HeatMat: Designing Internal Structures for Supporting Hands-on Design Activity with Heated 3D Printed Objects

Donghyeon Ko
Wonder Lab, KAIST
Daejeon, South Korea
donghyeon.ko@kaist.ac.kr

Yujin Lee
Wonder Lab, KAIST
Daejeon, South Korea
neaj0812@kaist.ac.kr

Jee Bin Yim
Wonder Lab, KAIST
Daejeon, South Korea
jeebiny@kaist.ac.kr

Woohun Lee
Wonder Lab, KAIST
Daejeon, South Korea
woohun.lee@kaist.ac.kr

ABSTRACT
Recently, adopting a hands-on approach to conventional 3D fabrication has been attracting attention due to its advantages in design activity. In this context, we aim to support hands-on design activity in digital fabrication by designing internal structures for alleviating issues of external heating for shape deformation. As a first step, we simulate four simple structures with Computational Fluid Dynamic (CFD) simulation to investigate effective structural parameters such as cavity's ratio, its geometry, exposure to the heat source for influencing thermal properties, and deformation in a malleable state. Through the pilot experiment, we figured out that the simulation results of the basic structures are valid, the structure is stable in a malleable state, and the parameters are effective. In the future, we will design functional structures based on the explored parameters and embed them on various topologies.

Author Keywords
Physical manipulation, metamaterial, 3D fabrication, malleability

CSS Concepts
•**Human-centered computing~Human computer interaction (HCI)**;

INTRODUCTION AND BACKGROUND
As the developed technologies in digital fabrication have been adapting, users could fabricate an object with fewer constraints of conventional 3D printing (i.e., enriched material properties or cost-efficient process) [3,4,7,8,11,13]. In this context, explorative approaches, e.g. users engage in digital fabrication with their hands, were suggested. The hands-on approaches, such as interactive hands-on fabrication [3,9,10] or shape manipulation after printing [2,14] , introduce new possibilities to design activity. First of all, users can utilize well-suited methods, both digital and tangible. Thus, it leads to better expressiveness and convenience. Also, it allows users to iterate during printing, e.g. interactive fabrications [3,9,10], or after printing like HotFlex[2]. In addition, users can proceed with the design activity by experiencing an object's physicality such as size and proportion, unlike conventional 3D printing's virtual workspace. Finally, physically modifying an object can stimulate rigorous ideation during design activity [6]. Although studies have shown strengths of the hands-on approaches, it is still an open field, especially by means of changing to malleable state, i.e., the state of being able to manipulate its shape physically. For instance, the explored ways are yet few, embedding heating elements [2] or global heating [14]. Because design activities are usually accompanied by design tools, locally heating from outside with hand tool would be an intuitive way adapted to the design process. Thus, in this research, we focused external heating and explored ways to support hands-on design activity with 3D printed objects. Inspired by the metamaterial approach [5], we aim to control objects' thermal properties to support shape deformation by designing the internal structures.

UIST '19 Adjunct, October 20–23, 2019, New Orleans, LA, USA

ACM ISBN 978-1-4503-6817-9/19/10.
https://doi.org/10.1145/3332167.3357111

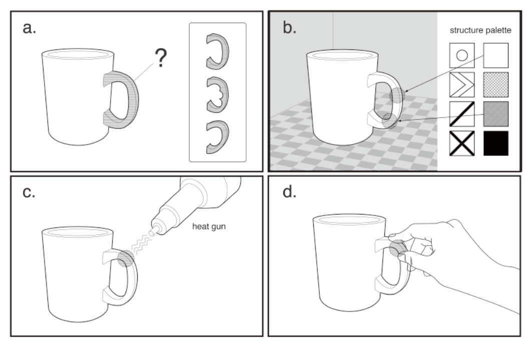

Figure 1. Workflow of HeatMat: (a) select area, (b) embed structures, (c) externally heating, (d) physically edit.

