Virtual Pottery: Deformable Sound Shape Modelling and Fabrication

Sarah Dashti, Edmond Prakash, Fiaz Hussain and Fiona Carroll
Cardiff Metropolitan University, Cardiff, United Kingdom
klam2006@hotmail.com | {*EPrakash* | *FHussain* | *FCarroll*} *@cardiffmet.ac.uk*

***Abstract*—We introduce a novel system and technique for materialising the deformable shapes of sound-resonance on 3D objects. This technical framework presents a novel approach using a series of simple processes to manage complex object transformations that can be used in virtual, 3D modelling and augmented reality interaction. Our method involves:**

- **First step is on materialising sound resonance images by 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.**
- **Next we experimentally explore ways of using volumetric deformable shape maps to blend these intricate sound resonance patterns in virtual pottery applications.**
- **We then extend the method to 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 then 3D printable object forms, with high-quality sound texture examples overlayed and blended, that changes the form of underlying 3D objects.**

We demonstrate our method using off-the-shelf tools.

***Keywords*-deformable-shape; virtual pottery; sound-resonance; volumetric textures; 3D printing**

I. Introduction

In this paper, we explore the fabrication of integrating deformable shape models with detailed volumetric texture modelling using sound resonance from Chladni plate[1] software to visual property of a rigid and non-rigid surface [2], also called Cymatics [3], representing the unique information contained for AR/VR applications.

Interactive modelling of sound resonance shapes for 3D making have several challenges and desirable properties:

- **Labour and Compute intensive:** Sophisticated approaches for 3D deformable shape modelling are available to create realistic output, through 3D data input of deformable physics-based simulation, still considered as a labour-intensive and time-consuming [4].
- **Innovative Art Designs for Artists:** Recently, several traditional ceramic artists are engaging with digital modelling, and others of different artistic backgrounds towards creating contemporary innovative art designs [5], using creative technologies and approaches to capture interactive data [6].
- **Fabrication:** Our focus is to assist users on interactive physical modelling with sound materialised designs as a deformation effect [7], [8] using virtual modelling application for the basic shape and then create mesh designs with 3d modelling software, e.g. Unity-mesh [9] and Blender with ability to export STL files for rapid prototyping using different mediums [10].
- **Capturing Energy Forms on Material:** In the past few years, artists and users explored ways of physicalising energy forms as active data, e.g. magnetic energy [11], sound waves. Our focus is on Cymatic resonance on a flat surface [12], capturing the concept of real object physical deformation properties and how would the volumetric texture react on a 3D model (Figure 1).

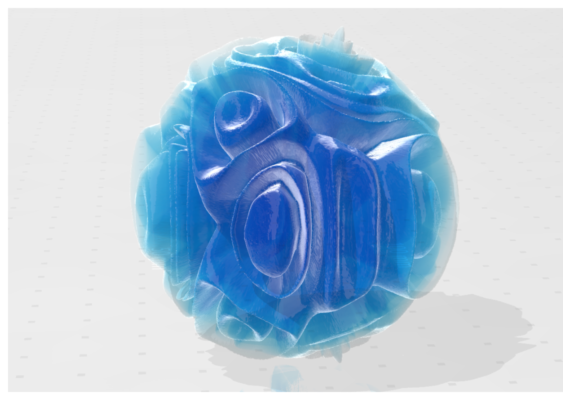

Figure 1. Volumetric 3D Sound-Structure Texture Modelling.

- **Representations:** Deformable shape modelling uses algorithms and techniques to represent the shape and realistic surface transformations [13]. The proposed new approach incorporates ways to design, develop and demonstrate a simple system and workflow innovation, for art embodiment of physicalised acoustic resonance of 2D sound data through 3D deformable modelling and control [14] to produce textured mesh maps.
- **Blending Sounds in Fluid:** Real physical shapes and textures are the primary sources of information towards deformable shapes of rigid and non-rigid forms [15]. This technique creates low technical user engagement of a digital modelling and fabrication [16], towards creating a natural parametrisation with material manipulation of physical forms and properties [17], e.g., density and viscosity[18], using a series of images and animated graphical sounds exploring volumetric

deformable 3D textured shapes [19].

