Building and Environment 72 (2014) 188–200

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Acoustic absorbers by additive manufacturing

Foteini Setaki [a,*], Martin Tenpierik [a,1], Michela Turrin [a,b,2], Arjan van Timmeren [a,3]

[a] Faculty of Architecture, Delft University of Technology, Julianalaan 134, 2628 BL Delft, The Netherlands
[b] Faculty of Architecture, Yasar University, University Street, No:35-37, Ağaçlı Yol Bornova-İzmir-Turkey

ARTICLE INFO

Article history:
Received 30 May 2013
Received in revised form
8 October 2013
Accepted 19 October 2013

Keywords:
Acoustic absorbers
Passive destructive interference
Additive manufacturing
Performance driven design

ABSTRACT

Acoustic design has a large impact on comfort in the built environment; and reduction of noise, by means of sound absorption, plays a crucial role in acoustic design. Depending on the peculiarities of functions and spaces, acoustic design requires a variety of customized solutions. However, current sound absorbers have limitations in being tailored to the specific acoustic requirements of a space; these limitations mostly regard geometry and materials, and are related mainly to design and fabrication limitations. In order to investigate solutions for highly customized sound absorbers, this research focuses on absorbers based on the passive destructive interference principle (PDI). This choice is due to the close relationship between geometry and acoustic performance, which is peculiar of PDI absorbers. When focusing on customized geometry, fabrication techniques become crucial for the project feasibility. In this paper, this aspect is addressed with reference to additive manufacturing, which allows for the fabrication of unique pieces even in case of complex and freeform geometries. Focusing on these aspects, this paper presents the preliminary results of research at TU Delft. The first phase of this research focused on laboratory tests measuring the sound absorption coefficient of samples fabricated with additive manufacturing. This allowed understanding the acoustics underlying the performance behaviour. In the second phase, the acoustic rules have been formulated into guidelines, relating geometric factors to acoustic performance; and in parametric relations between performance and geometric design parameters. Finally, a case study has been developed.

1. Introduction

This paper focuses on sound absorbers based on the principle of passive destructive interference (PDI) and presents a research aimed at investigating the potentials for customized devices. The close relationship between geometry and acoustic performance, which is peculiar of PDI absorbers, is explored for tailoring absorbers on the specificities of different projects. This is conceived by taking advantage of the emerging digital technologies for modelling and fabrication. Although the principle of PDI is well-known and for instance takes the form of a Herschel-Quincke tube for reducing car exhaust noise [1,2] and ventilation duct noise [3], only a small number of studies considered the use of this principle for sound absorbers in combination with new manufacturing technologies. The ultimate aim is to establish sound absorbing products where geometry, production technique and acoustic performance are inherently related and constitute integral aspects of the design process. By taking advantage of the emerging digital technologies, the proposed acoustic treatment is highly customizable and is shaped by the soundscape of its context.

This research proposes the use of acoustic performance as a design driver. It opposes the fact that there are only a few examples where sound becomes the main driver for the tuning of the architectural design process and customized product development. In this perspective, it is the authors' conviction that increased comprehension and skills of how to utilize material, form and technology are key factors behind successful acoustic design. Specifically, the emergence of new digital tools and fabrication techniques raises new potential in the design process that is engaged with performance, allowing the development of novel types of building components and dedicated add-on modules or furniture.

New software supports interdisciplinary design processes, in which geometries are investigated based on the desired performance of the design. This enables high customization of the design based on the specifications and demands of each case, including

* Corresponding author. c/o Michela Turrin, PO Box 5043, 2600 GA Delft, The Netherlands. Tel.: +31 (0)6 428 75665.

E-mail addresses: foteini.setaki@gmail.com, fofiset@gmail.com (F. Setaki), M.J.Tenpierik@tudelft.nl (M. Tenpierik), M.Turrin@tudelft.nl, michela.turrin@yasar.edu.tr (M. Turrin), A.vanTimmeren@tudelft.nl (A. van Timmeren).

[1] Tel.: +31 (0)6 392 50976.
[2] Tel.: +31 (0)6 293 21839.
[3] Tel.: +31 (0)15 27 84991.

0360-1323/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.buildenv.2013.10.010

particular performance requirements. This regards the ways in which geometry is both generated and assessed. The research presented in this paper puts major attention in encoding performance driven rules for the generation of geometric design solutions. Only a few preliminary experimental case studies have been developed in this direction and these few precedents mostly concern sound diffusion. Focusing on large spaces, Mahalingam [4] has worked on algorithmic support for designing auditoriums; focusing on large enclosures, Peters [5] has modelled the large roof of the Smithsonian Courtyard as giant surface for sound absorption; Dühring et al. [6] on optimization for distributing reflecting and/or absorbing materials along the ceiling or walls of rooms; focusing on smaller surfaces, Koren [7] worked on a parametric pattern for sound diffusion; Peters [8,9] worked on the development of computational design tools for parametric geometry generation, prototyping and measurement of acoustic performance for surfaces scattering sound. Similarly, Peters et al. [10] worked on a responsive surface highly customized in order to shape the acoustic experience of a given space, exploiting the acoustic heterogeneity created by aggregating hard and reflective finish (sound-amplifiers) and soft and absorbent finish (sound-dampeners).

