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Parametric Propagation of Acoustical Absorbers

:abstract

The following paper deals with a performance-driven morphogenetic design task to improve the conditions of room acoustics, using as a case study the material laboratory of the School of Architecture at Federico Santa Maria University of Technology. Combining contemporary Parametric Modeling techniques and a Performance-Based approach, an automatic generative system was produced. This system generated a modular acoustic ceiling based on Helmholtz Resonators. To satisfy sound absorption requirements, acoustic knowledge was embedded within the system. It iterates through a series of design sub-tasks from Acoustic Simulation to Digital Fabrication, searching for a suitable design solution.

The internal algorithmic complexity of the design process has been explored through this case study. Although it is focused on an acoustic component, the proposed design methodology can influence other experiences in Parametric Design.

1   Introduction

In contemporary architectural practice, designers' intentions are achieved through resource administration know-how, constructing algorithms that can consistently build and refine design conceptuality. Since Parametric Modeling tools are capable of managing various kinds of numerical data, the achievement of performance while we are producing form is a door opened to the architectural discipline (Figure 1). This is a chance where the gap between context and project can be erased, as we take seriously contextual parameters as demanded aspects for developing form. These kind of approaches to form and matter could free architecture from use and abuse of spatial typologies inherited from modern style, and start a new era where context-aware structures will adapt continually to gradients, reading them to satisfy a specific programmatic issue when a set of conditions are met *(Oxman, 2007)*.

Figure 1. Perspective view of canopy instances.

2   Design Paradigms

2.1 Parametric Design

Parametric design is characterized by the use of multiple associations between design parameters and with the parameters resulting of these relations, creating networks that calculate the design solution through a congruent sequentiality of input-output transactions. Designers may consider the development and algorithmic characteristics of this system itself also as second level design, a custom construct that is the active history of the actual geometric model. *(Aish, 2005; Burry, 2003)*.

When weaving the parametric network, the authors need to sense possibilities in design space for its successful

development, testing congruency at every node of data exchange. If the author misses coverage of some aspect, by evaluating variables somewhere outside the current "healthy" parameter interval or some act capable of causing a congruency crisis on the topology of the system, outputting will not be successful.

4   Design Task

Design Task corresponds to the strategy for decomposition of design problem and re-composition in a parametric system or any algorithm proposal for problem solving. The resulting parts, called sub-tasks, can be composed by other minor tasks; this can be made recursively until we reach the basic operators or native commands in the parametric software that we are currently using. In the case-study proposal, we observe the Decomposition-Solution-Re-composition method for task decomposition. Briefly, it consists in choosing the proper decomposition for the design problem, generating specifications for sub-problems and taking each sub-problem as a design problem. The design problem re-composition is made when these sub-problems are solved *(Chandrasekaran, 1989)*.

4.1 Performance–Based Design

Performance represents the level of accomplishment of work in an element's aspect, resulting from an evaluation act where the expected goal satisfaction is judged. In a Performance-Based approach, design is conceived as a progressive response to evaluation outputted mostly from simulations, seeking for requirement satisfaction by observing Performance Indicators, or the actual values of the performance aspects in a potential design solution *(Kalay, 1999; Becker, 2008)*. Design action is made through a generative design act (i.e. a transformation of the feature, addition of a new detail level, etc). All these issues are ruled by knowledge in expertises invoked by performance aspects.

