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Chladni Plate Visualisation

S.Dashti †[1,2] and E. Prakash[2] and AA. Navarro-Newball[3] and F. Hussain[1] and F. Carroll[1]

[1]Cardiff Metropolitan University, Cardiff, United Kingdom
[2]University for the Creative Arts, Farnham, United Kingdom
[3]Pontificia Universidad Javeriana, Cali, Colombia

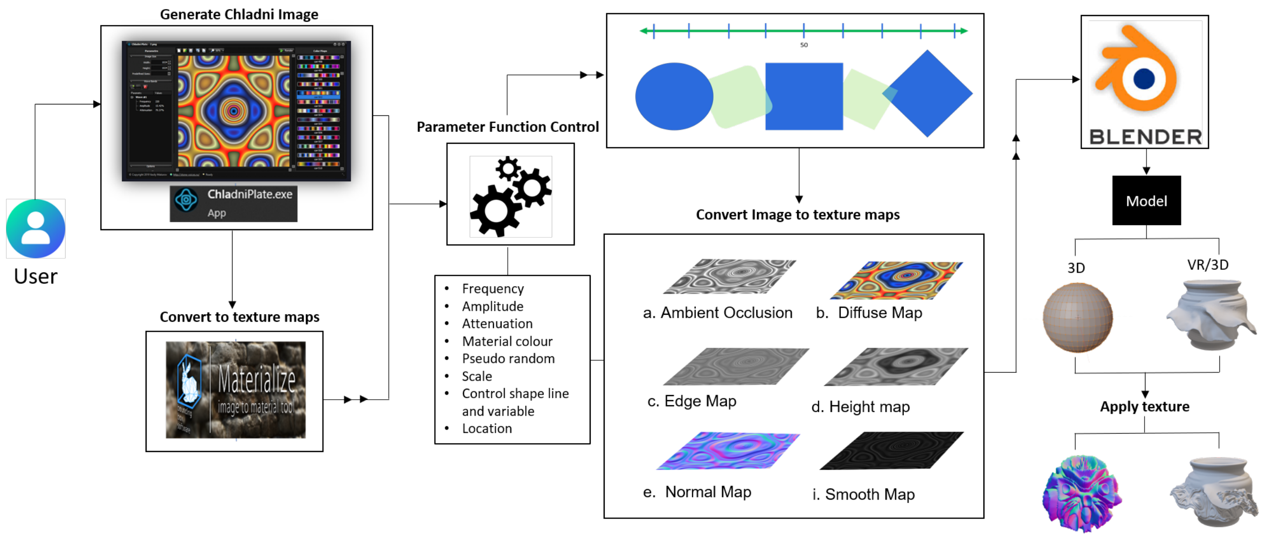


Figure 1: *Our Chladni Texture System*

Abstract
The creation of images made out of sound is an ancient discovery from many civilisations, called Cymatics. Cymatics can be referred to as the science of visualising audio frequencies through the Chladni plate. Over the past several years, many scientists, artists and designers have tried to visually and physically represent sound. Physicalising sound was through using liquids and particles as a medium with sound energy to deform and reform the medium aesthetically, creating a unique texture. In the visual arts of computer graphics, the texture is the perceived surface quality showing details of the surface model and colour. The use of texture in computer graphics for modelling and gaming industries is still growing, opening new possibilities for new complex textures yet simple to apply. The paper explores methods of integrating art and science, showing the practices of contemporary Chladni visualisation from an artist's perspective in 3D modelling. The paper also introduces the technique of using computer graphics to compare procedural textures with Chladni's plate representing visual aspects of our novel approach.

CCS Concepts
• ***Computing methodologies*** → *Computer Graphics; 3D Modelling; Visualisation;*

1. Introduction

The world is full of rich textures and can be observed both in artificial and natural mediums. It is possible to visually refer to an immediate tangible feel of a surface's characteristics and appearance from the object's shape, size, density and proportion of its primal parts, arrangement and colour. The major goal in Computer Graphics CGI is to achieve realism. in most 3D modelling, video games and movies. We introduce the visualisation of Chladni's plate as

† Chairman Eurographics Publications Board

an advanced CG technique that can be used to produce a unique complex, yet easy to apply texture.

Our approach involves deformable shape modelling and sound-resonance texture use of external data to influence the object shell surface, creating a unique, organic geometric deformation pattern using 2D images of sound fractals as a novel approach, as seen in Fig 1.The concept of our approach relays on how the principle of sound resonance affects the medium, as explained , using image-based modelling data to deform and visualise the representation of sound resonance on the surface of the 3D object. The approach uses direct internal/external force of a sound frequency image on the mesh, changing the mesh position and direction.

The aim of our paper is to review the Chladni plate, identify its relationship to textures, model Chladni as a 3D surface and demonstrate a practical system to achieve this. To accomplish our objective, first, we describe the methods to to use an appropriate tool to synthesise Chladni; the, we explain the procedure to translate Chladni to synthesise 3D shapes/patterns; next, we design experiments to showcase Chladni surfaces; finally, we Compare Chladni plate texture functions with Perlin noise. Our main contributions in this paper include a detailed review of the Chladni plate and its graphical synthesis and visualisation. In another companion paper, the authors have shown Chladni plate use in VR modelling for Virtual Pottery [DPNN*22].

