

# Speed of Deposition

## *Vehicle for structural and aesthetic expression in CAM*

Ashish Mohite<sup>1</sup>, Mariia Kochneva<sup>2</sup>, Toni Kotnik<sup>3</sup>

<sup>1</sup>Aalto university <sup>2</sup>unaffiliated <sup>3</sup>Aalto University

<sup>1,3</sup>{ashish.mohite|toni.kotnik}@aalto.fi

<sup>2</sup>kochnevamariia@hotmail.com

*This paper presents intermediate results of an experimental research directed towards development of a method that uses additive manufacturing technology as a generative agent in architectural design process. The primary technique is to varyate speed of material deposition of a 3D printer in order to produce undetermined textural effects. These effects demonstrate local variation of material distribution, which is treated as a consequence of interaction between machining parameters and material properties. Current stage of inquiry is concerned with studying the impact of these textural artefacts on structure. Experiments demonstrate that manipulating distribution of matter locally results in more optimal structural performance, it solves printability issues of overhanging geometry without the need for additional supports and provides variation to the surface. The research suggests aesthetic and structural benefits of applying the developed method for mass-customized fabrication. It questions the linear thinking that is predominant in the field of 3D printing and provides an approach that articulates interaction between digital and material logics as it directs the formation of an object that is informed by both.*

**Keywords:** digital fabrication, digital craft, texture, ceramic 3D printing

### INTRODUCTION

This paper presents intermediate results of ongoing research directed towards devising methodology on utilizing 3D printer as a generative element of design process. The overarching thesis is that manipulation of fabrication parameters leads to various architectural facets being informed by the process of making. The objective is to develop a rigorous system for materializing interdependencies between geometry, material, machining instructions and physical forces.

The project started with series of experiments on adding and subtracting mass from basic, hollow cylinder by manipulating deposition speed of a 3D printer. The faster printer moves the less matter it deposits. In order to render that simple principle operational, a system of multiple speed gradients arranged in rhythmic sequences was devised in G-code. The suggested method of printing creates webbing and looping, weaving and knotting ornamental expressions. To design the relationship between the speed

Figure 1  
Materiality studies

extruded ribs

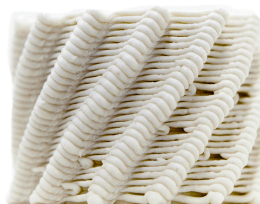
metal, 12 extruded ribs, 30°



plastic, 12 extruded ribs, 30°

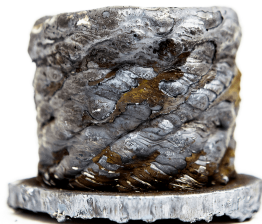


ceramic, 12 extruded ribs, 30°



ribs

metal, 12 ribs, 90°



plastic, 12 ribs, 90°



ceramic, 12 ribs, 90°

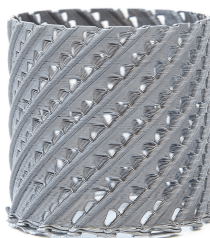


tessellation

metal, 18 indents, 90°



plastic, 18 indents, 90°



ceramic, 18 indents, 90°





of deposition and a material is to design time contingent, controlled variation of semi-ornamental mass distribution at the surface scale and beyond. Series of experiments on role of materiality in the method suggested that these textural formations may have structural implications. Slower speed can, for example, contribute to fortification of weaker points of the structure, looping and webbing excess provide a way to carry following cantilever layers without the need for additional supports. Larger surface area of the connections between layers leads to increase in structural integrity. This paper presents the work done on determining how exactly undesirable texturization can be both an expression of tectonic forces operating in a model and a field of reinforcement and stabilization.

## RESEARCH CONTEXT

Research attempts to build upon recent projects that explore unexpected and innovative ways of practising digital manufacturing (Atwood 2012) as indeterminate translation of G-code through a specific matter. Drawing partly from the concept of digital materiality (Gramazio and Kohler 2008), partly from the work on material computation (Fleischmann and Menges 2012), such approach implies the design of how numerical input is processed through a materiality constituted by properties and behaviours. In case of the project described here, that approach results in emergence of textural effects, semi-controlled formations; effectively a by-product of interaction between material and fabrication. Stringing, which is commonly perceived as erroneous side effect of unskilled design of a G-code, is encouraged in this case by intentional modification of production parameters. That subversive technique owes its theoretical base to the discourse on craft in digital fabrication. "Misuse" of the machine converts the space of making into space of discovery (Kolarevic 2008). Discovery implies an element of risk, therefore the process is continuously concerned with producing an outcome that falls within a pre-specified range, determined by certain criteria (Pye 1968). Value of indeterminacy, er-

ror, glitch and deviation resides in questioning the use of CAM as a linear sequence meant to engender continuous variation, a process that merely extends industrial mass production (Perez 2017). Digital craftsman's project is to design the interaction between digital and material logics (Gramazio and Kohler 2008) by building a system that directs how material is going to be shaped in a specific fabrication environment and allowing material to affect the outcome (Satterfield and Schwachhamer 2017).

