Improving Auditorium Schematic Designs with Real-Time Architectural and Acoustic Feedback

Lu Shuai[1, 2]

[1] *Institut für Technische Akustik, RWTH Aachen University, E-Mail: shuai.lu@akustik.rwth-aachen.de*
[2] *School of Architecture, Tsinghua University, E-Mail: lyushuai@sina.com*

Introduction

A new design process of auditoriums containing 3 parts is proposed and implemented here, aiming to provide architects with real-time architectural and acoustic feedback in schematic design stage.

1) A parametric model of auditorium in Rhinoceros, which can generate various auditorium designs automatically (architectural feedback);

2) An interface connecting Rhinoceros and CATT, which supplements the input, manipulation and output of CATT to facilitate architects' utilization (acoustic evaluations);

3) an acoustic aiding tool based on regression splines, which can provide quick acoustic tests, acoustic potential of forms, and suggestions for design modifications (acoustic feedback).

Difficulties of Auditorium Design

1) Architects need a lot of time and efforts to achieve or modify designs

2) Any design by architects needs to be tested by acousticians and the feedback loop causes delay and discontinuity

3) Architects and acousticians have divergent ways of thinking and judgments.

These factors could affect the efficiency and thinking continuity of architects and reduce the possibility of novel and acoustically appreciated designs to occur.

Objective of this research

To raise and implement a new interactive design process of auditorium in the schematic stage with the help of computer.

To provide architects with real-time architectural and acoustic feedback to improve work efficiency and design quality.

To let 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.

Architectural Feedback

The architectural feedback is provided by a parametric model of auditoriums. The idea of parametric model 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 "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 hall is implemented based on Rhinoceros (V.5 SR11) with 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, accordant with architects' design customs. Therefore, this parametric model is effective and could be used in design practice.

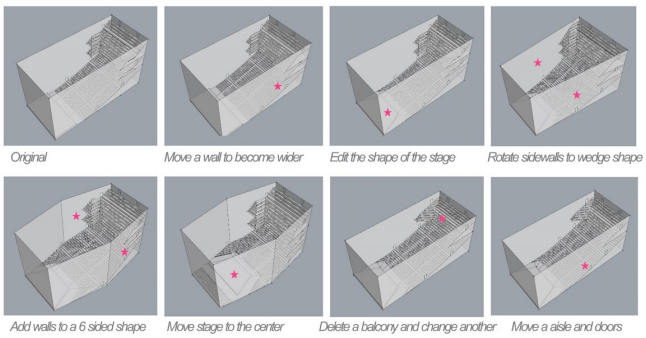

Figure 1: Designs that can be generated by the parametric model (star indicates changed component)

Acoustic Evaluation

The method to implement acoustic evaluation is to build an interface bridging Rhino and CATT, which improves architects' utilization of acoustic simulation in the input, manipulation and output.

For input of simulation, this interface can facilitate information collection 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).

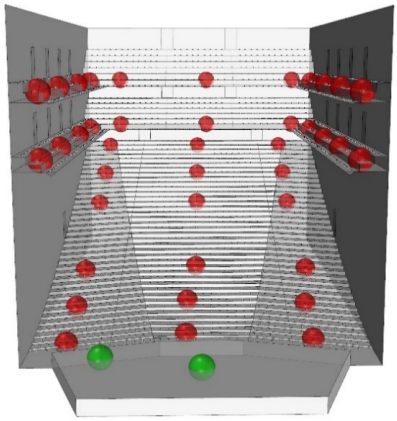

Figure 2: Distribution of the sources (green) and receivers (red)

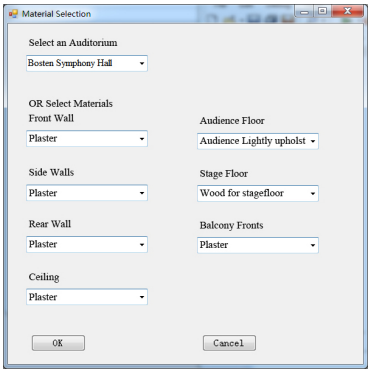

Figure 3: User interface to input material information (select materials for each kind of components or select an auditorium)

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

For output, the interface simplify and visualize the results. For concert halls, RT, EDT, BQI, G, ITDG, C80 are selected as acoustic indices according to the recommendations of Leo Beranek's research (LF is not used for its relevance to BQI. BR and SDI are not used for their not relating to form design but material design). The recommended ranges of the indices are also from Leo Beranek's research. 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).