Adding intricate 3D detail to any 3D surface remains a challenge. Our research gives the advantage of adding generative complex organic detailed textures, using Chladni plate to the object's surface with easy steps for creating unique volumetric deformations. The proposed technique removes the tedious human effort involved in generating intricate detail for 3D modelling, gaming and 3D printing.

Section 2 describes related work, focusing on the Chladni plate visual aspects. The section starts by introducing the invention of sound motion and the scientific explanation and ends by introducing its relationship with art. In Section 3, we present relevant literature. Section 4 presents the method of generating Chladni's pattern and formation using CG. Section 5 describes a related procedural technique overview so we can compare it with our approach. In section 6, we demonstrate the results and at the end is the conclusion in section 7.

2. Related Work

Chladni plate is a physicalisation invention of sound motion. Here, vibrating plates made from metal plate surfaces with particles of sand that produce characteristic patterns associated with the physical dimensions of the plate. It allows visualising the effects of vibrations on mechanical surfaces, and it was invented by Ernest Chladni. Ernest Florens Friedrich Chladni (1756 - 1827) demonstrated multiple experiments at the *French Academy of Science* in 1808, studying the nodes of oscillation of circular and square plates, typically fixed in the centre and driven with a violin bow. The modes of vibration were identified by scattering sand or salt on a plate and particles end up in places of zero vibration. Figure 2 shows the drawings from Chladni's original publication [Chl87]. Chladni patterns depend on resonant modes of flat plates.

Sound physics is the vibration that propagates as an acoustic wave through a medium, and the five primary elements of sound waves include frequency, amplitude, time period, velocity and wavelength. Sound is a tension wave created through a vibrating object, and vibration indicates the particles' periodic back-and-forth motion, transporting energy through a flexible body or medium. The vibration then is multiplied as an acoustic wave via a transmission medium such as liquids, gases and solids. Vibration is simply a mechanical phenomenon via oscillations at a stable point. The vibration of sound leads us to a phenomenon called resonance. Resonance is explained through an object with a natural frequency that receives a forced vibration at the same frequency, and it is a non-mechanical system such as the electrical and visual ones

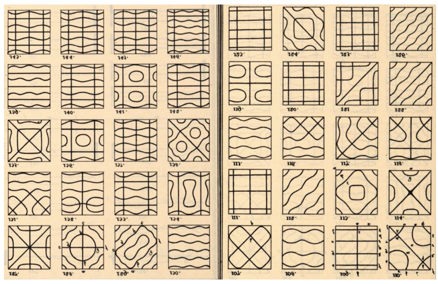


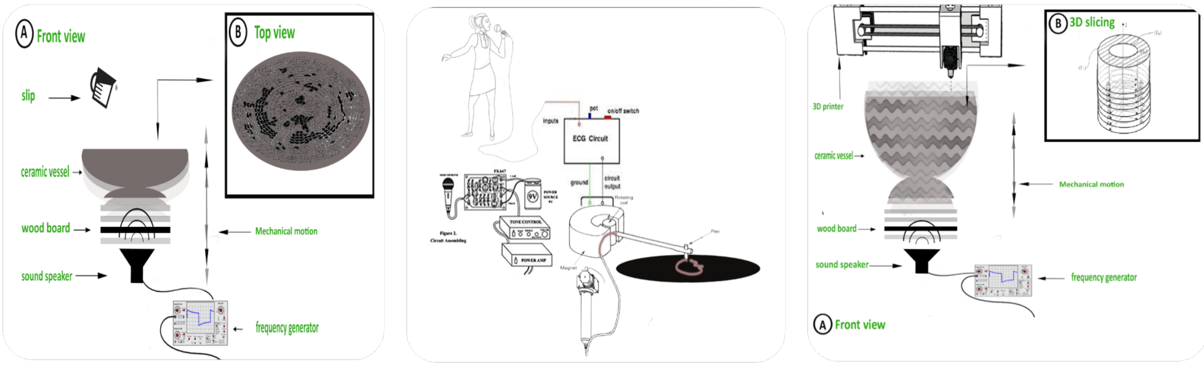
Figure 2: *Chladni geometry patterns of nodal lines on a vibrating plate [Chl87].*

2.1. Chladni Plate Patterns in Art & Science

Chladni plate visualisation can be considered as an artistic manipulation interference that creates unique complex patterns. The human being, explores ways to express the aesthetic of emotions, religion and science, using the surrounding of nature with the environment in an artistic vision or in a physical way to complete the image of reality. The creation of images made out of sound is an ancient discovery from many civilisations, called Cymatics. Cymatics can be referred to as the science of visualising audio frequencies. This section explores the integration of art and science, showing the challenges from an artist's perspective, using technology to represent Cymatics's visual and physical aspects. Over the past years, many artists tried to physicalise sound, using clay as a medium and sound energy to deform and reform the medium aesthetically to create a unique texture [The69]. In visual arts, the texture is the perceived surface quality of a work of art & craft. It may be perceived physically, through the sense of touch, visually, or both. The artists involved in CG have created labels for their artwork, such as digital art, telematics, generative art, computer art, computational art, process-based art, software art, electronic art, and technological art.