- **Sound as a Volume Texture:** There are many works on creating deformed surfaces using different types of maps and modifiers integration to represent a genuine detailed surface extending the concept of volumetric texture [20], displacement and bump maps [21].
- **3D Fabrication of Sound:** Therefore, sound-structure texture explores ways to model and fabricate 2D images [22] using maps with mantaflow physics[23], creating a volumetric surface that generates fine detailed features [24]. The prototypes explore different printable materials, e.g. ceramic resin and PLA.
- **Physical-Simulation:** Object deformation simulating real-physical object flexibility by transforming shells is demonstrated, e.g., bending and stretching [25]. These maps and textures techniques, allow the geometric object of substantial volumetric shapes to produce a real physical simulation for a considerable flexibility [26], having a more realistic prototype of sound resonance textures diffing real-world physical constraints [27].
- **Natural phenomenon:** A fundamental reason for traditional and digital artists to consider this novel approach is that it utilises natural phenomenon [28] with creative designs using 3D modelling technology and rapid prototyping, that can communicate digital and sound energy[29]. Also, developing textured forms promoting creativity and productivity of having a functional art embodiment of physicalised data.
- **Contemporary Designs for Other Applications:** Finally, understanding the impact of high-detailed manipulation interference with digital modelling and fabrication would be beneficial for contemporary designs [30] for, e.g., ceramic artist, product designers, makers and also game designers to produce distinctive immersive deformable textured shape models.

Furthermore, we present a novel approach for virtual pottery and 3D modelling with augmented reality interaction, delivering a high-quality prototype. The framework offers a simple 3D texture modelling and digital material properties manipulation [31], using sound images to produce '3D Sound-Structure Texture' exploring new horizons of making in contemporary ceramic art.

II. Mouldable Shape Representations

Mouldable shape representations and research on these models have attracted the attention of several computer graphics researchers and modellers over the past few decades. We present some classical representations below.

1970-1990: In the 1970s early ideas and concepts on digital and graphical Clay Moulding and Sculpting were proposed by Parent [32]. Technology allowed wire-frame shapes to be modelled. Geometric shapes and their interaction led to intersection of surfaces which were addressed to form complex 3D shapes. Terzopoulos et al. [33] have proposed representations both for elastically deformable objects, as well as objects that exhibit more fluidity as well as plastic deformation. Coquillart [34] introduced free form surface shape deformation (sculpturing and moulding) and also used the term 'mouldable shapes' based on an extended free form deformation of latices. The article also shows realistic shape changes through a range of examples including cloth.

1991-2000: Szelski and Tonnesen [35] present surface modeling with oriented particle systems.They demonstrate greater flexibility in defining surfaces using particles that facilitates bending, cutting and merging. Gibson and Mirtich [36] present a comprehensive survey of Deformable Modeling in Computer Graphics. This captures a wide spectrum of techniques from the free form to a more physically based deformation representation.

2001-2010: Sourin [37] first demonstrated highly intricate and detailes functionally Based Virtual Computer Art. The examples of carving and embossing highlighted that the time for virtual art has come. Gu et al. [38] deomonstrated that geometry can indeed be represented as images. These images enabled to capture geometry as a 2D array of vertex positions, vertex normals and textures. This added a new way of representing shapes and provided avenues for compression, sharing and deformation easier than before.

2011-2020: inFORM (Folmer et al., 2013) system attempts to use shape displays to create physical interfaces, The system however is limited to 2.5D shapes. The physical shapes themselves are captured using 1-D pins in a 2D array controlled by actuators. Arango and Neira [31] use a Unity Procedural modeller for representing deformable meshes in their virtual pottery example.

III. System and Workflow Design for Deformable Shape Modelling

This research is in physicalising the full effects of sound data on ceramics. To achieve this, our research designs, develops and demonstrates a widely deployable interactive Digital Pottery system as shown in Figure 2; and it uses deformable shape modelling to extend physical ceramics. It captures visual sound parameters through creative technologies such as augmented, virtual and rapid prototyping.

Workflow: The proposed workflow process of interactive modelling (see Figure 3) allows the users to detect flaws of the design in different layers of dimensions and realities. With this in mind, the fabrication modelling process would be much easier to generate a volumetric texture for 3D organic forms. Importantly, the deformable models and texture integration may intrigue some basic errors in 3D modelling software, and this method can make the user perception one of the analysis tools for having a high-quality textured organic form with the aid of experimental software.