The way the actualization is executed after the evaluation is variable. Some of the actual implementations use iterative feedback actualization between separated software *(Al-Haddad, 2006)*, adaptation of geometric design, and real-time evaluation-generation-modification of the mode*l (Oxman, 2008)*.
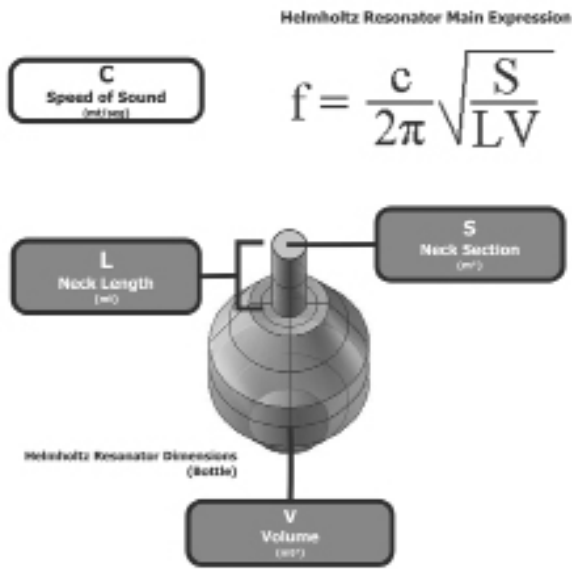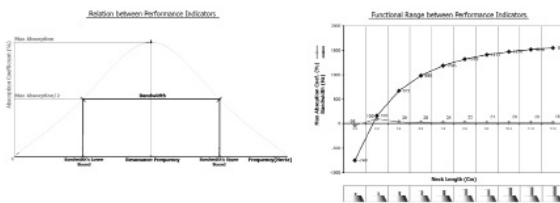
Figure 2. Helmholtz Resonator main expression.

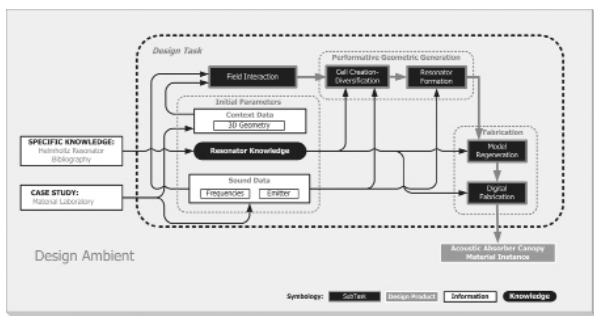Figure 3. Relations between Performance Indicators.

Figure 4. Design Task.

5 System Foundations

5.1 Case Study

The case study is placed in a material laboratory, equipped with analog and CNC machinery. The current user needs on the laboratory are:

- Ceiling: Sanitary and other installations are not covered by any type of ceiling.

- Sound Absorption: Reverberation time reduction on low sound frequencies.

Ceiling is adopted as the work typology. Sound absorption sets the algorithmic complexity of the projected system, and it is defined by the Helmholtz Resonator.

5.2 Component Definition

A Helmholtz Resonator (H.R.) is defined broadly in Architectural Acoustics bibliography as an absorber for specific low frequencies of sound. The principle of absorption of this device is based on the air's mechanical opposition inside the resonator, resisting incoming sound pressure while consuming sound energy *(Rossell et al., 1999)*. This bottle-shaped sound absorber's main characteristic is the change of dimensions for absorption frequency variation and performance. Main H.R. expression sets the relations between resonator dimensions (Figure 2).

For managing absorption quality other expressions complete the main expression (Arau 1999). The sound absorption aspect is observed through two Performance Indicators (Figure 3): Absorption Coefficient (A.C.): Total absorption of the target frequency

- Bandwidth: Interval of frequencies absorbed more than (Absorption Coef.)/2.

5.3 Initial Parameters

The initial inputs for this parametric system are:

- Sound frequency spectrum: Sound taken from machines at the material laboratory, sound spectrum is taken in thirds of octave.

- Contextual geometry: Building geometry and obstacle-objects geometry.

- Location of emitters: Point coordinates for every sound emission.

5.4 Task Proposal

The design sub-tasks that compound the generative system are (Figure 4):

- Field Interaction: The process of generating a surface defined by points of maximum acoustic pressure.

- Performative Geometric Generation phase: It is based on component propagation parametric modeling patterns *(Woodbury et al. 2007)*, and is composed by two subtasks:

- Cell Creation and Diversification: Cell generation for H.R., and recursive subdivision of cells.

- Resonator Formation: Process for obtaining resonator's dimensions.