2.2. Chladni Plate Generative ART

Generative art is still contemporary within the artistic community. Since 1998, there have been conferences about generative art, and Brian Eno [Eno96] has been influential in promoting and using generative art methods. Integrating music and visual art lets a computer



a. Cymatics on Ceramics

b. Physicalising sound with Plate Recorder

c. 3D printing ceramics using Sound Resonance

Figure 3: *Sound Data Physicalisation Experiments.*

system carry over some decision-making, with the artist determining the rules from a step-by-step algorithm.

Grzegorz [Kęp] explored generative art using an autonomous system. He explored ways to emphasise generative art algorithmically determined by computer-generated artwork. Here, the artists can use chemistry, biology, and mechanics data and use robotics, smart materials, manual randomisation, mathematics, data mapping, symmetry, tiling, etc. He created an artistic generator tool for an arbitrary number of complex abstract graphics and unique artworks, using an integration of a reaction-diffusion system and spatial Chladni figures in numerical simulation. This tool is based on random Chladni patterns and selected 2D space deformations, which are applied to equation coefficients. The system's output is a unique and non-periodic image representing the result of the Gray-Scott system simulation. In summary, he managed to implement the following:

- Combination of various patterns in a single simulation.
- Spatial generation of smooth and continuous regions related to patterns using Chladni patterns amplitude functions.
- Deformation of the patterns.
- Perturbation driven by the nonlinear transformation applied to Chladni patterns.
- Generation of nearly infinite random parameters.

Other works focus on incorporating sound energy with ceramics as a texture creating unique deformation from sound resonance.

Sidlauskaite [Mee14] is an artist that explored technology and sound resonance phenomena to affect clay. She created Cymatic patterns using liquid clay with a mix of glazes targeting the surface of a ball. Sidlauskaite used a frequency generator connected to a sound speaker, as represented in Fig 3a. She used the mechanical variation of motion (up and down) to create Chladni plate patterns on a semi-flat surface, leaving them dry. Though there was a visible result, the surface was not flat enough to create an even layer. Also, the properties of clay, glaze, and real-world constraints such as air and gravity didn't preserve the richness of Chlandni's pattern.

Segal and Maayan [Maa17] presented a plate recorder that analogues sound visually and physically. The experiment focused on decorating and texturing. The experimentation operated on ready-made ceramic plates, used as a medium for recording sounds with real-time printing from printed human vocals, represented in Fig 3b. The experiment was established by using an ECG *electrocardiogram* to record the electrical signals. The signal of sound created had a unique texture printed on the surface of the plate, using glaze and clay material to decorate the surface.

Herpt, in 2013 [Gür18] explored unique ways of designing clay, using the technology of 3D printing with sound vibration to deform the layers of the print, creating a distinctive pattern. It is another way of using sound resonance energy to affect the vessel's structure. The design control was by trial and error method in a vertical motion (up and down) with the mechanics of sound speaker represented Fig 3c. Though the method is good, this method creates texture using the basic vessel with minimum control and located area of layering deformation. The design details are affected by the properties of the material with the air pump of the 3D printer.

3. Literature Review

3.1. Texture in CG

In computer graphics, texturing is the application of the surface to a 3D image, giving the sense of feeling, touching, and actualisation. There are many textures, such as brick walls, wood, marble, etc. The traditional method uses a 2D image called a texture map and wraps around the object, which is the process of wrapping up the 3D model with 2D images to give a more natural visual appearance as a real-world equivalent.

Peachey [Pea85] in 1985 presented an effective method of demonstrating the visual complexity of simulating the surface of geometric models details at a relatively realistically rendered with low cost for **Solid texturing** of complex surfaces. The function of the texture was defined in 3D space with diverse materials, including wood and stone, using Fourier synthesis 1822, projections of two-dimensional textures, and combinations of other solid textures. Peachey's method extended the concept of texturing from a surface coordinates basis to a solid coordinate basis, creating realistic, flexible texturing simulation. The method also can be used as individual patches automatically or applied traditionally.

Edbert et al. [Pea03] explained how **procedural techniques** have been used for many years in CG to produce realistic textures and objects. They had the conception that simulating natural phenomena is either impossible or impractical in most cases to develop physically accurate models. Still, on the other hand, procedural textures are a tractable alternative. They articulated how procedural techniques have been used for many years in computer graphics to create natural textures and objects with the power of parametric control. They explained how procedural texture language incorporates image-based texture mapping as one of its primitive operations of a combination of modification or distortion of image textures. Edbert et al. also explained how there are explicit and implicit methods. In explicit methods, the procedure directly generates the points that make up a shape. In implicit methods, the procedure answers a query about a particular point. The most common implicit method forms iso-curve in 2D or iso-surface in 3D.

