



*Interior view of Elbphilharmonie's Great Concert Hall under construction (Image: M. Commentz)*

## PRESS RELEASE

### **One Million Cells and Ten Thousand Panels: Digital Fabrication of Elbphilharmonie's Acoustic Interior**

- Herzog & de Meuron's Elbphilharmonie concert hall due to open in January 2017
- Parametric design and digital fabrication techniques in the fabrication of the Great Hall's 10,000 unique acoustic gypsum fiber panels developed and carried out by ONE TO ONE

**NEW YORK, 28 November 2016** – The Elbphilharmonie, Herzog & de Meuron's spectacular concert hall project in the northern German port town of Hamburg is due to open in January of 2017. Nearly a decade in the making, the entire project is comprised of approximately 1,300,000 sq ft of layered spaces, including three concert halls, a hotel, apartments, restaurants, a parking garage, and a public observation platform. The heart of the project is the Great Hall, developed by Herzog & de Meuron in collaboration with the highly esteemed acoustician Yasuhisa Toyota. It seats 2,150 people and exhibits a highly advanced, custom developed acoustic interior skin. The curvilinear, intricately intertwining wall, balustrade, and ceiling design of the Great Hall is comprised of 10,000 unique gypsum fiber panels with a special sound diffusing pattern applied to each piece, which all fit together like a large puzzle. To

achieve this momentous task, Ben Koren of ONE TO ONE implemented a slew of highly advanced technologies, from parametric design to digital fabrication techniques.



*Interior view of one of the balconies in Elbphilharmonie's Great Concert Hall (Image: Peuckert)*

### The Company ONE TO ONE

Ben Koren founded ONE TO ONE in January of 2009 as a computational design and digital fabrication consultancy with offices in New York and Frankfurt. Koren explains, "the idea for the company, as its name directly implies, was to assist architects and artists carry out design ideas with a level of mathematical rigor and fabrication precision necessary to accomplish even the most complex design challenges." To achieve this goal, a very close collaboration between the designers and the contractors is



*Ben Koren of ONE TO ONE  
(Image: ONE TO ONE)*

necessary. Since its founding, ONE TO ONE has worked on a number of highly challenging art and architecture projects by leading architectural firms including Jean Nouvel, Zaha Hadid, and Shigeru Ban as well as artists such as Jeff Koons, Anish Kapoor, and Pae White. Koren was trained at the Architectural Association in London. His workday mainly consists of writing software code to develop algorithms and solve complex geometric problems. His ability to fluently speak the language of design as well as his deep understanding of construction puts him in a unique position. "We very much understand ourselves as translators," Koren explains. "In comes the design idea, however complex it may be, which we abstract, solve, simplify and convert into the language contractors understand: simple shop and assembly drawings." In the case of the Elbphilharmonie's acoustic interior, this process can best be summed up in quantitative terms: creating one million cells and ten thousand panels.



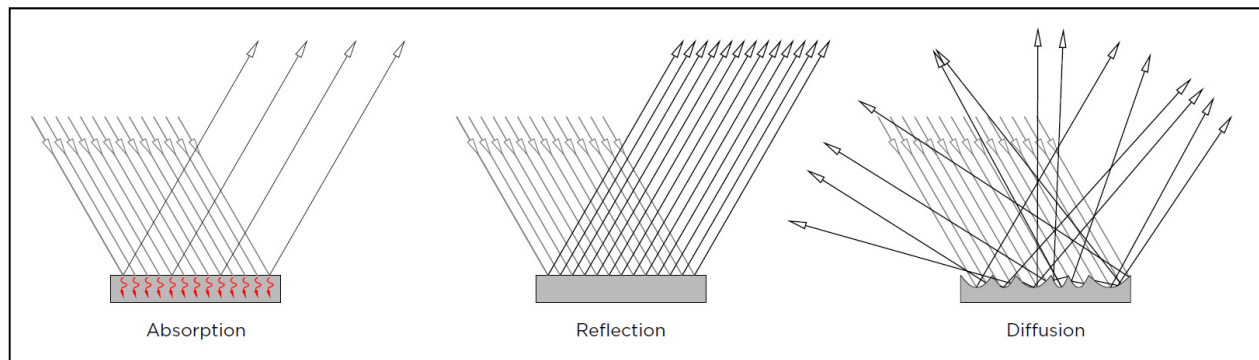
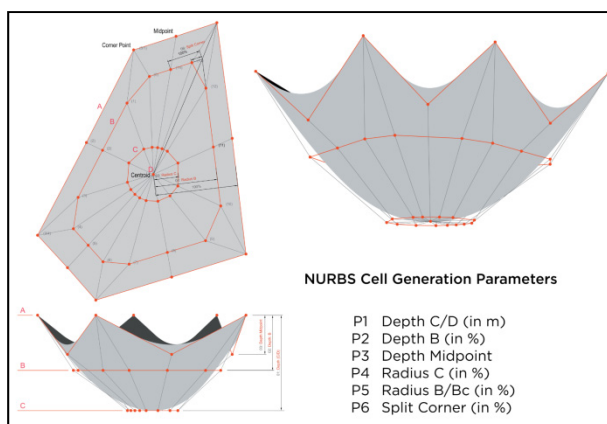


