresponding rows. After a click on the “Local Optimization” button, the software will provide architects with the design with the best performance within the given range, and also the performance indices of the optimal design.

6) Analysis of feasible range, which is to provide architects with the feasible ranges of one or more design parameters in advance from an acoustic performance point of view. In this case, architects need to input all

design parameters in the corresponding blanks of the first column and input “1” in the corresponding blanks of the second column to indicate which design parameter(s) to analyze. After a click on the “Pareto Optimality” button, the software will provide architects with the feasible ranges. Specific visualization form differs with different numbers of analyzing parameters. Due to the limitation of visualization methods, only one, two or three parameters can be analyzed at the same time currently.

5 CONCLUSION

In this research, a basic framework of architectural and acoustic feedback has been implemented and proved as feasible. Real-time architectural and acoustic feedback can be provided by the currently developed tools.

Possible future work of this research includes: 1) More design possibilities should be covered in the parametric models as well as in acoustic feedback tools (curvy components, vineyard, etc.). 2) More acoustic criteria should be included (more acoustic parameters, impulse response, etc.). 3) Scattering should also be considered (now only the absorption is considered). 4) Verifications of the actual effectiveness in design practice are needed.

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