Gutierrez et al. [GRGH20] presented **solid texture synthesis** based on a deep learning framework, allowing the high quality of 3D data at an interactive rate with addressing problems that occurred in their experiments. They showcased some simple and compact generative networks capable of synthesising portions of infinitely extendable solid textures. They demonstrated how the training was performed at high resolution, and textures of arbitrary size could be synthesised on demand. This method achieved high-quality results of fine-scale details on textures, generating a solid texture that interpolated and intersected with a surface mesh without parametrisation as required for texture mapping. Although solid texture synthesis from a single example image is an intricate problem, their method delivered compelling results giving the desired look imposed via the 3D loss function and aiming to simulate real-life objects.

3.2. Overview of Chladni Patterns in technology and CG

This section explores the literature on experimentation to generate Chladni patterns and Chladni plates in CG. The idea of using the Chladni patterns is to visually create unique geometry textures and interact with the object's mesh, changing the geometry. Considerable studies tackled the Chladni pattern from different perspectives and functions, generating various representations of the Chladni plate analogy. The following paragraphs show some important literature emphasising experimental resonance patterns using frequency spectrum.

3.3. Generating Chladni Patterns

Tuan et al. [TWC*15] presented a study on Chladni nodal line patterns and resonant frequencies for a thin triangle plate using salt particles. They used the *Helmholtz* equation exploited to derive the response function as a function of the driving wave number for reconstructing experimental Chladni patterns. Tuan et al. results indicated that the objective of the dispersion relationship established the agreement with the formula of the *Kirchhoff-Love* plate theory as shown in Fig 4.

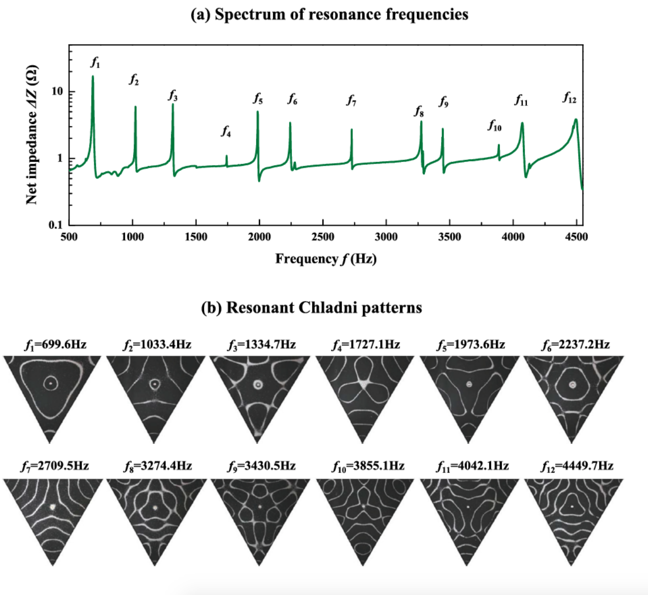


Figure 4: *Experimentation of Chladni patterns (a) Shows experimental frequency spectrum given by the net impedance of the triangle plate. (b) Shows a nodal line patterns at the resonance frequencies fi depicted in (a) [TWY*14] .*

3.4. Chladni Patterns Formation in Mediums

Latifi et al. [LWZ19] explored manipulation motion techniques with the Chladni pattern, using heavy particles submerging the resonating plate in a fluidic medium. Here, the acoustic radiation force and the effective lateral weight become dominant at the sub-mm scale. They experimented with frequencies in a broad spectrum of resonant and non-resonant frequencies, controlling single particles' motion with a group of particles on the submerged plate.

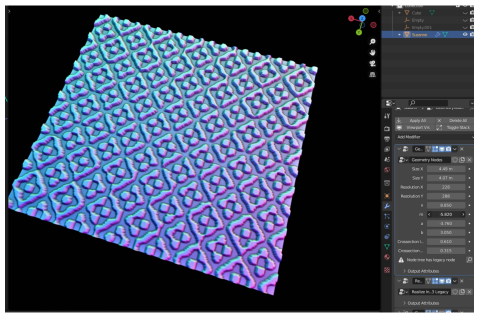


Figure 5: *Chladni geometry node experiment in Blender [Vla21] .*

3.5. Chladni Plate Tools Overview

Nowadays, the Chladni plate is used in CG not only for science but also as an artistic method for a visual unique geometrical pattern representation. Nevertheless, limited Chladni plate tools are available as open-source, limiting the opportunity of experiencing it by non-research-based users. The Chladni plate comes in different forms. The acoustic vibration on solid surfaces with mediums such as sand, salt or fluids forms patterns of nodal lines on vibrating plates, and this is the concept of Chladni software.