Deformable shapes: Clay as material presents challenges of preserving sound deformation on a non-rigid liquid form the real-world constraints such as gravity and evaporation

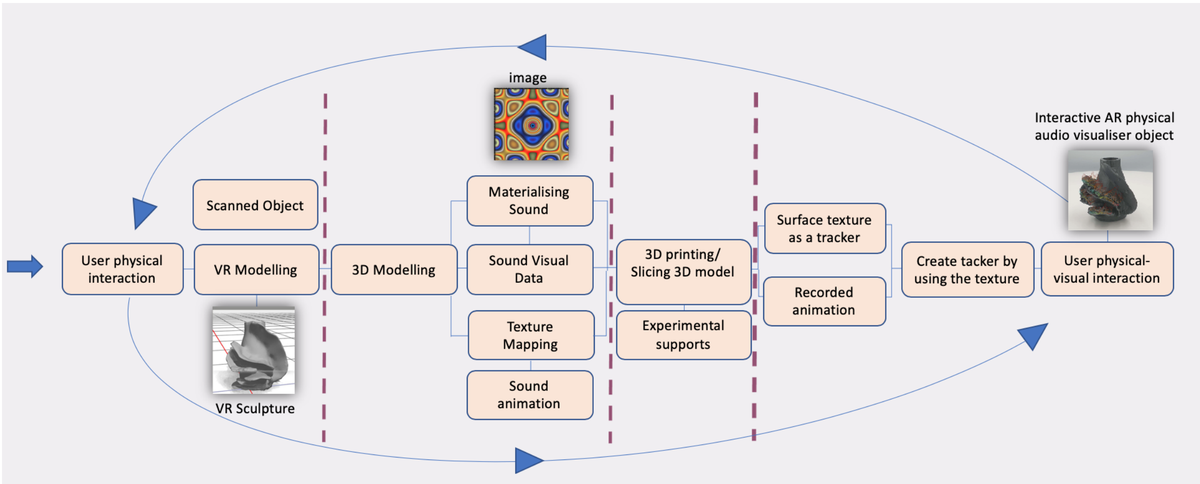

Figure 2. Digital Fabrication System.

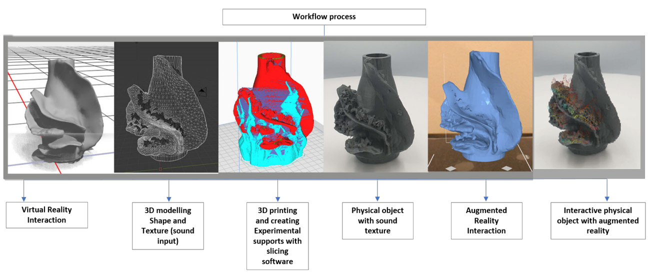

Figure 3. Snapshots from different stages of the pipeline.

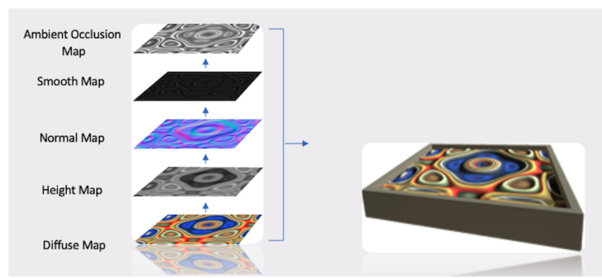

Figure 4. Materialising Maps.

prevent the consistent capturing of the dynamic visual patterns created during sound deformation on a ceramic vessel.

The innovative deformable shape modelling explores methods of integrating sound data with 3D modelling towards producing a Texture mapping technique for a volumetric sound-structure. The shape and texture are the primary sources of information to object recognition, and this approach brings more understanding of how sound travels through non-rigid forms. This technique creates a more natural parametrization of realistic fabricated graphics into interactive physical and 3D shapes.

Interactive virtual physical 3D modelling is chosen as a way of extending ceramic artist creativity of making, upscaling the boundaries of creative making and to develop a multi-modal interaction that simulates physical-virtual that captures real-world deformable pottery making (addition/ subtraction) using tangible hand and finger transformation.

