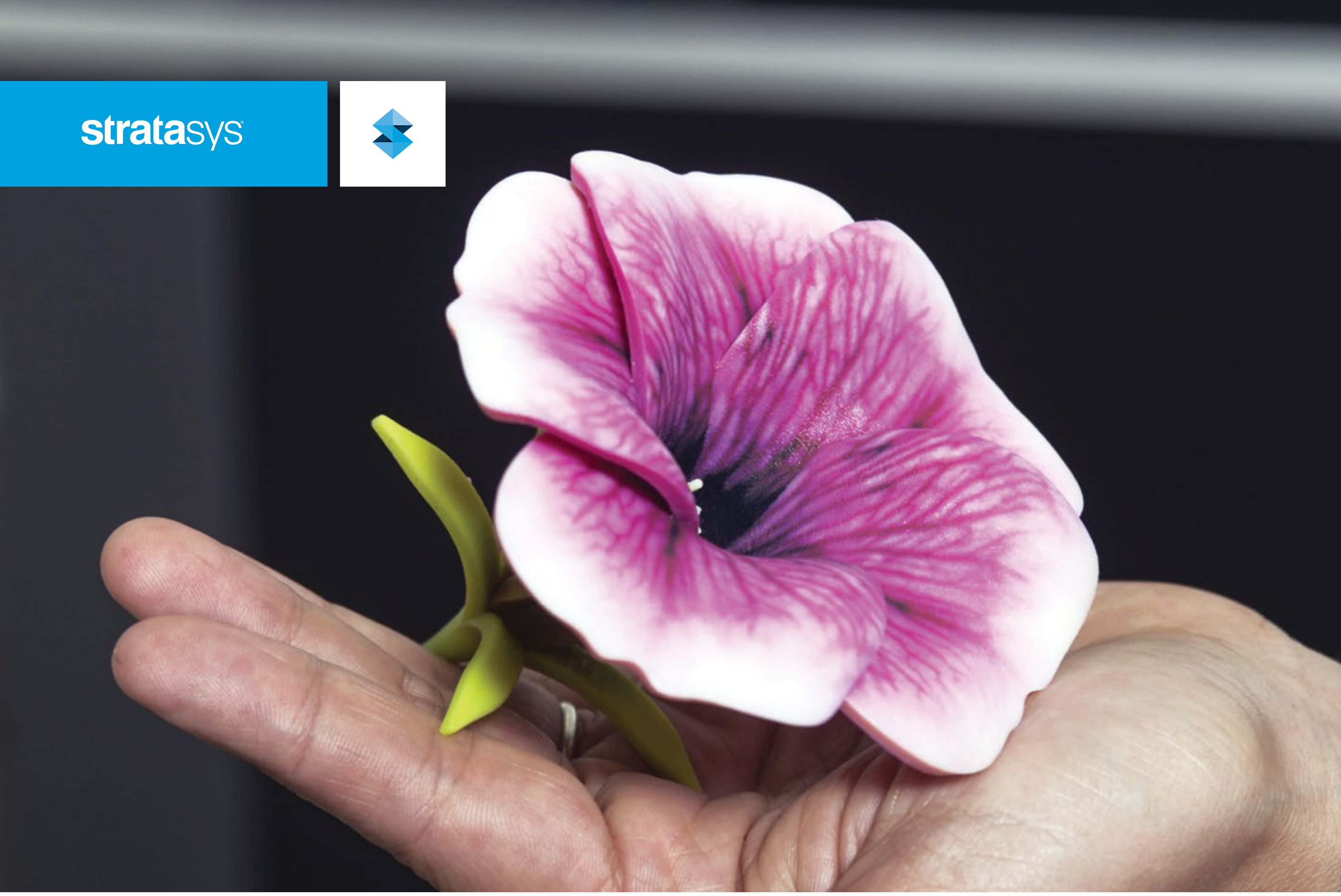

Multi-Color. Multi-Material. Multi-Disciplinary.

EXPLORING DIVERSE APPLICATIONS FOR FULL-COLOR, MULTI-MATERIAL 3D PRINTING IN EDUCATION

By Denis Cormier, Earl W. Brinkman Professor, AMPrint Center Director, Rochester Institute of Technology

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INTRODUCTION

Over the past decade, 3D printing technology has emerged as a valuable resource for colleges, high schools, maker spaces and even community libraries. The integration of 3D printing into mainstream society has given people of all ages and walks of life unprecedented access to technologies needed to turn innovative ideas into reality. All one has to do to gauge the impact of 3D printing is look at the explosion of successful crowdfunding efforts that would never have been feasible prior to the advent of 3D printing.