3.6. Nodal Line Overview

The nodal line is the line passing via the ascending and descending nodes of the rotation of a celestial body. The node represents the point with a standing wave where the wave has minimum amplitude, as shown in Fig 6. Therefore, the nodal patterns or topology match the shape of the nodal location of finite elements that are developed on a triangle, circle or square plate, as shown in Fig 7.

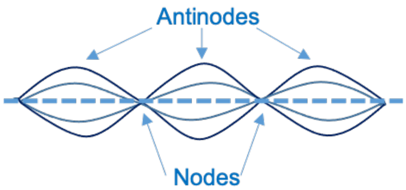


Figure 6: *Illustration: Nodal Line.*

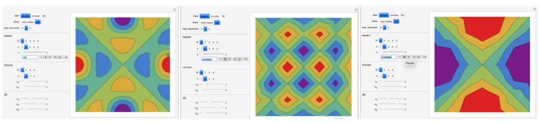


Figure 7: *Illustration: Chladni figures (nodal patterns) [Zel19].*

3.7. Antinodal Overview

Antinodal are points along with the medium, which oscillate between a big negative displacement and a big positive displacement. The overall aim is to find a way to visualise the displacement as a volumetric texture showing a unique sound resonance pattern and applying it to a VR object. Figure 8 shows how the antinodes resulting from the interference shape of two waves showing how antinodal positions with a crest meet a crest producing a large positive displacement. Though these tools are suitable for visualisation, it is still hard for a non-expert to implement Chladni patterns with 3D modelling. The aim at this point is to find simplified tools to create the Chladni patterns suitable for 3D modelling.

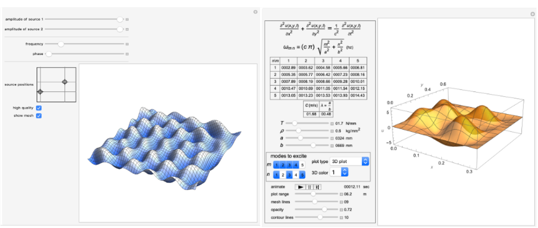


Figure 8: *Illustration: 3D Antinodal Displacement [Noc11].*

3.8. Chladni Surface Texture

Ikpe et al. [INE19] presented a study of an alternative method of determining the modal shapes on vibrating plates, simulating the modal frequencies and Chladni patterns in thin plates under acoustic excitation. The study showed applications where the displacement or response of components under the influence of vibration is vital. The experiment was performed on a thin plate subjected to acoustic excitation, using fine grain particles such as sugar, sand or salt with the Finite Element Method (FEM).The *HYPERMESH* speeds up CAD to FEM, working as an analysis of local structures identification and subtraction of duplicative material generated results relative to the experimental values.

Vladimirovich [Vla21] is an expert digital artist that uses the **Blender** tool to illustrate his creativity. In 2021 attempted to implement the Chladni pattern on the infinite plane, using geometry nodes, and changing the mesh geometry using metal material. The patterns were controlled by geometric algorithms with selected frequencies showing the *xz* size and resolution with cross-section level and width. The was also a deformation control to curve the plane. Although it is a reasonable approach, it has limited texturing abilities. The texture resolution was low, and the mesh blending or displacement was not smooth. This method is ideal for simple visual demonstration but can't be used for smooth, detailed texturing as it shows pixelated texturing. Finally, this approach is for advanced users in 3D modelling. The users of this project must understand how to create a material and change the geometry displacement of an object mesh, considering a longer baking time.

3.9. Chladni Plate Functions

Yucel & Yildan [YY17] proposed software interface that displays Chladni patterns, fractals of algorithmic visualisations of mathematical functions, and a menu for manipulating variables. The software is called **Cymatify**, and it has seven creation functions from the basic mathematical formula to manage type of function, allowing the users to generate patterns by modifying mathematical functions and variables such as:

- Frequency value
- Size of the grid
- Density of the grid
- Colour of the patterns
- Generating and manipulating patterns
- Stroke button
- Export fractals image

The result of the study contributes to the scope of the Chladni plate pattern in CG, discussing the complexity, unpredictability and diversity of patterns and exploring minimum displacement visible in particles, liquid or sand. The main goal of displacement understanding is to inform the digital particles by the sound waves coming from preset source points. This information contains the location data designated by the waves for the points. The essential trigonometric periodic functions, such as sine, cosine, and tangent, simulate sound waves in a digital environment.

Tuan et al. [TLW*18] experimented with point-driven modern Chladni systems subjected to orientation symmetry breaking. They suggested that the plates with square shapes were employed in the exploration, based on the property that the orientation-dependent elastic anisotropy is controlled by trimming the sides with a rotation angle matching the characteristic axes of the brass. The driving position of advanced resonant methods can turn into the nodal point, whereas this position is always the anti-node in the isotropic case. The method was numerically verified by resonant frequencies and Chladni patterns reconstructed with the developed model. The approach shows the feasibility of the produced model to define point-driven Chladni systems with orientation symmetry breaking, also providing a tool to use the analytical model, analysing elastic constants of orthotropic plates.

