# The Wide Adoption of Color in 3D Printing

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*Abstract* – **Rapid Prototyping and 3D Printing (3DP) have evolved over the past twenty years through advanced hardware and software development, user adoption and the application of these technologies to a wide range of uses in industry, architecture, design and education. One sub-set of applications is the use of full color 3DP. In the past, all visual communication media like print and television/computer/cell phone screens have evolved to the point where color became the standard and desired user format. This paper outlines several use occasions for color in 3DP, describes a case study for the use of color 3DP in industry as well as uses in education.**

## I. OVERVIEW

Full color three-dimensional printing has been developed by Z Corporation and commercialized for use in a variety of industrial and educational applications. This paper will summarize a set of use-occasions for the value of color in the design process. A Case Study of an industrial user will be presented as well as a description of how color 3DP is being used in the educational sector. Finally, a brief description of the technology that enables full color 3DP.

## II. COLOR AS THE STANDARD

Practically all forms of visual media have evolved over time to the point where full color has become the standard. Full color 2D Printing was commercialized on a wide scale in the 1930's when books and magazines began to move to this standard. Motion pictures moved from black and white to color during that same decade. Television became ubiquitous in the 1950's in the black and white form. But, by the early 1980's, 95% of new units sold where color and by 1990, black and white sets where no longer available on the market. The personal computer came to market during the 1980's with offerings from IBM (and all of its licensees) and Apple Computer. Early models were all black and white. However, by the mid-1990's, all systems had move to full color presentation. Even in the past five years, cell phone screens have moved from simple data in a black and white form to full color screens offering an order of magnitude more information and options. All of the examples listed have demonstrated that over time, full color has become the standard. Technology has evolved to enable this shift and consumers, if given the choice, would rather have color.

## III. COLOR 3DP USE OCCASIONS IN DESIGN

Z Corporation introduced color 3DP to the RP market in 2001 with the Z402C. Subsequent product releases have significant expanded the use of this technology through improvements in part color quality and resolution, ease of use and the reduction in equipment purchase price. Color 3DP provides opportunities for users to further expand the effectiveness of communication in the design process. In addition, the use of color 3DP has enabled new communication uses, especially in the areas of consumer product concept design and evaluation.

Color 3DP Use Occasions:

**Manufacturing:**
**Design, Packaging, Marketing**

- Concept models
- FEA (Finite Element Analysis)
  - Stress Analysis
  - Mold flow
  - Heat dissipation
- Texture Mapping
- Presentation

**Streamline the Design Process**

- Create more prototypes, sooner
- Make ideas easier to visualize
- Make decisions faster by reviewing tangible options
- Improve clarity of communication with suppliers, vendors, prospective customers

**Jumpstart Sales & Marketing**

- Create physical representations of concepts to win business even before the design process begins
- Create realistic prototypes for focus groups
- Affordably produce a variety of options, styles, fashions
- Develop and evaluate packaging
- Begin selling before manufacturing delivers product

Examples of models where color has significantly enhanced the communication value for users are shown in Figures 1-3 below.


Figure 1.

Figure 2.

Figure 3.

Aside from the additional applications in traditional product design, there have been a range of new industries that have adopted color 3DP. These include gaming and animation, architecture and geographic information systems (GIS).

## IV. CASE STUDY – HYDROFORMING DESIGN LIGHT AB

Hydroforming Design Light AB is a maker of diversified products that are shaped with pressurized water. Their customers include Volvo, Electrolux, and Metso. In 2008, their annual turnover exceeded €100 million. The company is based in Vansbro, Sweden.

Although Hydroforming Design Light AB is driving down the cost of hydroforming, the fabrication equipment is still expensive. So they were looking for a way to demonstrate to their clients of the benefits of hydroforming their products .

During the first four years of business, they communicated FEA analysis to customers through visuals 2D presentations, a medium that required customers to make a conceptual leap because of the limits of two dimensions.

To improve their effectiveness in communicating with customers, they purchased a Spectrum Z510 color 3D printer from Z Corporation.

For Finite Element Analysis (FEA) use, color was critical to communicate design issues:

- A bright red splotch on a part design indicates a high stress or potential weakness.
- A blue patch indicates low stress or part strength. See Figure 4 below.

Figure 4. Stress Profile of hydroformed part.

Design cycles range from a week to 3 months, depending on the product.. Because of the improved ability to communicate value to customers and eliminate errors in design and manufacturing, Hydroforming Light has been able to shorten their design and production cycles by 40%.

Color 3D printing has made a big difference in the ability to demonstrate the added value of hydroformed parts and as a result, to secure business.

Additional uses within their process include printing models to show fabrication steps. In Figure 5 below, the weld joint of an automotive part is shown in red.

## VI. COLOR 3DP USE IN EDUCATION

Part of the educational buying process is that educators have to believe that the technology being considered has already been adopted by industry.