Nowhere is 3D printing's influence on innovation more visible than on college campuses. One might think it is primarily the domain of engineering; however nothing could be further from the truth. 3D printing continually creates meaningful curricular connections outside of engineering — faculty, students, researchers and innovators are drawing on the technology in natural and physical sciences, mathematics, fine arts, filmography and even business school curricula. This widening scope of 3D printing applications has also led to unprecedented levels of multi-disciplinary collaboration between academic programs on college campuses.

The majority of 3D printers in academia operate in a single material with fixed color and mechanical properties. However, there are new options of digital materials and full-color 3D printing, in which the color and/or physical properties (e.g., stiffness, hardness) can be specified at a point-by-point basis. 3D printers that support digital materials are not inexpensive, though. However, broad adoption of the technology across a campus can justify academic units collaborating to share the costs and benefits.

Rochester Institute of Technology (RIT) recently established the New York State-funded Additive Manufacturing and Multifunctional Printing Center for Advanced Technology (AMPrint Center), equipped with a full spectrum of world-class additive manufacturing and 3D printing technologies available to every discipline and department. Among the installed equipment base are a professional grade Stratasys J750™ 3D Printer and a Fortus 450mc™ 3D Printer, the former of which can run the full spectrum of available materials. The cutting-edge, full-color 3D printing technology now available in the AMPrint Center supports innovative applications in nearly every college on campus, including fine arts, health care, natural and physical sciences, design and engineering.

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Figure 1: RIT's AMPrint Center

FINE ARTS

Full-color 3D printing could not be a better fit for the fine arts, including painting, sculpture, architecture, film and apparel. Each of these disciplines emphasize aspects of creativity and color that are perfectly suited for the Stratasys J750 and its digital material platform.

Apparel and Fashion Design

3D printed apparel and fashion accessories have received considerable attention in the popular media. The overwhelming majority of items are produced in either black or white rigid nylon via selective laser sintering. But the Stratasys J750 3D printer lets designers incorporate both color and variable material properties (i.e., hard/soft, rigid/flexible) into their designs. Industrial design departments can use color and 3D texturing to produce 3D printed apparel with aesthetics and design elements that would be impossible to achieve strictly through the use of fabric. RIT Industrial Design Professor Melissa Moukperian and industrial design graduate student Brad Dunn took advantage of the Stratasys J750's digital material capabilities to design and 3D print a woven dress in a flexible selectively colored digital material (Fig. 2).

Figure 2: 3D printed dress

3D Printed Artwork

Traditional oil paintings consist of layers of paint with very noticeable surface texture. The same digital scanning techniques used for reverse engineering and body scanning have been used to scan both the color and 3D surface texture of paintings.

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RIT Imaging Science Professor Jim Ferwerda and his team of Ph.D. students developed software that allows laptop or tablet devices to view 3D scanned artwork with a very high degree of realism. The software uses the computing device's tilt sensors and camera to track the user's orientation with respect to the displayed image. The software dynamically updates the displayed image in real time so the user sees similar color, lighting and texture one would see when looking at the real painting[1].

The next step in this concept is to use color 3D printing to produce authorized reproductions with the same color layering and 3D surface texture as the original work of art. Lithographic reproductions are commonplace; however, 3D printed reproductions can more faithfully represent the original work of art.

HEALTH CARE

3D printing has been used extensively to improve the delivery of health care. Medical models and assistive devices are two common areas that benefit greatly from the use of full-color 3D printing.

Medical Models

Universities with medical, dental or veterinary schools can use the Stratasys J750 to print medical models from CT or MRI scan data. Scan data is typically provided in the DICOM file format which captures the density of tissue at each point in a stack of scan images. Medical imaging software, such as Materialise Mimics or InVesalius, groups regions of scan images with similar density together in order to identify and separate different tissue types (e.g., bone, skin, muscle, blood vessels). After image segmentation, each type of tissue can be saved as a separate geometric file whose color can be uniquely specified within the Stratasys J750's GrabCAD Print™ software.

3D printed color models are used for presurgical planning where surgeons devise the best approaches for difficult procedures. They can also be used to produce much more realistic medical training models produced through injection molding. Figure 3 shows a color-coded model of a dog's brain in which each distinct region of the brain is assigned its own color. The digital model of this brain was created at NC State University's CAMAL Center and was 3D printed at RIT's AMPrint Center.