When designing for customization, geometry becomes unique and un-standard. This means fabrication requires techniques allowing the production of complex geometries as well as unique pieces, within acceptable costs. This raises attention on the second aspect mentioned for technological innovation, which is related to prototyping and fabrication techniques. New digital fabrication techniques allow for the production of complex geometries and highly customized products, which can be industrially manufactured in unique pieces.

New manufacturing technologies like additive manufacturing take away one of the main limitations of original passive destructive interference absorbers: the large size of the devices needed in order to target low frequencies. Godbold et al. [11] investigated the implications of solid freeform fabrication for the manufacturing of acoustic absorbers and studied one passive destructive interference absorber on a preliminary level. One year later, Bonwetsch et al. [12], explored the possibilities of adding acoustic performance criteria to digital fabrication and proposed a digital design and fabrication process to create non-standardized acoustic panels. Peters and Olesen [9], finally, developed a design-tool that is informing the design process with acoustic measurements from rapid prototype scale models. These studies demonstrate that the increasing interest in applying additive manufacturing to developing acoustic devices leads to the investigation of geometry-related acoustic absorption or diffusion principles. Hence, the design with acoustic performance-driven criteria is explored by taking advantages of the emerging digital design and fabrication tools and related possibilities for real time testing. On the basis of these premises, this paper investigates a new approach with regard to acoustics and proposes a customizable sound absorber, which is designed with performance-driven criteria. The departure point is the investigation of the merging fields of additive manufacturing, parametric modelling and acoustic engineering. This also constitutes the uniqueness of this research as compared to the precedents mentioned above. While the referred precedents study geometry either for sound diffusion or for distributing sound absorbent materials, this research focuses on geometry as main means for sound absorption. Design rules are proposed for a new type of acoustic device that regulates its performance by its geometrical characteristics using the principle of passive destructive interference (PDI).

This paper discusses the application of this type of acoustic absorber into room acoustics. When focusing on room acoustics, a direct application of the proposed research is expected to provide satisfactory results. However, PDI-absorbers seem to be applicable also to other fields. From a performance point of view, these are expected to range from the large scale of urban outdoor soundscapes to the small scale of products and components. The latter include various types of products that relate to the automotive, aerospace, or other industries. However in each field a number of additional explorations are needed. Especially for outdoor applications, exposure to atmospheric agents and wind conditions should be specifically addressed; as well as maintenance and cleaning can be challenging. Focusing instead on the small scale, the major limitation might be in the dimensions. In fact, in the past devices that used passive destructive interference for sound absorption tended to become very big, especially in order to adequately target low frequencies. However, due to the freedom in geometric design and fabrication, additive manufacturing opens up new possibilities for creating PDI absorbers that are more compact.

1.1. *Passive destructive interference*

Destructive interference means that two interfering sound waves that are in counter-phase cancel each other; passive means that no active components like speakers are used. Fig. 1 demonstrates the basic principle of a passive destructive interference absorber: through an air-path with a certain length, sound waves from a common source are entering from both sides. At a given point, the sound waves meet with a 180° phase difference (half of a wavelength) and therefore cancel each other by destructive interference. This method uses the sound itself to drastically reduce noise and does not require a secondary sound source like a speaker; hence it can overcome many problems of active noise control methods like energy use of equipment, needed fast processors to match the acoustic signal, difficulties with coping with varying

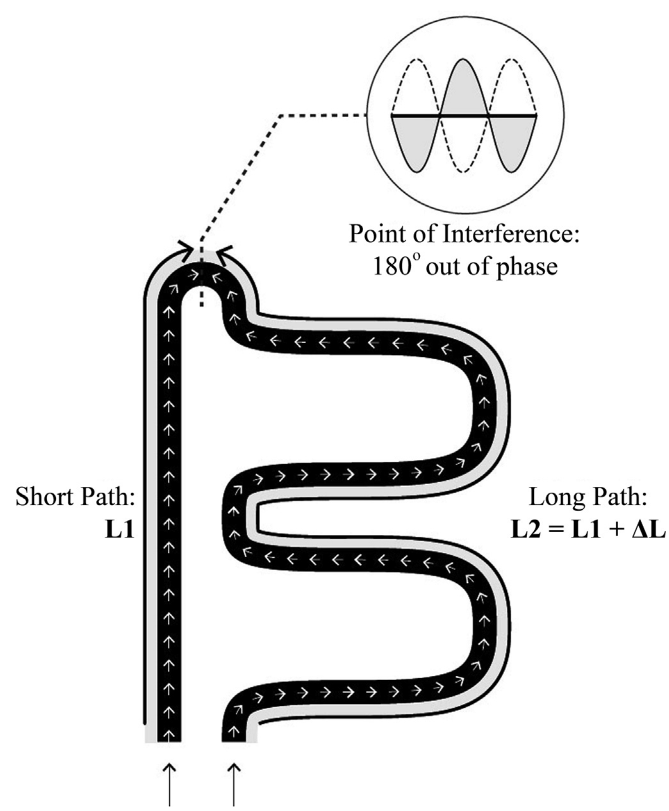

Fig. 1. Basic principle of a passive destructive interference absorber.