4. Methods

Therefore the research method involves the following steps:

- Exploring available Chladni plate software with a simplified user interface (SUI).
- Materialising sound resonance images, using a suitable tool such as the Chladni plate software for generating sound resonance shape maps, which can then be used in bump and displacement mapping.
- To experiment exploring ways of using volumetric deformable shape maps to blend these intricate sound resonance patterns in VR applications for bidirectional modelling.
- System refinement of integrating tools for bidirectional modelling towards fabrication.
- Transform the resulting complex 3D shape models from the above steps for rapid prototyping using appropriate pre-print tools by remeshing and physics manipulations.
- The result is a 3D printable object form, with a high-quality sound texture overlayed and blended, that changes the form of underlying 3D objects, demonstrated using off-the-shelf tools.

4.1. Creating Chladni image

Figure 9 shows our test -1, experimenting by trial and error approach and validating the outputs images of the frequencies through adapting some frequencies to compare the accuracy from Tuan et al. [TWC*15]. Figure 9 also illustrates the comparison of two outputs with similarities in the nodal and antinodal lines. The Chladni plate software used in test-1 is also straightforward and user-friendly. The software uses similar functions as **Cymatify** such as image properties, frequency value, amplitude, and attenuation. The render baking time is instant for an image sized 500x500 as a default setting in the software, and for an image sized 1024x1024, it takes about 3-4 seconds, depending on the used device. The export option format varies from png, jpg, tga, tiff, gif, bmp and wdp.

4.2. Materialising Sound

This section talks about converting the exported file from Chladni software to a .png file as an example to be converted to material in an open-source software called **Materialize** [Mat18]. It is an excellent tool for producing materials for 3D modelling and games from images. Materialize makes possible to design a complete material from a single image with export and import, controlling many

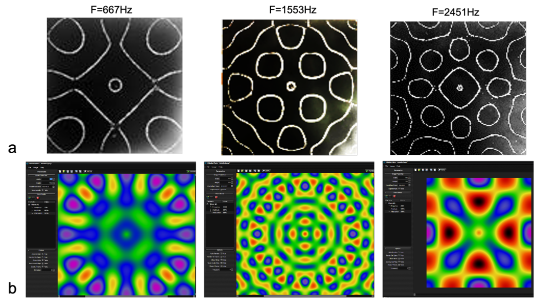


Figure 9: *Chladni Test-comparing outputs [THL*21]and Self-experiment (video demo) [Chl22].*

textures functions similar to the procedural texturing to generate the required detailed textures you need. This process opens up an extensive spectrum of opportunities to improve 3D designs for additive manufacturing with 3D textures. These maps can efficiently be generated using the Materialize software employing 2D images with a few simple steps. The render-baking time is instant. The software generates a collection of textures such as metallic, smoothness, occlusion and more textures for most environment materials. It can import and export in many file formats: bmp, jph, png, tga or iff. Finally, the texture collection is saved and exported as a png file as an example of this step to be imported into 3D modelling software.

4.3. Texture Folder

Next, it is essential to save the collection in a folder using 3D modelling software such as **Blender**. To archive textures, a simple add-on is used for **Blender**, the **Poliigon Material Converter add-on**. It provides a folder for the PRB texture map by uploading the png files. This add-on appear in Blender as a set of visual texture folder. This method can be applied with any 2D texture map image and it adds a bunch of textures using a specific code name file to work in the nodes as seen in Fig 10.

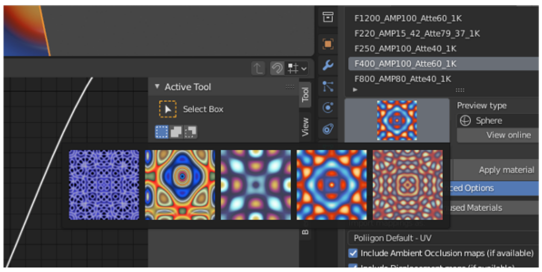


Figure 10: *Texture Map Folder collection for the end user to ease the process of texture application.*

4.4. Blender Software

After preparing Chladni sound resonance patterns, convert them into texture maps and archive them in folders, the next step is testing the textures on a 3D modelling object. First, we apply a test texture to a 3D object. Next, we test the texture application on the VR/3D object. Finally, we analyse the VR/3D object mesh and retopology the mesh using a 3D print tool to close seam lines and fill zero faces to be prepared for slicing towards 3D printing. The novel volumetric sound resonance texture aims at surface deformation of VR/3D objects showing the diversity of geometric patterns with high quality using 2D images and minimum effort of texturing a 3D object.