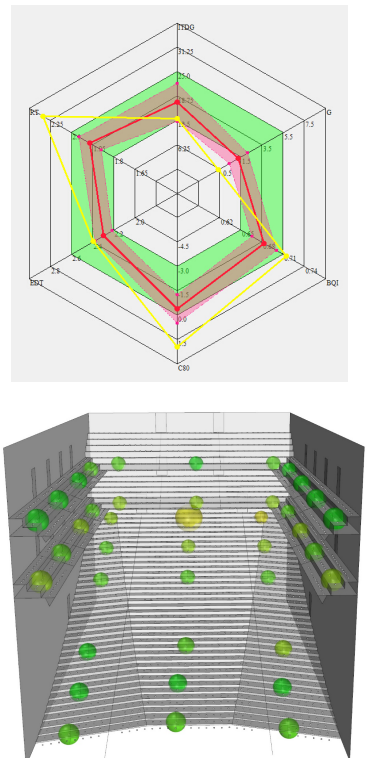

Figure 4: The radar chart and the distribution map that show architects the simulation results

Acoustic Feedback

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

The methodology is shown in Figure 5. First all information in a design problems (including formal, environmental, materials, construction, etc.) need 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 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 then into segments and connecting them using smooth splines) to build statistical model using these samples. 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.

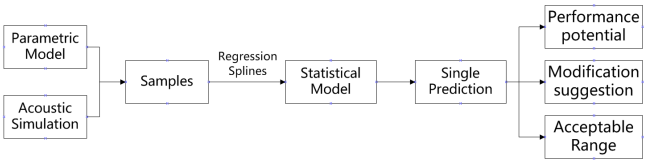

Figure 5: Methodology of the acoustic feedback part

A performance aiding system of shoebox concert hall 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 balcony; 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. The statistical indices of the regression models are good and acceptable to do prediction (Figure 6).

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

Figure 6: Methodology of the acoustic feedback part

The functions of the acoustic feedback system includes:

1) Single prediction, which is to predict the performance indices of current design very quickly. In this case architects only need to enter all design parameters correspondingly in the blanks of 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 is shown in radar chart, where red dots corresponds to prediction results of different indices, while green area corresponds to recommended ranges of indices, thus architects can intuitively understand whether their current design has acceptable performance quality (as in Figure 7, where C80 beyonds the green area and suggests architects to revise the design).

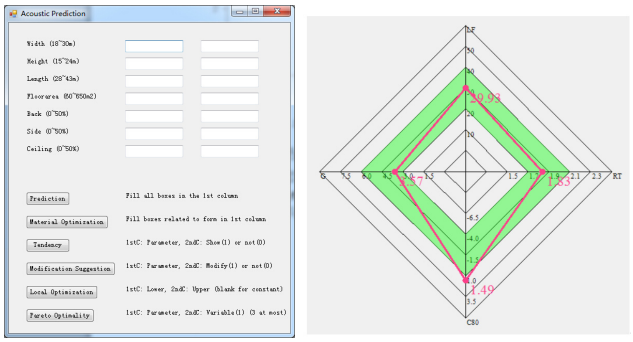

Figure 7: The input of single prediction and the visualization result

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 form of current design. In this case architect need to input all parameters regarding form (i.e. width, height, length, area of balcony, not including the absorption coefficients) correspondingly in the blanks of 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 tendency analysis of performance, which is to show the variation tendency of performance indices with design parameters, so that architects can get advises about how to modify 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. 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 performance point of view, and this is also called Pareto Optimization. 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 number of analyzed parameters. Due to the limitation of visualization methods, only one, two or three parameters can be analyzed in the same time currently.

Conclusions and Future Work

Conclusions

In this research, the 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.

Future Work

More design possibilities should be covered in the parametric models as well as in acoustic feedback tools (curvy components, vineyard, etc.).

More acoustic criterion should be included (more acoustic parameters, impulse response, etc.).

Scattering should also be considered (now only the absorption is considered).

Verifications of the actual effectiveness in design practice are needed.

References

[1] Beranek L.: Concert Halls and Opera Houses. Springer, New York, 2004.

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