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Figure 3: 3D printed color-coded medical training model of a dog's brain

Assistive Devices

The eNABLE[2] open source prosthetic hand movement was co-founded by RIT professor Jon Schull in 2014. The foundation is supported by a group of worldwide volunteers who design and 3D print prosthetic hands and arms. Prosthetics for children are a challenge given the extremely high cost given the fact that the child continues to grow and therefore requires constant refitting. Additionally, some children requiring prosthetic hands do not wish to draw attention to themselves, while others want bright and colorful prosthetics. The Stratasys J750 3D Printer is particularly well suited for this type of application, allowing for 3D printed prosthetics that match the skin tone, or done in vivid colors chosen specifically by the child.

Another inspirational example of assistive devices was created by an elementary school physical education teacher named Joe Kabes. Kabes was troubled by the fact that the school's disabled student population had few options to participate in physical education (PE) classes. He came up with the Overcomer[3] — a system of devices that connect to wheelchairs and walkers and let disabled students participate in PE class activities like bowling, soccer and floor hockey (Fig. 4). Kabes, who is also a personal trainer, approached RIT to collaborate with a senior design team of students to help refine and prototype his designs. The team, made up of undergraduate design students from a mix of different engineering disciplines, are currently finalizing the designs which will be 3D printed in a variety of colors on the AMPrint Center's Stratasys J750 3D Printer.

Figure 4: Joe Kabes' Overcomer Project helps children with physical disabilities participate in activities during PE class.

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NATURAL AND PHYSICAL SCIENCES

Anthropology

Museums often have historical or archeological artifacts that were recovered with damaged or missing pieces. Scanning technology coupled with CAD tools can be used to produce digital models of replacement and replica components complete with color information. Color 3D printing is a perfect fit for this type of application.

In some cases, an artifact may be considered sacred and thus not allowable for public display. In one such case, RIT was contacted by a museum that had several comb artifacts believed to have been used in 18th century Seneca Indian burial ceremonies (Fig. 5). Cultural sensitivities for these sacred objects prohibit their public display. In order to share these important artifacts with the public now, RIT scanned the combs with a NextEngine 3D scanner, and 3D printed color replicas for display in the museum.

Figure 5: Moose antler comb

Entomology or Botany

Faculty in some of the life sciences benefit greatly from non-perishable 3D printed color models of plants, flowers, insects and more for use in the classroom. A color 3D model can be enlarged to multiple times the real size to allow for more effective demonstration and learning without the need for microscopes. True 3D coloring lets students see actual depth of features that are not apparent with surface coloring of molded plastic parts.

Figure 6: 3D printed flower in full color

DESIGN

Marketing Studies

Color is also extremely important in consumer acceptance of products. A color 3D printer allows an entire array of product color choices to be quickly and easily produced. Marketing students using the Stratasys J750 can produce prototypes of new products in a range of different color schemes. The models can be used in customer focus group studies to evaluate consumer preferences. Researching and exploring the potential for multi-color plastic housings with non-moldable appearance texturing is invaluable to marketing students.

Personalized 3D Printing

Scanning and CAD modeling tools can be used to produce products that need to be customized for an individual, like swimming goggles whose contour is customized to fit the face of the wearer. Selective coloring allows one to have fun with the aesthetics of the personalized products as well. For example, RIT's mascot is the tiger. The AMPrint Center hosts hundreds of visitors and tours every year, and the staff wanted to design a high-impact giveaway item that was small and relatively inexpensive. The solution was

Figure 6: 3D printed RIT Tiger dice

RIT-themed tiger dice. Figure 6 shows the dice designed in SolidWorks to have the appearance of tiger stripes in RIT's exact RGB colors for the orange, brown and white surfaces. Several hundred of these dice can be printed in a single build on the Stratasys J750.

ENGINEERING

Tooling

Manufacturing engineering students can learn complex mold design principles from 3D printed tooling splits that are produced in a fraction of the time it would take to machine them. Likewise, investment casting patterns that would be impossible to produce via conventional wax molding processes can be 3D printed quickly. Time-saving assembly jigs and fixtures can be produced with molded text, color and/or icons intended to error-proof assembly operations.

Figure 7 illustrates an example of 3D printed tooling created by the AMPrint Center in partnership with a local company. After designing a new product requiring a small plastic housing to hold electronics, the company needed several hundred housings produced for testing and customer demonstrations. But they didn't have experience with injection molding or material selection, nor did they have money to produce

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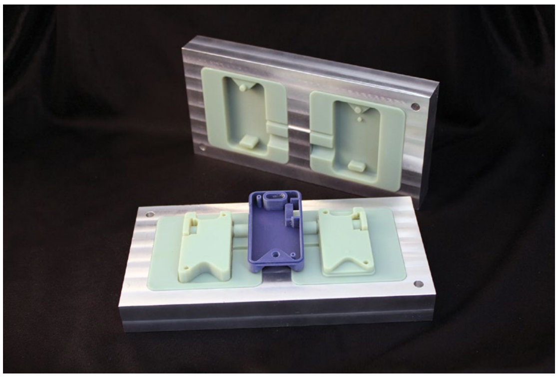

Figure 7: 3D printed injection molding inserts created by the AMPrint Center staff in partnership with a local company.

a production injection mold without knowing if the demand for the product was there. The AMPrint Center staff and students were able to assist and designed the injection molding insert tooling to mold both halves of the housing. The inserts were then 3D printed on the Stratasys J750 using Digital ABS material.