- Fabrication of Helmholtz Resonators: It is based on digital fabrication sequence specified by Sass *(Sass et al. 2007)*, and it will be discussed later in the paper.

These subtasks are introduced by presenting three issues: (I) design topics of interest, (II) the technical procedure and (III) a local conclusion.
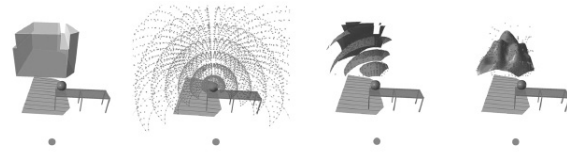
6   System Development

6.1 Field Interaction

I

Contextual data and knowledge about physical phenomena are the substrates that bred Performance-Based design product. Making this concomitance effective depends on the design problem decomposition, and also, in author's inference over the characteristics inherited to resulting objects through all the sequences of transactions.

II

Field Interaction is the task of generating a surface (Figure 5), for drafting resonator's main section over parametric space. It is based on data intersection from the main actors of sound propagation: Emission and space of emission.

- Emission (Omni-directional 3D emission): Ray-tracing emission, with line ending on first reflection location. Picks of acoustical pressure at every half wavelength on the primary target sound frequency are stored as a set of points on every line, simulating sound emission at a frozen moment on time.

Figure 5. Field Interaction, steps for surface generation.
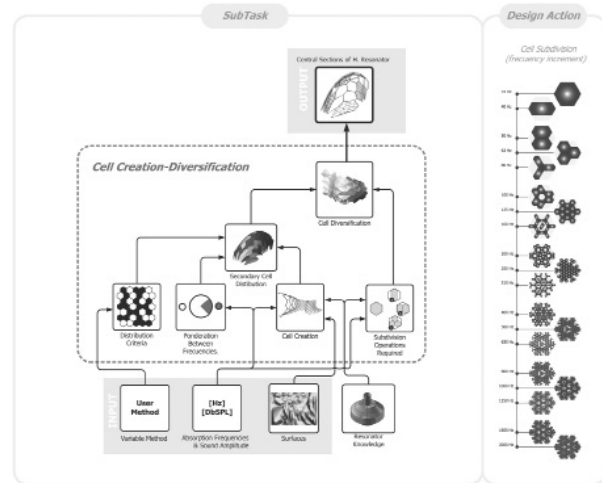
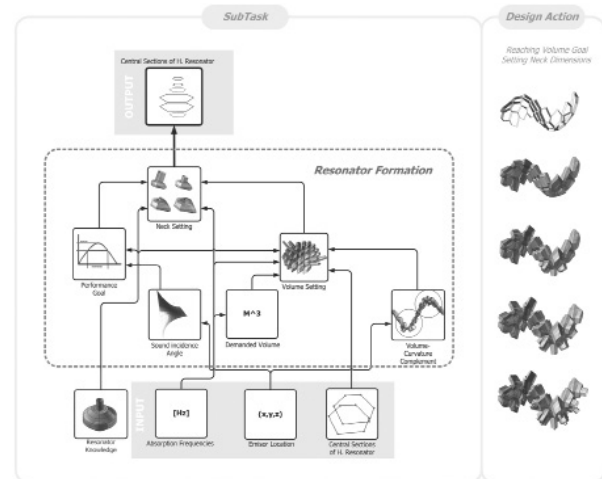Figure 6. Cell Creation- Diversification Subtask.

Figure 7. Resonator Formation Subtask.

- Space of Emission: Volume where the Resonator's formations are permitted, so the volume is set over 2.2 meters up to ground level. In this volume we exclude also the material entities, taking them as obstacles, so intersections with the context are prevented.

The intersection of these features returns segments of ray-tracing lines, so from the resulting subset of points at every segment we chose one as the better candidate. Through all these points we fit a surface.

This output will make resonators receive maximum sound amplitude at the same time, while revealing sound shape in the Cartesian Space.

