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Brick Geometries: Characteristics of 5-Axis Tooling for Ceramic 3D Printing

Abstract

Digital Technologies offer computational models and interfaces for strategies to analyze structure, articulate design intention and develop creative production workflows. The knowledge and practice of material science, fabrication techniques and structure analysis are now well integrated with advanced geometric architectural proposals but often operating only at the scale of buildings. This work investigates the role of geometric scale within a digital framework for the production of architectural building components, namely, 3D printed ceramic bricks.

Brick Geometries uses additive manufacturing techniques to build on to more than 6000 years of knowledge in architectural ceramics. Historically associated with craft-based manufacturing or high-volume industrial production, novel ceramic forms and innovative brick structures are typically developed from a ready-made, already existing selection of building components on sets of already made or custom fabricated machines, dies and/or fixtures. In this light, 3D printing technologies offer architectural designers a break from well established manufacturing techniques. This exploration proposes a novel approach to the geometries embedded within ceramic components fabricated by 3 & 5-axis Fused Deposition Modeling (FDM) printers using Multi-Axis Additive Manufacturing as a function to rethink construction methods and geometric form.

Sample brick during extrusion (shown fully fired at right) . Part fabricated on an open-source platform[3] for ceramic 3D printing. Toolpath setting framework for discrete looping extrusion at finish layer. Photo: K. Hinz, 2016.

Contribution

1] A production platform and workflow for use of with an existing 6-Axis Industrial Robotic arm (IR) for 5-axis ceramic extrusion.
2] Introduce and identify benefits for using 5-axis 3D ceramic printing when compared with limitations encountered in 3-axis printing.
3] Propose a geometric logic for analyzing typical CAD geometry and using the output to design an parallel alternative set of geometry and/or code required to guide a typical IR.

Fully fired sample brick (shown during printing at left) illustrates unique tooling parameters that cause viscous folding in the final extrusion layer. Photo: K. Hinz, 2016.

Digitally designed with deliberate tooling strategies - traditional slip-cast production. *Chromosomes*, screen wall exploiting tooling strategies for surface articulation of columnar tile structures. Material Practice as Research, Harvard GSD Fall 2014 course.[2] Photo: Harvard Graduate School of Design - Maggie Janik, 2014.

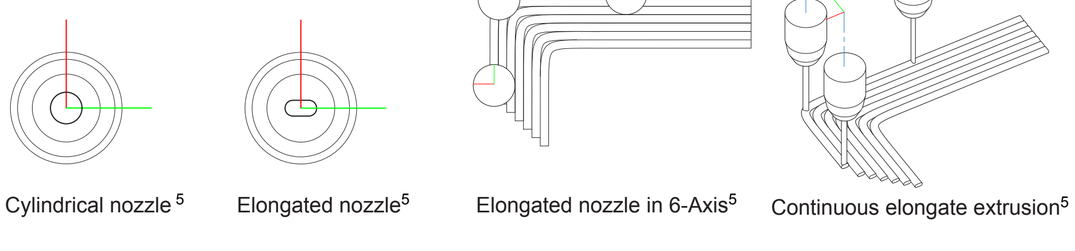
Digitally designed - traditional slip-cast production. *Ceramic Shell*, ceramic installation at the 2014 Cevisama, Spain. Material Processes and Systems Group at Harvard GSD.[1] Photo: Felix Raspall, 2014.

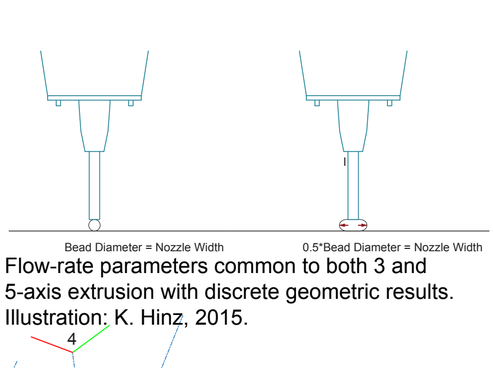
3-Axis extrusion production samples. *Brick Geometries*, MArch I Thesis, K. Hinz. Photo: K. Hinz, 2016.