Diagram explaining sound diffusion, the 'scattering' of sound (Image: ONE TO ONE)

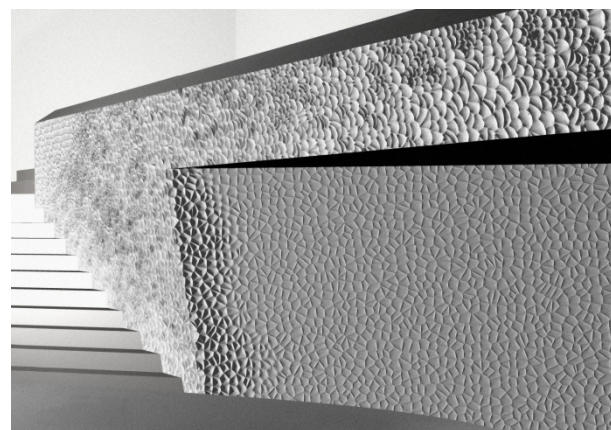
## One Million Cells: Parametrically Defined Acoustic Surface Pattern

Herzog & de Meuron first contracted ONE TO ONE to create the digital data for the Great Hall's sound diffusing surface pattern. In broad terms, sound diffusion is the even scattering of sound energy in a room. Non-diffusing, reflective surfaces in concert halls can lead to a number of unwanted acoustic properties, which can be rectified in part by adding diffusers. A perfectly diffusive space is one where acoustic properties such as reverberation are the same, regardless of the listener's location. Diffusion in some of the best concert halls in the world, such as the Great Hall of the Musikverein, built in 1870 in Vienna, is now understood to be a byproduct of the uneven surfaces of the rich, neoclassical ornamentation of their interiors. The antipathy to elaborate ornamentation by 20th Century architects may have come at the expense of good concert hall acoustics.

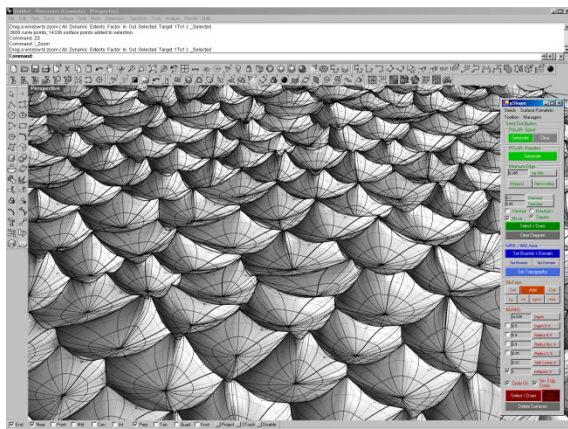
In the past, bad acoustics could be treated at a later stage by retrofitting absorbers or diffusers, resulting in a disjunction between the original architectural intent and its modifications. For the Elbphilharmonie, the architect's intention was to integrate this acoustical requirement from the beginning. The design of the diffusing pattern was meant to reflect some of the design motives of the project as a whole. The characteristic peak-trough-peak shape of the building's roof is, therefore, echoed in the sound diffusing pattern. For Koren and his team, this meant generating approximately one million cells, two to six inches in diameter, based on a range of specifications given by the acoustician, which would ultimately consist of randomly placed, individually shaped cells for regions of the concert hall.



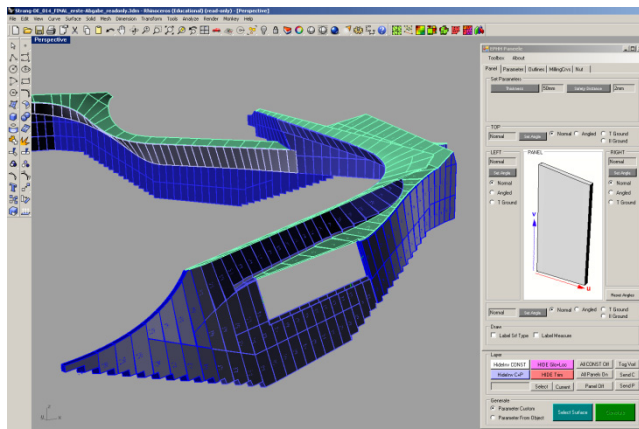
Parametric definition of one of one million sound diffusing cells (Image: ONE TO ONE)



Sound diffusing cells applied to concert hall walls and balustrades (Image: ONE TO ONE)