III

Here the foundation of our parametric system is based upon the achievement of the platform, the surface, starting from it the design proposal is increasingly specified, and thus products from processes forward will find proper development space using these outputted surfaces.

6.2 Performative Geometric Generation.

I

In the discrete geometric response over physical parameters, increments are taken in a specific operations palette, so changes in inputs drive the state of components characteristics. Transformations, aggregations, subdivisions, indexing lists of entities and other actions can be gradually specified, in this way the grain of change can be some magnitude interval of the parameter and can permeate as an identity aspect of the design product aesthetic.

II

The Performative Geometric Generation phase consists of finding H. R. global disposition and component dimensions. The two subtasks of this phase are:

Cell Creation-Diversification (Figure 6): The process of drafting closed polylines on the surface's parametric space using a classical honeycomb pattern. The goal area is the main volume section of the H.R. needed for absorbing the primary target frequency.

Diversification happens when we have more than one target frequency. The secondary frequencies are higher that the primary one, so by definition the areas and volumes of their respective resonators are smaller. This relative decrement is made by tree types of subdivision over primary frequency cells: Reduction, Bidivision and Tridivision; these actions are executed in that specific order, and each increases 1/3 octave in the frequency scale. We should repeat this sequence depending on how acute is the secondary frequency.

The Resonator Formation (Figure 7) consists of two steps: volume setting and neck dimension setting. Neck dimensions will set the sound absorption performance.

- Volume dimension setting is used for reaching absorption frequency. Direct volume adaptation of a given non-regular polyhedron is a complex task, so the absorption volume goal is reached by an increment-test loop of the distance between the sections that define volume geometry.

- Neck dimensions will be used to define sound absorption performance, by predicting Performance Indicators values, A.C. and Bandwidth.

Once the resonator's volume is fixed, by increasing neck length we enter into a functional range where the two Performance Indicators expose gradients variables enough to satisfy diverse absorption performance criteria. Figure 3 shows A.C. and Bandwidth driven by neck length, we observe changes on A.C. to set goal values that stop necks increment. This goal is set by the incidence angle, or the angle from the resonator's normal and the vector pointing to the emitter. If the incidence angle is high, it is assumed that sound from other sources may enter to the resonator; so Bandwidth has to be increased and A.C. decreased.

III

This task manages generative design actions as direct settlers of the resonator's characteristics. An important feature of this work is recognizing the pattern of change in features involved in performance aspects, and proposing a geometric regime according to these patterns. For instance, subdivision engine was a technical problem conceived to solve from the beginning of the process, thus it was highly relevant not only for requirement satisfaction, but because diversity on H.R. is recognized as an aesthetic good to integrate in design product.

6.3 Model Regeneration and Digital Fabrication

I

Form implications on a particular product can disable its constructability. Conceiving fabrication techniques from early stages of design development is an iterative process, therefore the material integrity of the design product stands as a performance aspect.

II

We choose a 2½ axis routing CNC process, because of time saving and cost versus tridimensional fabrication of monolithical components or formations. The material instance was fabricated on 2 mm aluminium sheets (Figure 8).

According to Sass *(Sass, Michaud and Cardoso 2007)*:

Materializing a design is a four step process starting with—

1)   an initial shape generated in CAD.

2)   A new CAD model is generated of smaller components.

3)   Components are regenerated in as a two dimensional geometry in a horizontal position for cutting. This set of drawings is defined as machine tool paths.

4)   Component cutting and hand assembly.

We propose two final sub-tasks: Model Regeneration (step 2 and 3) & Digital Fabrication (step 4). H.R. has two main material constraints:

• Resonators can only have the specified openings: Joins permeable areas should be avoided or corrected.

• Resonators can be of any shape, if relations between dimensions are kept.