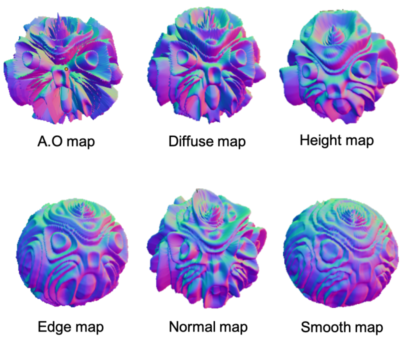


Figure 11: *Sound Resonance texture on a Sphere.*

4.5. Texture Integration

The user can select the vertex group by changing the weight to be less than the rest of the object, e.g., 0.2. to 1, or select the whole object as shown in Fig. 11. Fig 11 also shows how can one image be translated into a different relief, edges, and smoothness and can be further manipulated. The Chladni plate, in reality, mainly is physicalised on a flat surface, and shows an advantage of how we can further deform the texture matching the surface of the 3D object.

5. Related Procedural techniques Overview

This section presents some fundamental procedural techniques and algorithms that have been successfully employed within the domain of computer graphics, showing the fundamental elements and functions so we can compare them with our approach of using Chladni's patterns but not as an alternative. Next, we list some of them.

Fractals conventional geometric methods do not easily describe natural shapes. Natural shapes are complex, irregular, or fragmented from regular geometry.

L-Systems Lindenmayer developed L-Systems [Lin68] to study bacteria, and it is being used for computer graphics to visualise and simulate organic growth.

Tiling The tiling texture can be applied side by side as a copy without a seam, and it can be applied on a large surface by repeating, using images representing the formation of characters, e.g. stone, earth, wood, liquids or gases.

Voronoi Texture Basis was developed by Worly [Wor96] as a cellular texture basis function. The texture function is calculated by the distance between a lattice and a pixel point for colour control information with randomly distributed feature points in space organised as grid cells.

Perlin Noise Generates random data, and to acquire parametric control from the noise generator, a seeded random function is used, typically arranged in a line or a grid developed by Perlin [Per85].

5.1. Procedural Coherent Noise

The noise is formed by using a pseudo-random function to generate a sequence of values which are then interpolated into coherent noise. The pseudo-random function is the key of an input indistinguishable from a truly random function of the information. Several layers of this coherent noise are then composited together using different ratios to create a more natural texture similar to fractal details [BLV*10].

5.2. Pattern Generation

Pattern generation is challenging when generating a particular texture pattern procedurally. The shader can call the stored shading language function texture if the texture is simply an image texture. Nevertheless, finding particular desired textures that can be executed by locating the material or taking a photograph to be scanned to produce a unique texture image is challenging. Even if flat and smooth, the material of photographic texture images will record variable lighting conditions reflections of the environment. Moreover, this kind of texture cannot be enlarged infinitely. The procedural pattern generators are more complex to write, creating a small piece of program code that produces a conceivable representation of a material sample and is still considered an art form. The real material data are colour variations reflection properties, with surface attributes, e.g. smoothness, roughness, bumpy or hollowed.

5.3. Procedural Noise

The procedural noise shows a distinctive texture, adding a type of visual deformation and can change the object's geometry mesh by displacement. Perlin [Per85] developed an image synthesiser through an algorithm to create a paradigm extremely fast, highly realistic, and asynchronously parallelisable at the pixel level. The system's output effectively represents clouds, fire, water, wood, rock, soap films, stars, marble and crystal. Procedural noise holds many benefits of generating patterns using a very low memory for complex visual details; with a practical set of parameters, procedural noise can easily generate a large number of different patterns. Eventually, procedural noise is randomly accessible to be evaluated independently with the advent of massively parallel GPUs and multi-core CPU systems.

Next, we list the kinds of Perlin noise:

- Classic Perlin noise
- Improved Perlin noise: this is an improved version of classic Perlin noise.
- Simplex noise: it is a method developed by Perlin [Per01] same as a Perlin noise based on a simple grid, generating a smoother pattern of dimensional noise function, and it is comparable to Perlin noise but with fewer directional artefacts and, in higher dimensions, a lower computational overhead.
- Value noise: this method uses simple values and smooth and natural appearance without the block hash pattern, and the noise function produces a continued pattern.

5.3.1. Noise Function

The Perlin noise function generates random data, and for the parametric control, there should be a noise generator and a seeded random function. There are three functions: *fade function*, *hash function*, *gradient function* and *pseudo-random function*. These functions are useful for games and other visual media.

5.3.2. Interpolation Function

The interpolation is the curve fitting process that intersects through data points and this function. The function a discrete data set of the function through the provided data points.

5.3.3. Turbulence

The turbulence is more artificial than natural, and it is produced from interpolated noise with random properties. Each layer of noise is called an Octave, and layers are combined with various frequencies and amplitudes. The variety of frequency and amplitude can be expressed as a Persistence value that helps describe the influence successive octaves have on the previous iterations by defining the amplitude with octaves as a fraction. The Perlin noise generated appears smooth with a lower ratio smoothness with very fine detail [SB08].

6. Results

This section presents how we used a primitive approach of image-based modelling in simple steps, capturing the Chladni pattern phenomena of detailed geometric compared with procedural textures. The Chladni pattern delivers a different texture of geometric shapes rather than curves or straight lines. The material's generative colour helps create a dimension of depth in each image with high resolution and fast in render baking.