## PREVIOUS EXPERIMENTS AND METHOD

Multiple series of hollow cylinders in three different materials (plastic, ceramic, metal) were printed using ribbing and tessellation as patterning techniques (Figure 1). Corresponding models in each of material sets were produced with the same machining setup. Accumulating or shedding mass through ribbing or tessellation requires a specific toolpath augmented by a pattern of deposition speed. The essence of the approach is to design how fast or slow or not at all printer moves in certain locations of the toolpath, how and when it accelerates, how fast does it come to a standstill. It is a temporal process augmented by materiality (Cohen 2018). Fundamentally, the framework of experimentation consists of four main agents: geometry, fabrication, material and physical forces (currently, gravity plays an important role); each of the agents in the system has a set of parameters, some are used as variables, some as constants; behavior of each agent is informed by others. Three groups of models, which have matching digital geometry and same manufacturing instructions, diverge significantly not only in the local geometry of resulting patterns, but in the nature of overall effects that they produce. Correlating models in all three materials were compared and studied to understand the difference and its possible causes. Results (Mohite et al. 2018) led us to believe that textural formations could play a structural role because adding and removing mass from an object necessarily affects its tectonic performance.

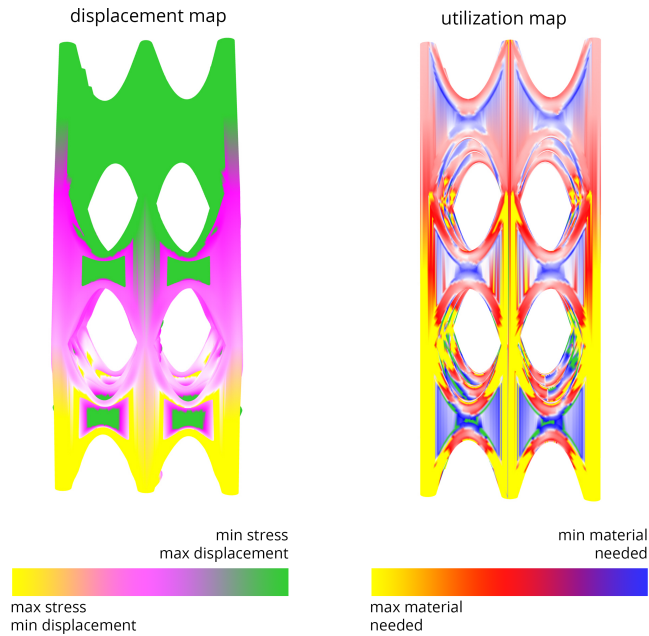


Figure 2  
Utilization and  
displacement map  
in Karamba3D



Figure 3  
progression of  
arches from  
three-pointed arch  
to round arch to  
determine the  
geometry with  
most severe  
printability issues

## PROCESS

Current project started with determining three main tasks to accomplish by employing our method:

- to print a relatively large structure with cantilever geometry without additional supports.
- to resolve structural problems that arise from self-weight and geometry.
- to provide textural variation, which is governed by tectonic forces acting in the model.

A large lattice structure, consisting of a 3-D system of 16 arches was designed to be printed. Displacement and utilization structural analyses were carried out in Karamba3D (Figure 2). Displacement map shows the distribution of stress in the shell and allows to understand where tension, compression and lateral stress occur. Utilization map demonstrates how much matter any given area of the model needs to be structurally sound. Studying both maps revealed the necessity of testing different areas of the model before printing it. Three main structural cases were discovered within the model, and it was decided to test them individually to ensure the successful production of the large model. To address these cases three models were designed to be printed with and without textural treatment. Due to time constraints, this paper presents only that preparatory work, however, these intermediate results clearly demonstrate ornamental and structural performance of speed modulation technique.