OUR APPROACH
As shown in Figure 1, HeatMat allows the users to embed functional structures into design areas while 3D modelling. The object is printed using PCL filament. Then the external heat gun is used to convert selected areas into a malleable state, and the users could physically edit the object using their hands or other tools. For this concept, we first explored

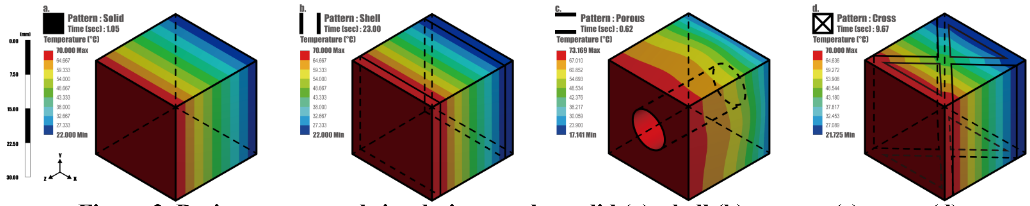

Figure 2. Basic patterns and simulation results: solid (a), shell (b), porous (c), cross (d)

external heat sources and basic internal structures. The structures were analyzed through simulation and pilot experiments to derive parameters for functional and structural design.

Exploration of external heat source

We explored externally heating sources, a laser and heat gun. For laser heating, the effectively heating spot size was relatively small and thus hard to sense and control the temperature. Also, the safety issue imposed excessive process. To test the heat gun, we built a heat gun interface with Arduino Mega 2560 manipulating temperature and wind power through PID control. We concluded to use the heat gun because of its feasibility to heat without deforming the target.

Exploration of internal structures

In case of external heating, it is hard to transfer heat up to an intended spot and easy to transfer heat to the unintended area. To resolve this issue, we adopted the metamaterial approach, designing internal structures to get the desired material properties [5]. In addition, structures would serve directional and different level of deformation in a malleable state. We set the following purposes. First, the structure would contribute to transfer heat from an external source to the intended spot. Also, the target part should have a similar level of sensitivity in shape deformation and keep stability for its structures in the malleable state. Finally, the structures would support the shape deformation like serving affordance for malleable manipulation. As heat mechanism is normally dominant with both conduction and convection, we assumed direct exposure to the heat source(convection), cavities' ratio to solid(conduction), and cavities' shape(conduction) are effective parameters. We selected four patterns: Figure 2-(a) is the control structure, *solid*; Figure 2-(b) is simple structure with cavity, *shell*(solid/cavity=4); Figure 2-(c) is representative structure of exposure to heat source, *porous*; Figure 2-(d) is the structure with different shape of cavity compared to Figure 2-(b), *cross*.

For the selected patterns, we conducted CFD simulation with *ANSYS*. As a simulation condition, we assumed multiple unit structures are infinitely connected in x, y direction and heated from z direction. Our specimen was a cube with a side length of 25mm, the temperature 70°C for heating surface, and the other side considered as a heat sink with 25°C. The results showed that porous, solid, cross, and shell has different heat transfer rate, diffusivity (37.1:21.9:2.38:1) and more higher temperature is distributed in porous . This means that convection oriented structure(*porous*) is promising for heat transfer and inner geometry affect different temperature distribution also implying directional deformation.

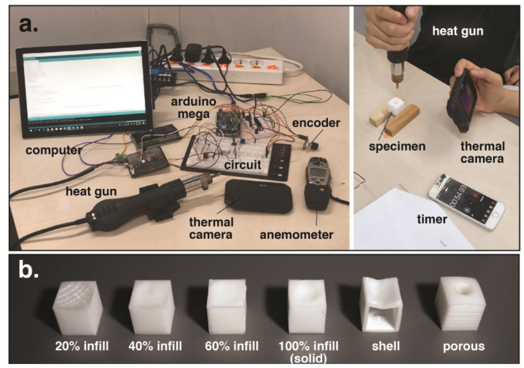

Figure 3. Pilot Experiment: (a) setting, (b) results

A pilot experiment was conducted with three basic structures (Figure 2-(a),(b),(c)) to check the validity of the simulation, examine the stability in malleable state, and realize effective parameters. We also added solid structures with different infill % to investigate different cavity ratio. We tested with a heat gun interface (Figure 3-(a)) set 5 cm away from the specimens. We pressed each specimen after heating it until the surface temperature reaches and remain 80oC for 30 seconds. As shown in Figure 3-(b), in a malleable state, all structures show high stability after compression. Also, the results (Figure 3-(b) solid, shell, porous) show a similar tendency with simulation for different heat transfer rate. For solid structures with different infill % (Figure 3-(b)), the less infill % show higher compression. However, interestingly, for 60% and 100% infill specimens, there is almost no difference implying that lower infill results in both lower transfer and easily transformed.