Future Research

-Exploit material properties for architectural effect using 5-axis tooling and modification of extrusion flow-rate.
-Perform structural analysis tests to characterize load bearing capacities of 3 & 5-axis ceramic printed bricks and tiles.
-Establish protocol for CAM-CAM software integration for conducive Tooling generation workflow.
-Machine and material science development for integration into ceramic manufacturing facilities.

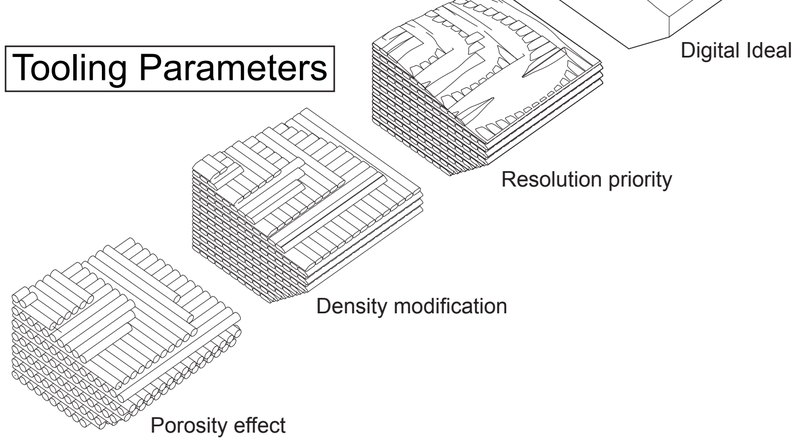
Defining Multi-Axis



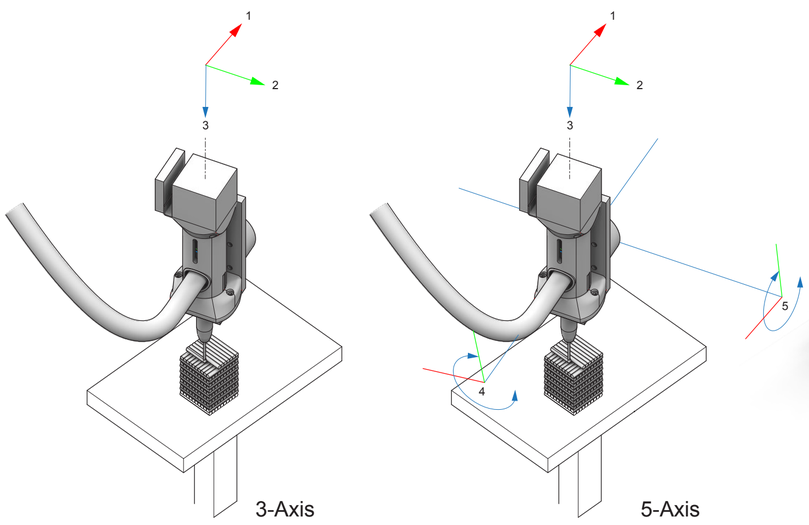


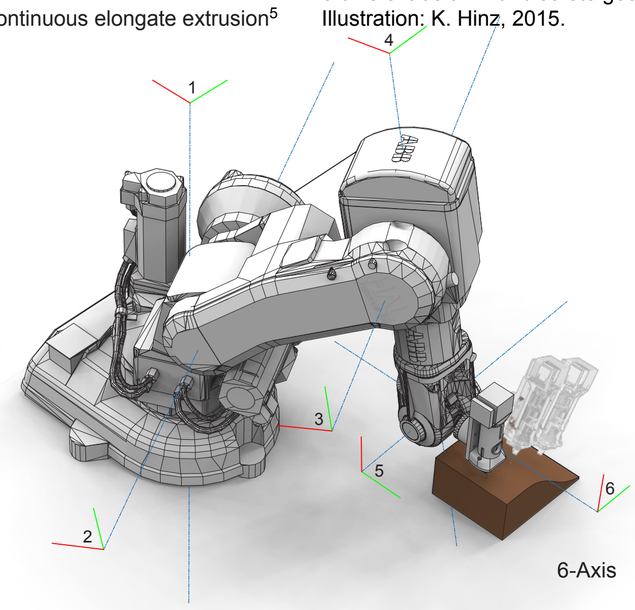
Flow-rate parameters common to both 3 and 5-axis extrusion with discrete geometric results. Illustration: K. Hinz, 2015.