Computational generation of one million sound diffusing cells (Image: ONE TO ONE)

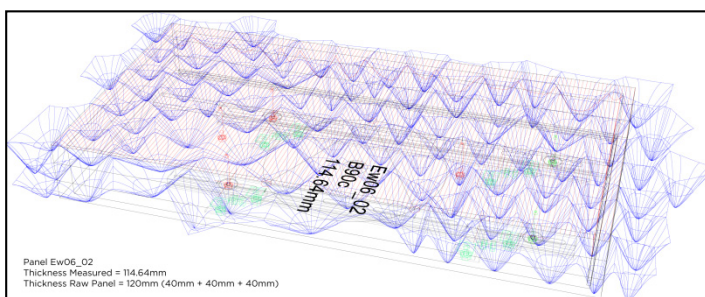


Computational generation of ten thousand acoustic panels (Image: ONE TO ONE)

This momentous task, impossible to achieve by conventional means, was ultimately resolved by ONE TO ONE's development of custom algorithms employing parametric definitions for the cells. Each cell was placed topologically onto the Great Hall's wall surfaces and controlled in shape, size, depth, and location computationally based on the acoustician's requirements.

## Ten Thousand Panels: Digital Fabrication and Assembly

Once ONE TO ONE had completed the task of creating the acoustic surface pattern, Koren and his company was subsequently commissioned by Peuckert, the Bavaria-based contractor of the Great Hall, to plan and develop the fabrication documentation for the acoustic panels. Since Peuckert was not only responsible for the production, delivery, and installation of the acoustic panels but also for its plant and assembly planning, a long-standing intensive cooperation between Peuckert and ONE TO ONE ensued.



Milling file for one of ten thousand acoustic panels (Image: ONE TO ONE)



One panel being CNC milled (Image: Peuckert)

As each panel is unique, Koren developed further software programs to automate the 3D planning and digital production of approximately 10,000 CNC-milled gypsum fiberboard panels and to optimize the acoustic surface's substructure. The architects defined a precise and intricate network of gap lines, which, not unlike the sound diffusing pattern itself, was meant to be seamless places across the hall's surfaces. Therefore, the edges of the panels were defined in such a way that they would always align with the edges of the neighboring panels, resulting in planar, curved, and twisted edges including rabbets in some cases. Because of the varying degrees of complexity in edge conditions, the employment of a five-axis milling machine in the manufacturing of the panels was inevitable. The curvature of the front surface was



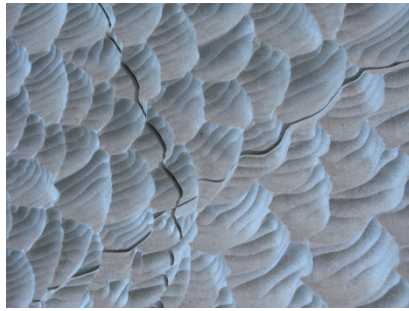
achieved by keeping the backside of each panel planar, while the front would be milled to shape. For each panel, the edges had to be digitally generated, the fixings had to be placed, and a groove along the entire perimeter had to be created for the placement of a sealing band. Koren and his team ultimately streamlined the entire task into a fully automated, digital process. Afterward, the panels were ready for manufacturing.



*Manufactured panels in the workshop (Image: Peuckert)*

Koren gradually delivered 10,000 digital files, which fed the CNC machines that milled each panel individually, to the Bavarian company. Each raw panel was prepared to size. The panels were CNC milled in two stages. First, each panel was milled from the back, which included the five-axis formatting of the edges and the placement of the holes for fixing the substructure and for mechanically securing the glued layers. Then, each panel was flipped, repositioned on the machine, and milled from the front, which included a stage for three-axis milling of the sound diffusing pattern using a ball-end cutter, milling in parallel tracks spaced at fairly large center distances. This process resulted in a rough, final surface texture that would also exhibit the characteristic peak-and-trough motif down at the scale of the trails left by the milling head.

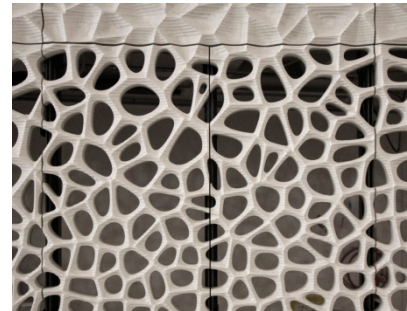
Because of the advanced computer-aided planning and manufacturing methods employed, the panels were produced very efficiently and to a high degree of precision. This process was necessary in order to ultimately assemble the final panels at the desired tolerances, which, in most cases, was less than 1/8". In the end, all the panels fit together perfectly. The number of faulty panels was kept at a minimum despite each panel being non-standard and assembled in a complex manner. Only 20 out of approximately 10,000 panels had to be replaced due to dulled tools, an error rate of only 0.2%. This extremely small error rate is an achievement in itself, especially given the scale and complexity of this project.



