The Distributed Design and Fabrication of Metal Parts and Tooling by 3D Printing

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Abstract: This new program will strive to enable and demonstrate the Distributed Design and Fabrication of Parts made by Solid Freeform Fabrication using 3D Printing of metal parts and tooling as a model system. Technical barriers to the use of an interface between design and fabrication which is based on a one-way-flow of information (no discussions) include; the design and specification of parts with local control of composition, anticipation of surface roughness and anticipation of dimensional control. These barriers will be addressed by the development of more capable representations, by the application of design rules and by the use of simple process simulation, as required. A test bed will be operated at ExtrudeHone for the purposes of: i) Testing the design tools developed, ii) realizing creative designs which exploit local composition control and iii) inserting SFF into the undergraduate curriculum at MIT.

Goals And Introduction: The goals of this new program are to:

- Identify and overcome the barriers to the practice of Distributed Design and Fabrication of Solid Freeform Fabrication (SFF) with 3D Printing of tooling as a model application.
- Operate a test bed which will allow designers in the research, educational and industrial communities to experiment with Distributed Design and Fabrication.

The successful practice of Distributed Design and Fabrication requires that a designer must be able to transmit to a remote fabrication site, a design which is known to be manufacturable. Arguably, a requirement for the practice of Distributed Design and Fabrication is the implementation of a "clean interface" between design and fabrication. The concept of the clean interface dictates that a design be communicated to those who will fabricate it by information only and not through discussion between individuals. Preferably, the information flow should be in one direction only, i.e. from designer to fabricator with no need for iteration.

There are two polar approaches in practice today for the creation of a clean interface; i) design rules, and ii) process simulations. Design rules are simple statements which capture the limitations of the manufacturing process for use by the designer. The best example of design rules is to be found in the design of digital VLSI where design rules typically take the form of constraints on the geometry of the layers in the VLSI fabrication processes. The use of process simulations is exemplified by applications such as injection molding where simulations allow designers to visualize the distribution of temperature, residual stress and other parameters within the plastic part during the molding process and thereby to modify the design of the part and aspects of the tool.

Identification Of Technical Barriers And Approaches:

Local Composition Control Many SFF processes offer a degree of control over the local composition of parts. However, current CAD representations cannot contemplate such local composition control, a clear technical barrier to Distributed Design and Fabrication. In this project we will: i) develop a solid modeling method which can represent parts with local composition control, ii) create tools which allow the designer to specify and interrogate these models, and iii) create the "post-processor" which creates the 3D Printing - specific machine instructions for making the part with local control of composition.

The solid modeling method being used as the foundation of this work is the cell-tuple data structure; a topological graph consisting of cells representing the model as different parts. Composition information will be attached to the cells representing volumes. In this way, our solid model will be decomposed into volume cells (similar to a finite element model) which contain the information about an object's composition. Initially uniform compositions will be associated with each volume. Later, analytic functions will permit the representation of smoothly varying compositions. The designer will interact with the model through a set of design approaches such as specifying cells of uniform composition, composition profiles normal to a bounding surface, etc.   The translation from idealized composition profiles to profiles realized by 3D printing will necessitate the development of algorithms to render compositions through the placement of discrete droplets of varying composition.

The discrete drop-by-drop nature of local composition control through 3D Printing makes this area an ideal candidate for the application of design rules. Design rules will play a key role in constraining the designer to the specification of compositions which can be printed and which remain true to design intent through any post-processing of the part. The definition, quantification, codification and application of these design rules will be a key aspect of this program.

Surface Finish A key barrier in many applications is the surface roughness of parts due to the effect of the layering inherent in many SFF processes. This roughness can be altered substantially by changes in part orientation during the build process and the judicious selection of layer thickness. In current practice, the choice of these parameters is left to the fabricator, with the result that the designer is sometimes surprised by the part that comes back. In order to provide the designer with the ability to anticipate and to optimize the surface finish on parts, a process simulation tool is envisioned which will allow the designer to visualize the impact of part orientation and layer thickness.

Dimensional Control The dimensional control of SFF processes, including 3D Printing is not good enough for many tooling applications. The designer must therefore have access to the dimensional control capabilities so that proper allowance can be made for finishing operations. Highly simplified models of dimensional control can be captured as design rules and this approach will be explored. However, more capable models may involve treatment of the 3-D problem in order to capture part distortions and such models are more like process simulations. Thus, in this area, we must come to grips with the basic approach to be pursued.

Operate Test Bed: A key element of this program is the operation of a test-bed facility at ExtrudeHone Corp of Irwin, PA. This test bed will be used to verify the efficacy of the representations, design rules, and simulations developed under this program first by remote design at MIT. It is expected that other University research groups will use this fabrication service to design and create parts which exploit the freedom of composition possible with 3D Printing and it is hoped that new classes of applications emerge from this work. University groups can test both MIT's design tools as well as design tools that they have developed. Industrial designers will also be offered access to the test bed and this will serve both as a test of design tools and an opportunity for creativity. Finally, 3D printing of tooling will be brought into the undergraduate curriculum at MIT by having some of the students in the Junior level class in Design and Manufacturing class create and use tooling.

Acknowledgments: Funding for this work was provided by NSF grant number DMI-9617750 and ONR grant number N00014-96-1-0857.