Tooling Parameters

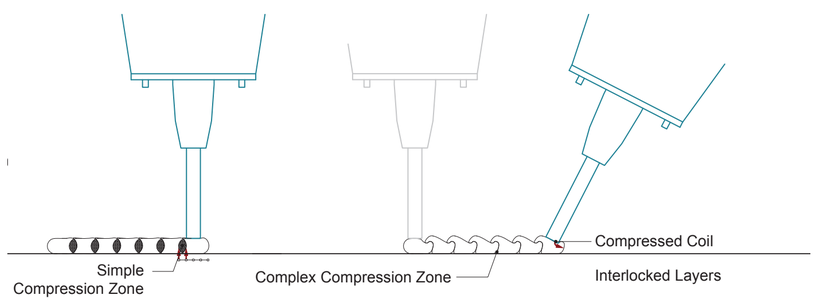


Typical 3-axis tooling parameter for priorities with limitations and their effects. Illustration: K. Hinz, 2015.





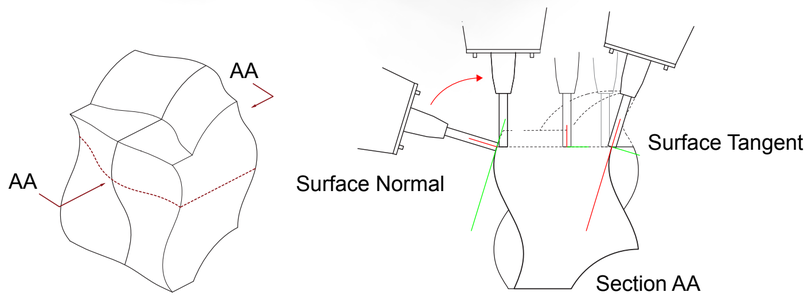
Geometric diversity of 3-axis, 5-axis and 6-axis tooling. 3 and 5-axis additive manufacturing techniques are addressed in this work. Illustrations: K. Hinz. 2015.



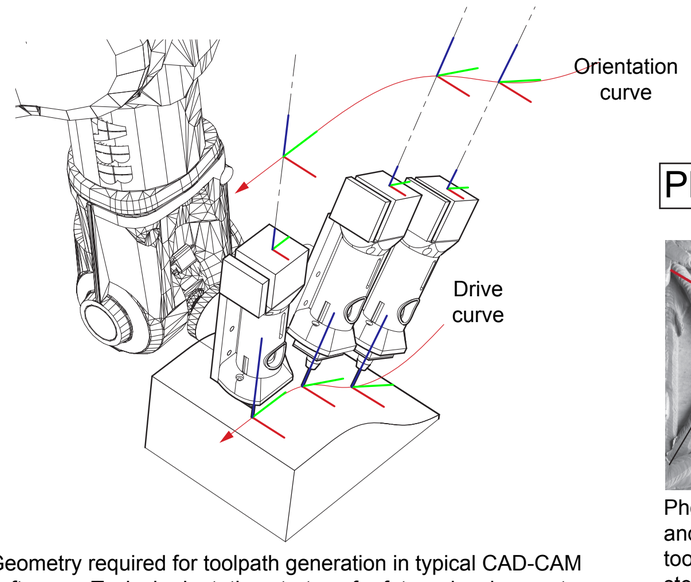
Flow-rate parameters common to both 3 and 5-axis extrusion with discrete geometric results. Illustration: K. Hinz, 2015.