The process started with finding out which arch cannot be printed without supports as one of the goals was to demonstrate how using speed variation method can improve printability of cantilever geometry. A progression of arches from three-pointed arch to round arch was produced. It was decided to work with an arch, which when printed without speed variation fails in that a hole at the top section of the arch is large enough to instigate structural collapse (Figure 3).

Models are printed in ceramic because of larger layer height, which complicates printing of cantilever geometry. Material studies were carried out to determine the ceramic mixture, which, on the one hand is

ductile enough to allow stringing and, on the other hand, is solid enough to not break down due to excessive flowability. The final ceramic composite contained 50% kaolin, 25% feldspar, 25% quartz, to which following elements were added: 33% water, 0.5% bentonite. Ceramic is a material that undergoes several phase transitions. First, it is in viscous liquid state, then it dries naturally and then it is fired in a kiln. That means that as it dries naturally the moisture level in the model has to be continuously controlled to prevent rapid drying, otherwise cracks will appear. In a kiln it significantly shrinks, so for all the models a special base was designed so that it contracts with the model avoiding the deformation in the lower part.

The analysis of displacement and utilization maps of the large model showed that there are three main structural cases (Figure 4):

- top area, where geometry has minimal load and therefore needs least amount of material, however it is most susceptible to lateral stress and therefore deformation.
- middle area, where two different printability issues occur due to cantilever geometry. Also that area experiences lateral stress and tension.
- bottom area, which is in compression and needs most amount of the material to support the weight from above.

Based on that, three models were designed to structurally mimic the behavior of the described cases (Figure 4). They were printed without applying texturing technique. As was expected, the model representing the top section was subject to lateral stress, which produced bending (Figure 5). The model representing the middle section has failed because of lateral stress in cantilever geometry; excessive deformation rendered the model unprintable (Figure 6). The third model, while also demonstrating extensive printability problems, shows bending in its lower section, because the mass is insufficient to support the structure (Figure 7).

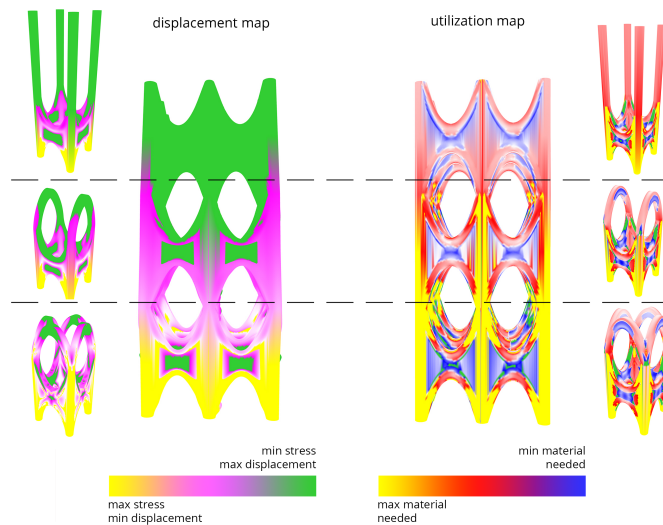


Figure 4  
Displacement and utilization maps of large model and three corresponding models.

The strategy for designing textural effects in G-code uses displacement and utilization maps as its foundation. It was decided to employ extruded ribs as main texturization technique. In some areas they are directed outwards and in some inwards. Inward ribs are mainly used to improve printability by connecting the walls that surround cantilever geometry. They are also utilized in the areas that are under minimal compression and are highly susceptible to deformation. The density of ribs depends on utilization map, directionality and length of extrusion depend on displacement map. Maps are exported from Karamba3D as a mesh into Grasshopper. Vertices' RGB values are used as color gradient that drives density and distribution of texture. Three models with effects show how the proposed method of speed variation can alleviate certain structural problems as well as ensure printability of overhanging and unsupported arch geometry (figure 8,9,10). A field of knotting and looping formations accumulates mass where it is needed and provides structural reinforcement for areas under lateral stress. As the method is focused on working with speed of deposition and

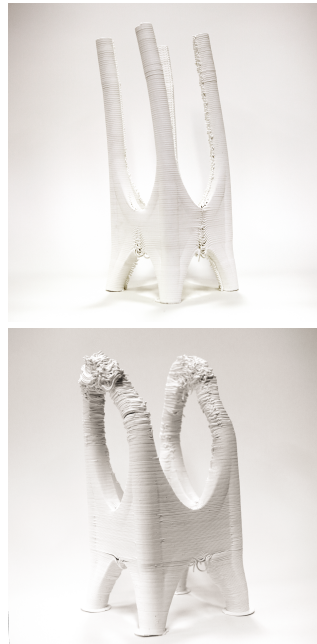


Figure 5  
Model printed without effects under lateral stress



Figure 6  
Model printed without effects. Two cases of printability issues and lateral stress

Figure 7  
Model printed  
without effects  
under compression.