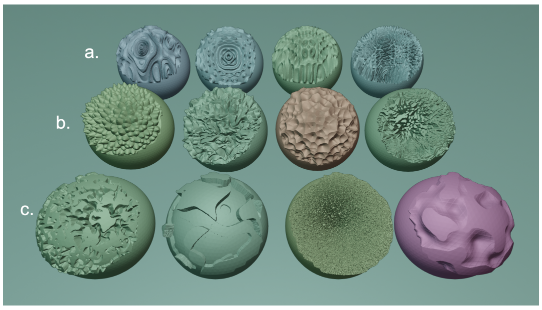


Figure 12: *Texture example: (a) shows the Chladni texture as a geometry based fractal pattern, (b) presents noise textures of Voronoi and (c) is a perlin texture*

The integration of the Chladni plate with the Materlize software generates the output by using a controllable material function [Mat18]. The tool can be described as a tool that converts the outputs of images to a material that can be used to overcome shortcomings with attributes such as location, orientation, and diffuse colour. The outcome of the integration of the software creates an adequate control and generates a texture map pattern during the baking process. On the other hand, the Chladni plate method cannot be used for any procedure; conversely, Perlin noise can be used for any set/range of function/procedures. The Chladni technique could be done as a special Perlin, but cannot be used for any Perlin function/procedure. In Fig 12 we show the comparison of Perlin, Voronoi textures and Chladni patterns , demonstrating the differential functions of each method and how it can be implemented on a 3D model. Also, we demonstrate some of our successful application on 3D models as illustrated in Fig 13. Fig.14 shows a texture on curved surfaces to the left and uneven block surface to the right. Fig 15 demonstrates a texture on a low thickness plane.

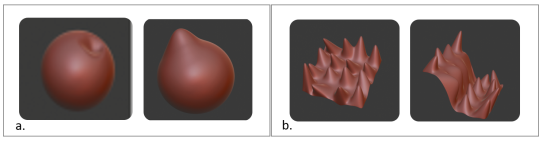


Figure 13: *Texture Deformation Properties. Source: [DPNN*22].*

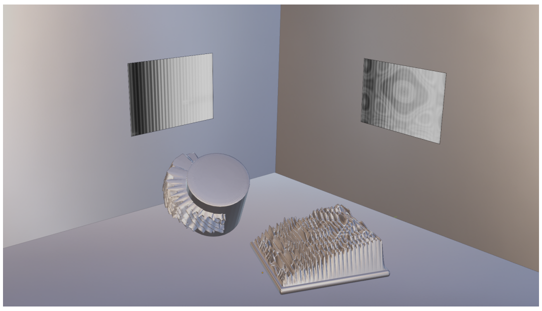


Figure 14: *Sound texture test 2: integrating two Chladni textures on one model creating an advanced deformation shown on the background walls.*

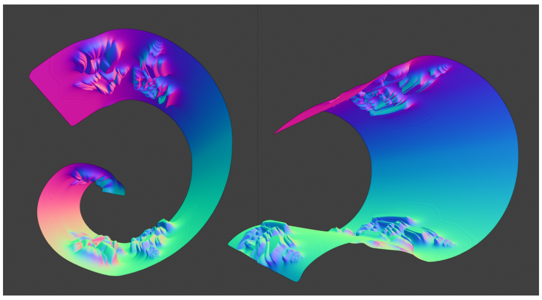


Figure 15: *Sound texture test 2.1: we demonstrated how to apply Chladni texture on on a curved plane, showing interactive texture deformation.*

The Chladni plate system can be implemented using software that generates a fractal and then converts it to an image. The image then should be converted into a texture map to be displaced in 3D software with re-topology. Finally, a slicer software transforms the model into a 3D printable object as illustrated in Fig. 16

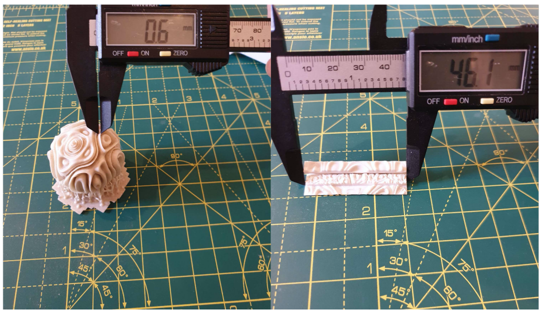


Figure 16: *3D print outputs using Chladni texture: on the left, we demonstrate a Chladni texture application on a sphere, and on the right are 3D prints of three patterns on plane slices.*

7. Conclusion

The paper presented a novel 3D sound resonance texture for deformable shape modelling, showing new results to contribute towards texture visualisation knowledge. The approach showed how to capture the essence of sound energy through simple applications, and the outcome image can be used in 3D modelling software and applied as a texture. The workflow processes have been accomplished using standalone information systems of Chladni plate and the Materialize software with an addon folder that contains Chladni's image texture maps for easy user access.

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