Tooling Geometry

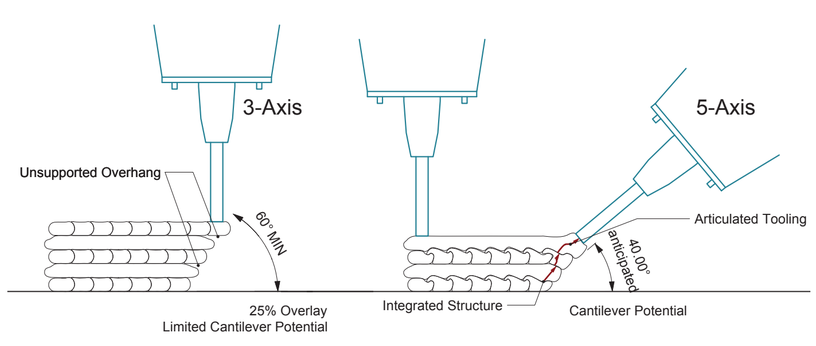
Common layer building and infill strategies for typical 3D FDM printing with ceramic extrusions. Illustration: K. Hinz 2015.



Surface analysis and orientation strategies for perimeter toolpath generation of idealized part geometry. Illustration: K. Hinz, 2016.



Geometry required for toolpath generation in typical CAD-CAM softwares. Typical orientation strategy for future development Illustration: K. Hinz, 2016.



3-axis tooling geometry limits for unsupported ceramic 3D printing. Illustration: K. Hinz, 2016.

5-axis tooling geometric potential for unsupported ceramic 3D printing. Illustration: K. Hinz, 2016.

Physical Results

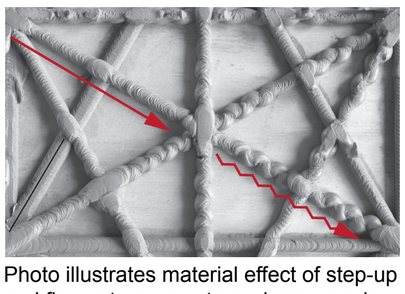
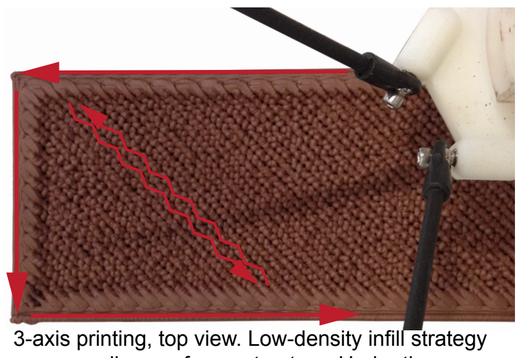


Photo illustrates material effect of step-up and flow-rate parameters where crossing toolpaths laid on the same plane disrupt steady extrusion flows.[4,6] Photo: K. Hinz, 2016.



3-axis printing, top view. Low-density infill strategy causes collapse of core structure. Under these circumstances, when flow rate > Feed rate, viscous looping can be reliably produced.[4] Photo: K. Hinz, 2015.

Notes + References

1] GSD MaP+S team: M. Bechthold, Leire Asensio Villoria, Felix Raspall, Stefano Andreani, Jose Luis Garcia del Castillo Lopez, Amanda Lee, Kevin Hinz.
2] Design team: Laura Day, Mehdi Khelif, Kevin Hinz, Quratulain Malick. Faculty: Leire Asensio-Villoria, Felix Raspall.
3] Keep, Johnathan. http://www.keep-art.co.uk/Self_build.html
Marlin Firmware. https://github.com/MarlinFirmware/Marlin
World's Advanced Saving Project (WASP). http://www.wasproject.it/
4] See authors for the mathmatics of folding, coiling and meandering viscous threads:
Bergou, Miklo´s, Basile Audoly, Etienne Vouga, Max Wardetzky, and Eitan Grinspun. "Discrete Viscous Threads." In ACM SIGGRAPH 2010 Papers July 26-30, 2010, Los Angeles, California, 1-10. Proceedings. New York, NY: ACM, (2010).
Morris, Stephen W., Jonathan H. P. Dawes, Neil M. Ribe, and John R. Lister. "Meandering Instability of a Viscous Thread." Physical Review E Phys. Rev. E 77, no. 6 (2008).
5] Illustrations by K. Hinz, 2016.
6] Prototype by Steve Fuchs. "Interactive 3D Printing." Workshop at Robotic Fabrication in Architecture, Art and Design 2016, Sydney, Australia.
7] Faculty Advisor: Leire Asensio Villoria. Sponsor: M. Bechthold Harvard GSD MaP+S.
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