*Close up view of four assembled panels (Image: ONE TO ONE)*

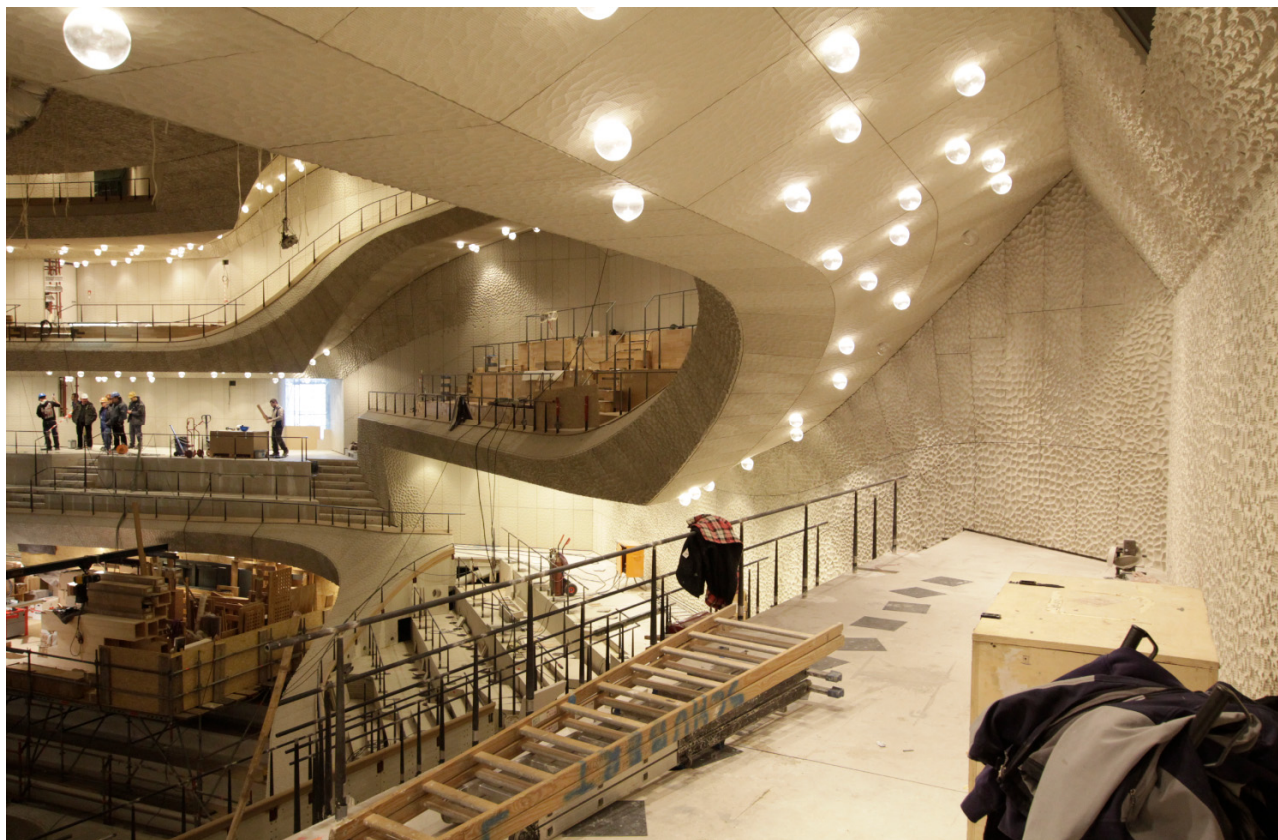


*Close up view of two assembled panels (Image: ONE TO ONE)*



*Close up view of transparent panels (Image: Peuckert)*

The construction of the Elbphilharmonie has already been completed, and the keys to the building were handed over to the city in early November. The public is eagerly awaiting the opening concert scheduled to be held in about two month's time on January 11, 2017.



*Interior of view of the Elbphilharmonie's Great Hall (Image: Peuckert)*



## About ONE TO ONE

Offices in New York City and Frankfurt. ONE TO ONE specializes in bespoke geometric computation, precision 3D-CAD construction, integrative CAM fabrication and innovative R&D at all scales. Further information at: [www.onetoone.net](http://www.onetoone.net)

## About Ben Koren



Ben Koren was born in Frankfurt/Main and grew up in the United States, founding the company, ONE TO ONE, in Frankfurt/Main in 2009. Prior to founding the company, he worked for the Basel architects Herzog & de Meuron on the Elbphilharmonie Hamburg as well as for the engineering firm ARUP's Advanced Geometry Unit on the Battersea Power Station project in London. Koren studied architecture at New York University, the University of Miami, the University of Applied Arts in Vienna, and the Architectural Association in London.

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