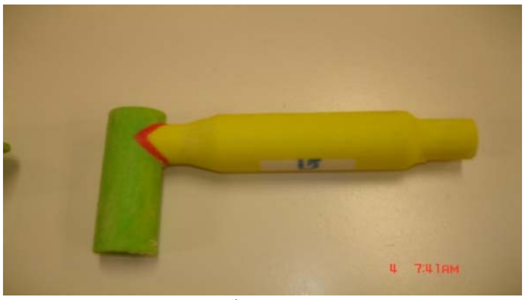

Figure 5.

Fundamentally, institutions that use 3DP / RP do better design than those that don't. They get better revenue results on their new products. They stay within their development budgets. They hit their launch dates. These are critical product development metrics and 3DP clearly helps firms improve performance on these key metrics.

Educational institutions will wish to use the tools that are being successfully deployed in industry.

Figure 6 below shows a tie between a company's use of advanced productive development tools like RP and their results.

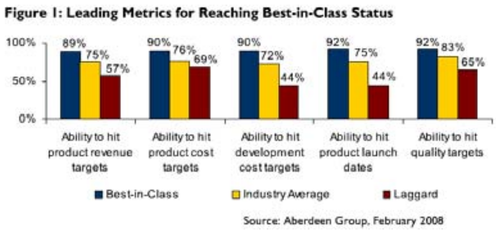


Figure 6.

IDEO is a product development firm based in Palo Alto, California and is considered by many to be the preeminent company in the field of new product design, especially for consumer products. As shown below in Figure 7 below, IDEO includes prototyping as a key element in design process excellence.

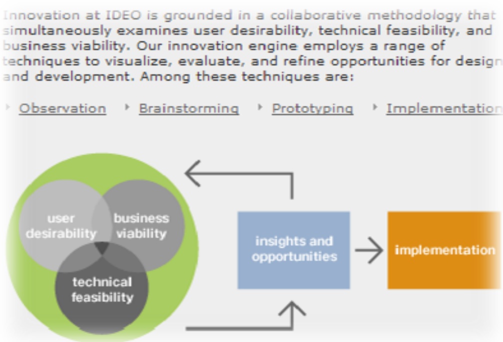


Figure 7.

Aside from industrial adoption and the use of 3DP technology as design best practice, Educators often site motivational and practical benefits of having these tools for student use. These Educators point out that 3DP, especially systems utilizing color:

- Engage students
- Enhance learning
- Encourage advancement

"When students hold parts in their hands, they're closing the loop. Until then, it's all conceptual, virtual and 2D. Completing the circle is important. *It turns kids on*."

– Bruce Weirich, Instructor, Ontario High School, Mansfield OH

"Showing off their innovations in the trophy case is a point of pride for SITHS students and *keeps them inspired* to continually improve their work."

– Frank Mazza, Instructor, Staten Island Technical High School

"Experience with 3D printing is *helping students win prized jobs* at companies like Dyson, Lego and Black & Decker, as well as admission to exclusive higher education institutions like the Royal College of Art."

– Chris Charlesworth, University of Huddersfield

Finally, it is important in the education sector that tools and process fit within established norms and standards.

In Figure 8 below, we see design process from the National Science Education Standards for Technological Design. It shows an iterative process whereby students identify problems, develop solutions, and evaluate those solutions.

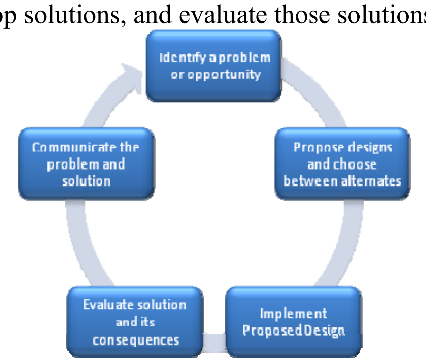


Figure 8.

"The design process includes defining a problem, brainstorming, researching and generating ideas, identifying criteria and specifying constraints, selecting an approach,

**making a model or prototype**, **testing and evaluating** the design, refining the design, **making it** and communicating results."
– International Technology Education Association - Standards for Technology Literacy

## VII. COLOR 3DP TECHNOLOGY

Traditional 2D inkjet printers have the following characteristics.

- Full, 24-bit color
- When printing 2D images from digital files, computers convert RBG values (Red, Green, Blue) to CMYK (Cyan, Magenta, Yellow, Black).
- 2D color desktop printer has a print head with 3 of the color channels CMY and another for black, K
- Using these 4 inks, printer combines several dots in each printed pixel through use of ordered dither patterns to create appearance of thousands of colors

*Application of 2D inkjet technology to 3D printing*

Full color 3DP uses many of the same concepts, except printing is done on a thin layer of powder instead of on paper. Z Corporation uses commercially available Hewlett Packard (HP) print heads in all of its platforms (see Figure 9. Below). The technology steps include:

- Input color data into software
- Software "slices" CAD file into thousands of thin layers
- ZPrint software communicates color information to printer within the slice data
- Physical model is built one layer at a time
- The ZPrinter 650 uses 5 print heads, each with a color binder: cyan, magenta, yellow, clear, black to print colors onto the shell of the part
- The same color is produced as the actual product

Figure 9.