Finite Element Studies

Many engineering programs participate in SAE Formula or Baja vehicle competitions. These competitions often include a segment in which students must explain to judges why and how they arrived at a specific design for critical components. This inevitably includes the use of finite element studies to assess how a particular design geometry will perform under the expected loading conditions. Figure 8 shows an instance where a finite element study was conducted on a vehicle upright in SolidWorks. The color-coded FEA model was saved in the VRML 97 file format within SolidWorks and

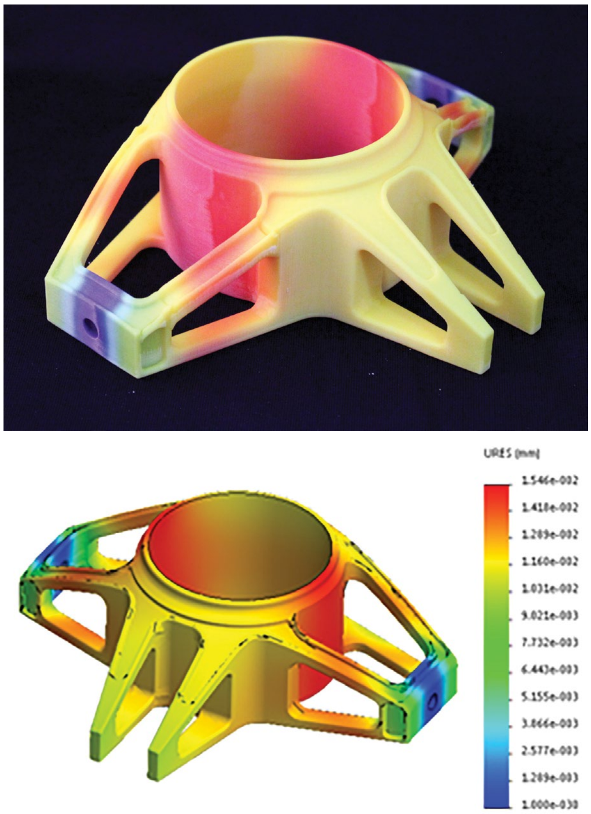

Figure 8: Color 3D printed FEA model of an SAE Formula racecar upright. Model by David Browne via GrabCAD.

then 3D printed in full color on the Stratasys J750. Colorful, 3D models such as these are invaluable communication tools in competitions where team members must explain their design process.

Conclusion

As this white paper has shown, full-color 3D printing is a great resource and provides much benefit across nearly every discipline on a college campus.

The ability to give form and substance to ideas with realistic colors and materials is instrumental in opening up opportunities and fostering curricular connections across departments. From design to fine art, life sciences to health care and engineering, full-color 3D printing pushes the boundaries of what students and faculty can do on their own, and together. The versatility of materials, application and interdisciplinary use builds bridges, inspires collaboration and ingenuity, while building a broader list of alums and strong support from donors, researchers and peers. The cutting-edge technology challenges students and faculty to drive academic programs forward by combining imaging, ingenuity and research to innovate, discover, create and design without limits.

Author Bio

Professor Denis Cormier is the Earl W. Brinkman Professor of Industrial and Systems Engineering and the director of the AMPrint Center at the Rochester Institute of Technology. His teaching and research is centered on additive manufacturing, 3D printing and printed electronics for the synthesis of novel materials and geometric structures. Professor Cormier has a B.S. in Systems Engineering from the University of Pennsylvania, M.S. in Industrial Engineering from the State University of New York at Buffalo and Ph.D. in Industrial Engineering from North Carolina State University. He is the Associate Editor for the International Journal of Rapid Manufacturing, and serves on the Editorial Advisory Board for Additive Manufacturing journal and the Rapid Prototyping Journal. He is a founding member of ASTM's F-42 additive manufacturing standards group and serves on the Society of Manufacturing Engineer's Additive Manufacturing advisory committee. He received SME's Outstanding Young Manufacturing Engineering award in 2003.

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