As hexagonal based volumes, every H.R. is decomposed in six elements. Resonator fabrication steps are shown in Figure 8.
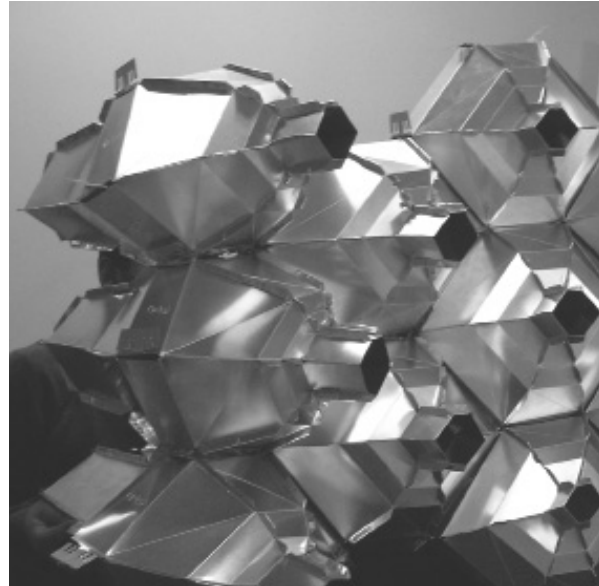

Figure 8. Digital Fabrication, steps for constructing the resonator aggregation.
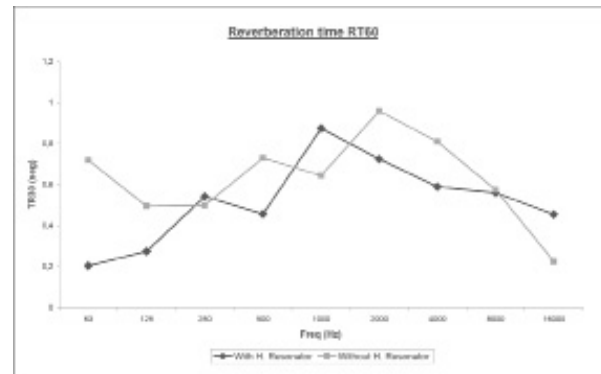

Figure 9. Reverberation time test.

III

In CAD-CAM relationship, an integration of knowledge about fabrication on form generation is encouraged. A well-fabricated product can show the generative logic of its conception. Corrections on digitally fabricated product ask for author's conception of a second network over the parametric system, for the review of every subtask and operation. After finishing our design product, digital production bred in real-world has to be judged. Material quality of the product and real performance test are indicators of success in the global design process.

7   Results

7.1 Fabricated Resonator Aggregation

We chose to fabricate a non-diversified resonator aggregation for absorbing 63 Hz frequency; if a diversified aggregation were fabricated, resonators with different frequencies must be isolated, due to the interference between movements caused by the resonation. These resonators are not completely impermeable, so it is necessary to improve joining between component sub-parts.

7.2 Test

We performed a reverberation time testing (made with WinMLS software in a 9 m^2 room), comparing a room with H.R. and without them. This type of testing outputs which frequencies were absorbed. The results are shown in Figure 9.

The resonator worked pretty well at the specified frequency, focusing on that specific frequency the result is satisfactory. Nevertheless, for further work several frequencies (or a great part of sound frequency spectrum) must be included for their absorption and into the design proposal, because this material instance disturbs the entire sound frequency spectrum. As a valid shortcut we propose shooting the resonator aggregation with expanded polypropylene, dosed for the case.

8   Conclusion

Method and technical aspects of a Performance-Based Design Task for generating sound absorber canopy instances where presented, testing of physical model demonstrates the Performance-Based orientation of the work.

In the achievement of contemporary formal distinction based on requirement satisfaction, emergent plasticity of architectural form can be pursuit and enhanced by adding performance criteria when making custom parametric systems. This addition is performed causing modulations in various scales. At a middle scale level these algorithmic modules can be geometrical, hybrid or mathematical. The hybrid type produce geometric solutions from the direct inputting of H.R. expressions. The main idea on these modules is not characterized by procedural techniques, but by the result of an induction process embedded in a geometric operation that searches for a certain parametric response. Working on this direct mediation designers and architects can cover the gap for multidisciplinary integration.

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