Materialising Sound: This process opens up an extensive spectrum of opportunities of how to improve 3D designs for additive manufacturing with 3D textures. These maps (see Figure 4) can efficiently be generated using Materialize software employing 2D images with few simple steps.

IV. Results and Discussion

Figure 5. Volumetric Sound-structure Texture prototype.

The experimental trials of each process made the practice more focused on how to develop physical modelling for basic users using creative technology by utilising a novel texture mapping technique within 3D modelling software. Also, the experiments (see Figure 5), explored ways of deforming virtual and augmented reality objects using Sound-Structure texture, integrating 2D images with maps and physics manipulation, creating a more realistic texture.

V. Conclusion

We have presented an intensive literature review and some results of novel texture for interactive modelling towards digital fabrication for basic users. Now digital fabrication can capture the essence of sound energy by the concept of creating an object with mixed realities through animated sound texture mapping. The workflow processes have been accomplished using standalone information systems for modelling, deformation, VR and rapid prototyping, which in our future work will be integrated in a seamless manner.

References

[1] E. Janusson, J. Penafiel, A. Macdonald, S. MacLean, I. Paci, J. S. McIndoe, and J. S. McIndoe, "Orbital shaped standing waves using chladni plates," 2019.

[2] Y.-H. Kim and J.-W. Choi, *Sound visualization and manipulation*. John Wiley & Sons, 2013.

[3] P. H. Tuan *et al.*, "Exploring the resonant vibration of thin plates: reconstruction of chladni patterns and determination of resonant wave numbers," *Jl. of the Acoustical Society of America*, vol. 137, no. 4, pp. 2113–2123, 2015.

[4] R. Boyle *et al.*, *Adv. in Visual Computing: Third Intl. Symposium*. Springer, 2007, vol. 4841.

[5] J. Brundell, "Investigation into integration of digital manufacturing with ceramics," 2017.

[6] M. F. van Dartel Jan, M. A. M. Nigten, and J. van der Ster, "Virtual reality and augmented reality art explained in terms of sensory-motor coordination." in *4th International Conference on Enactive Interfaces 2007*, 2007, p. 417.

[7] P. Huang, S. Serafin, and J. O. Smith III, "A waveguide mesh model of high-frequency violin body resonances." in *ICMC*, 2000.

[8] G. Strobl, G. Eckel, D. Rocchesso, and S. Le Grazie, "Sound texture modeling: A survey," in *Proceedings of the 2006 Sound and Music Computing (SMC) International Conference*, vol. 61, no. 5. Citeseer, 2006, pp. 1–7.

[9] T. Rabczuk, S. Bordas, and G. Zi, "On three-dimensional modelling of crack growth using partition of unity methods," *Comp. & Structures*, vol. 88, no. 23-24, pp. 1391–1411, 2010.

[10] T. M. Takala, M. Mäkäräinen, and P. Hämäläinen, "Immersive 3d modeling with blender and off-the-shelf hardware," in *IEEE Symp. on 3D User Interfaces*, 2013, pp. 191–192.

[11] C. Hu, Y. Sakka, H. Tanaka, T. Nishimura, and S. Grasso, "Fabrication of textured nb4alc3 ceramic by slip casting in a strong magnetic field and spark plasma sintering," *Jl. of the American Ceramic Society*, vol. 94, no. 2, pp. 410–415, 2011.

[12] L. R. Nemzer, "Data visualization and 3d-printing," 2018.

[13] G. Celniker and D. Gossard, "Deformable curve and surface finite-elements for free-form shape design," in *SIGGRAPH Comput. Graph.*, 1991, pp. 257–266.

[14] S. Parashar, "Image-based deformable 3d reconstruction using differential geometry and cartan's connections," Ph.D. dissertation, Clermont Auvergne, 2017.

[15] S. Coros, S. Martin, B. Thomaszewski, C. Schumacher, R. Sumner, and M. Gross, "Deformable objects alive!" *ACM Trans. on Graphics (TOG)*, vol. 31, no. 4, pp. 1–9, 2012.

[16] Y. M. Tang and H. Ho, "3D modeling, computer graphics in virtual reality," in *3D Comp. Graphics*. IntechOpen, 2020.

[17] D. Fernandez Comesana, "Scan-based sound visualisation methods using sound pressure and particle velocity," Ph.D. dissertation, University of Southampton, 2014.