CONCLUSION AND FUTURE WORK

To explored functional structures to support heat transfer and physical manipulation, we explored the basic structures. Through the pilot evaluation and simulation, we discovered that internal geometry, cavity's ratio to solid, and exposure area to heat source affects heat transfer and shape deformation. For future work, we will develop the internal structures and embed them to multiple topologies by developing G-code generation software. We believe our research contributes further insights to hands-on design activity with 3D printed objects and explore its design space.

ACKNOWLEDGMENTS

This research was supported by the KAIST(Developing a Digital Fabrication System Controlling Malleability of an Object, Venture Research Program for Masters' and PhD Students in the College of Engineering)

REFERENCES

[1] Fluent Inc. 2001. Chapter 11. Modeling Heat Transfer. *Flux*: 1–104.

[2] Daniel Gröger, Elena Chong Loo, and Jürgen Steimle. 2016. HotFlex: Post-print Customization of 3D Prints Using Embedded State Change. *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*: 420–432. http://doi.org/10.1145/2858036.2858191

[3] François V. Guimbretière Huaishu Peng, Amit Zoran. 2015. D-Coil: A Hands-on Approach to Digital 3D Models Design. *Proceedings of the 33rd annual ACM conference on Human factors in computing systems - CHI '15*, 1807–1815.

[4] Scott E. Hudson and Scott E. 2014. Printing teddy bears: a technique for 3D printing of soft interactive objects. *Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI '14*, ACM Press, 459–468. http://doi.org/10.1145/2556288.2557338

[5] Alexandra Ion, Johannes Frohnhofen, Ludwig Wall, et al. 2016. Metamaterial Mechanisms. *Proceedings of the 29th Annual Symposium on User Interface Software and Technology - UIST '16*: 529–539. http://doi.org/10.1145/2984511.2984540

[6] Youn-Kyung Lim, Erik Stolterman, and Josh Tenenberg. 2008. The anatomy of prototypes: Prototypes as filters, prototypes as manifestations of design ideas. *ACM Transactions on Computer-Human Interaction* 15, 2: 1–27. http://doi.org/10.1145/1375761.1375762

[7] Stefanie Mueller, Sangha Im, Serafima Gurevich, et al. 2014. WirePrint: 3D printed previews for fast prototyping. *Proceedings of the 27th annual ACM symposium on User interface software and technology - UIST '14*, ACM Press, 273–280. http://doi.org/10.1145/2642918.2647359

[8] Stefanie Mueller, Bastian Kruck, and Patrick Baudisch. 2013. LaserOrigami: laser-cutting 3D objects. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '13*, ACM Press, 2585. http://doi.org/10.1145/2470654.2481358

[9] Stefanie Mueller, Pedro Lopes, and Patrick Baudisch. 2012. Interactive construction: interactive fabrication of functional mechanical devices. *Proceedings of the 25th annual ACM symposium on User interface software and technology - UIST '12*, ACM Press, 599. http://doi.org/10.1145/2380116.2380191

[10] Stefanie Mueller, Anna Seufert, Huaishu Peng, et al. 2019. FormFab : Towards Shape Exploration in Interactive Fabrication.

[11] Simon Olberding, Sergio Soto, and Jürgen Steimle. 2015. Foldio: Digital Fabrication of Interactive and Shape- Changing Objects With Foldable Printed Electronics. *submitted to Proceedings of the 28th annual ACM symposium on User interface software and technology - UIST '15*: 10. http://doi.org/10.1145/2807442.2807494

[12] Lucie Trhlíková, Oldrich Zmeskal, Petr Psencik, and Pavel Florian. 2016. Study of the thermal properties of filaments for 3D printing. *AIP Conference Proceedings* 1752, July 2016. http://doi.org/10.1063/1.4955258

[13] Udayan Umapathi, Hsiang-Ting Chen, Stefanie Mueller, Ludwig Wall, Anna Seufert, and Patrick Baudisch. 2015. LaserStacker: Fabricating 3D Objects by Laser Cutting and Welding. *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology - UIST '15*, ACM Press, 575–582. http://doi.org/10.1145/2807442.2807512

[14] Christian Weichel, John Hardy, Jason Alexander, and Hans Gellersen. 2015. ReForm: Integrating Physical and Digital Design through Bidirectional Fabrication. *UIST '15 Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology*: 93–102.