Figure 8  
Model printed with  
effects under lateral  
stress



toolpath instead of manipulating actual geometry, the process of fabrication itself is designed, which ensures continuous local variation and at the same time repeatability of results. Textural artefacts are produced as an extra layer of embodiment of communication between fabrication and materiality. Patterns and effects illustrate structural tension and compression, the path and speed of a printer and behavior of composite paste. It is a materialized trace of making, not a designed shape (Cache 2004). Presented approach to 3D printing allows texture to play both ornamental and structural roles. It is not plastered on the object indiscriminately, instead, texture becomes an agent of translation of machine logic into material logic. The aim of the research is to understand and methodize affordances and constraints of a dynamic system of formation. Through persistent experimentation with patterns of semi-controlled material distribution, we hope to enrich the practice of 3D printing with the instrumentality to craft surface ornamentation as trace of structuring informed by a specific material.

## RESULTS

An established way to utilize a 3-D printer is to produce precise and predictable products, which geometrically match digital models. If customization is desired, it is achieved by creating series of parametrically manipulated digital models that are then printed. In mass construction, even if certain parts or configurations are parametrically customized as digital models, to achieve true variation from object to object is not a straightforward task. Concurrently, designing texture often lies on the margins of design process, it is rarely articulated or employed for anything beyond purely visual effect. However, it can be argued that short-range formal expressions are located in the space of convergence of material and digital logics, which makes texture into a suitable problem for digital craft. Our approach is a step towards devising a simple methodology that allows to feed textural variation directly into the process of making of construction parts based on geometry and



Figure 9  
Model printed with  
effects. Two cases  
of printability issues  
and lateral stress



Figure 10  
Model printed with  
effects under  
compression.



structural needs. With right degree of control, each instance will be slightly different in predetermined locations and in a designed way. That would allow to create 3-D texture on surfaces, reinforce structural elements and ultimately promote heterogeneity in our built environment.

## REFERENCES

- Atwood, A 2012, 'Monolithic representations', in Bordon, G and Meredith, M (eds) 2012, *Matter: material processes in architectural production*, Routledge
- Cache, B 2004, 'Towards an associative architecture', in Leach, N, Turnbull, D and Williams, CJK (eds) 2004, *Digital tectonics*, Wiley, pp. 103-109
- Cohen, Z 2018, 'Hold Up: Machine Delay in Architectural Design', in Willmann, J, Block, P, Hutter, M, Byrne, K and Schork, T (eds) 2018, *Robotic Fabrication in Architecture, Art and Design 2018*, Springer, pp. 126-138
- Fleischmann, M, Knippers, J, Lienhard, J, Menges, A and Schleicher, S 2012, 'Material Behaviour: Embedding Physical Properties in Computational Design Processes', *Architectural Design*, 82, pp. 44-51
- Gramazio, F and Kohler, M 2008, *Digital materiality in architecture*, Lars Müller Publishers, Baden
- Kolarevic, B 2008, 'The (Risky) craft of digital making', in Kolarevic, B and Klinger, K (eds) 2008, *Manufacturing material effects: rethinking design and making in architecture*, Routledge, pp. 119-128
- Mohite, A, Kotnik, T and Kochneva, M 2018 'Material Agency in CAM of Undesignable Textural Effects', *Proceedings of eCAADe 2018*, Lodz, pp. 293-300
- Pye, D 1968, *The nature and art of workmanship*, Studio Vista, Cambridge
- Pérez, SR 2017, 'Loss of control: error, glitch, and imperfection in architecture', in Borden, GP and Meredith, M (eds) 2017, *Lineament Material, Representation, and the Physical Figure in Architectural Production*, Routledge, New York, pp. 156-174
- Satterfield, B and Swackhamer, M 2017, 'Why architects should want to give up control and predictability', in Borden, GP and Meredith, M (eds) 2017, *Lineament Material, Representation, and the Physical Figure in Architectural Production*, Routledge, New York, pp. 52-60