[18] N. Rüther and N. Olsen, "Modelling free-forming meander evolution in a laboratory channel using three-dimensional computational fluid dynamics," *Geomorphology*, vol. 89, no. 3-4, pp. 308–319, 2007.

[19] N. Pavie, G. Gilet, J.-M. Dischler, E. Galin, and D. Ghazanfarpour, "Volumetric spot noise for procedural 3d shell texture synthesis," *Comp. Graphics and Visual Computing*, 2016.

[20] L. Baboud and X. Décoret, "Rendering geometry with relief textures," 2006.

[21] L. Wang, X. Wang, X. Tong, S. Lin, S. Hu, B. Guo, and H.-Y. Shum, "View-dependent displacement mapping," *ACM Trans. on graphics*, vol. 22, no. 3, pp. 334–339, 2003.

[22] Y. Chen and H. H. Ip, "Texture evolution: 3d texture synthesis from single 2d growable texture pattern," *The Visual Computer*, vol. 20, no. 10, pp. 650–664, 2004.

[23] Y. Hu, "Taichi: An open-source computer graphics library," *arXiv preprint arXiv:1804.09293*, 2018.

[24] F. Policarpo, M. M. Oliveira, and J. L. Comba, "Real-time relief mapping on arbitrary polygonal surfaces," in *Proceedings of the 2005 symposium on Interactive 3D graphics and games*, 2005, pp. 155–162.

[25] S. D. Porumbescu, B. Budge, L. Feng, and K. I. Joy, "Shell maps," *ACM Transactions on Graphics (TOG)*, vol. 24, no. 3, pp. 626–633, 2005.

[26] Q. Liu, E. C. Prakash, and M. A. Srinivasan, "Interactive deformable geometry maps," *The Visual Computer*, vol. 23, no. 2, pp. 119–131, Feb 2007.

[27] A. Menges, *Material synthesis: fusing the physical and the computational*. John Wiley & Sons, 2015.

[28] L. Shi, Y. Guo, C. Dong, J. Huddleston, H. Yang, X. Han, A. Fu, Q. Li, N. Li, S. Gong *et al.*, "Long-read sequencing and de novo assembly of a chinese genome," *Nature communications*, vol. 7, p. 12065, 2016.

[29] X. Zhu and L. Wyse, "Sound texture modeling and time-frequency lpc," in *Proceedings of the 7th international conference on digital audio effects DAFX*, vol. 4, 2004.

[30] T. Ohdake and H. Chikatsu, "3D modelling of high relief sculpture using image-based integrated measurement system," *Intl. Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. 36, no. 5/W17, p. 6, 2005.

[31] J. S. M. Arango and C. C. Neira, "Potel: low cost realtime virtual pottery maker simulator," in *Proceedings of the 2016 Virtual Reality International Conference*, 2016, pp. 1–4.

[32] R. E. Parent, "A system for sculpting 3-d data," *SIGGRAPH Comput. Graph.*, vol. 11, no. 2, p. 138–147, Jul. 1977.

[33] D. Terzopoulos, J. Platt, A. Barr, and K. Fleischer, "Elastically deformable models," *SIGGRAPH Comput. Graph.*, vol. 21, no. 4, p. 205–214, Aug. 1987.

[34] S. Coquillart, "Extended free-form deformation: A sculpturing tool for 3d geometric modeling," *SIGGRAPH Comput. Graph.*, vol. 24, no. 4, p. 187–196, Sep. 1990.

[35] R. Szeliski and D. Tonnesen, "Surface modeling with oriented particle systems," *SIGGRAPH Comput. Graph.*, vol. 26, no. 2, p. 185–194, Jul. 1992.

[36] S. F. Gibson and B. Mirtich, "A survey of deformable modeling in computer graphics," MERL TR-97-19, 1997.

[37] A. Sourin, "Functionally based virtual computer art," in *Proceedings of the 2001 Symposium on Interactive 3D Graphics (I3D '01)*. NY, USA: ACM, 2001, p. 77–84.

[38] X. Gu, S. J. Gortler, and H. Hoppe, "Geometry images," *ACM Trans. Graph.*, vol. 21, no. 3, p. 355–361, Jul. 2002.