## VIII. CONCLUSION

Color three-dimensional printing is beginning to evolve as a standard for use in improving industrial and engineering design processes as well as teaching and engaging students in the classroom. Like other media in the past that evolved from monochrome to color, it is expected that over time, users will demand full color output from the three dimensional printer or RP device.

## REFERENCES/SOURCES

References and sources are called out within the body of this paper.

Information regarding Hydroforming Light AB was provided by the company and approved for use by Z Corporation.

# Connecting Education and Industry Through Rapid Technologies

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*Abstract* – **RapidTech was established as the National Center for Rapid Technologies with funding by the National Science Foundation in September 2007. Since that time the center has assisted more than 500 companies and 150 higher educational institutions in the adoption of rapid technologies utilized in production of 3D solid models across many industries and applications. This paper will report the current status and future directions of RapidTech.**

*Keywords* – **Rapid Technologies, Reverse Engineering, Solid Modeling, Rapid Tooling, Additive Manufacturing (AM), Rapid Prototyping**

## I. INTRODUCTION

In September of 2007, Saddleback College in Mission Viejo, California, U.S.A. received funding from the National Science Foundation (NSF) as the National Center for Rapid Technologies. The goals of the center are to assist industry and education in the adoption of rapid technologies for design and manufacturing. We are also active in the Society of Manufacturing Engineers (SME) and the American Society of Tests and Measures (ASTM). Following, is general information of the activities of the center and of special note, the approach to self-sustaining activities to assist in financial support of the center.

## II. METHODOLOGY

This is an informative publication written to assist the educational and industrial audience with the role and services provided by RapidTech, the National Center for Rapid Technologies. Its intention is to broaden the awareness and existence of support available utilizing reverse engineering, rapid prototyping, rapid tooling and direct digital manufacturing.

## III. RESULTS

RapidTech focuses on Reverse Engineering, Rapid Prototyping, Direct Digital Manufacturing and Rapid Tooling. The industries utilizing these technologies are manufacturing, engineering, medical modeling, medical device, art and animation and architecture. The center works closely with industry on a national and local level by conducting research on processes and materials, and assistance in technology transfer for both industry and education. The results of this research and technology are then disseminated to the nation's higher educational institutions for adoption in engineering and/or manufacturing programs. RapidTech also works with national associations to assist industry and educational members with curriculum and technical findings to assist in decision making for adoption of the various technologies. Among the associations we are involved with are; National Coalition of Advanced Technology Centers (NCATC), Society of Manufacturing Engineers (SME), American Society of Tests and Measures (ASTM), American Society of Engineering Education (ASEE) and the Three Dimensional Users Group (3DSUG). The center is guided by an Industry Advisory Board (IAB) which meets monthly with members from leading manufacturing corporations such as Boeing, Proctor & Gamble and Ford Motor Company to name a few. Representation comes from all sectors who utilize rapid technologies. In cooperation with the IAB, oversight and guidance is provided by the National Visiting Committee (NVC) representing the National Science Foundation.

Of special interest is the relationship with SME, ASTM and 3DSUG. We are currently working on national certification for technicians in partnership with SME for standardization of skills required for the industry. This has been undertaken at the request of industry in the United States. With ASTM, we are involved with establishing the global standards for the Additive Manufacturing Industry. The membership for ASTM F-42 for this activity involves representation from the United States, Europe and Asia. Once the standards are adopted globally, RapidTech will be involved in disseminating the standards to the educational community and directly involved in the training for the standards. 3DSUG is the association of industry end users of additive and related technologies. Each year, during the summer, RapidTech puts on workshops for industry on specific processes for additive manufacturing and related technologies as well as a weeklong workshop for the nations higher educational institutions.

As mentioned in the opening paragraph, RapidTech has become the model for the National Science Foundation on sustainability. A major factor in the revenue generation is the establishment of positive relationships with industry. RapidTech provides services in consulting, research and product development services for individual companies. To date, the center has worked with over 500 companies large and small to develop first article and final products. Among this group, we have worked with individual inventors who have successfully brought new products to the global market place.

Our instructional program which is at the college through our national center is project based, with the students designing and developing products in a hands-on environment. Our philosophy is that students learn best by doing and often by making mistakes on first efforts. These are lessons that are not soon forgotten.

The data below will give you some idea of the volume of work we do with industry and education.

RapidTech is nearing the end of year two of the National Center grant with a great deal of success and activities. The Center and partners have developed new processes for the technology, are in the process of developing global standards, assisting other K-16 institutions in adopting the technology into their instructional programs and assisting industry with research on materials and processes necessary to be successful in Additive Manufacturing and Engineering. Several workshops have been presented and dissemination activities have been numerous and well attended and received. Workshops for high school counselors and faculty have been held in partnership with industry in an attempt to interest more non-traditional students into the technical programs. This newly developed workshop will be used as a model to disseminate nationally to assist other institutions with the “how to” encourage non-traditional students. In the coming year, RapidTech plans to work with two other centers to disseminate three different workshops models for adoption by higher educational institutions across the country. The following information is an attempt to synthesize and condense the activities to date so that a concise and clear snapshot of the achievements can be better understood.

- 2,000 students have been exposed to rapid prototyping technology and job opportunities.
- 175 students have enrolled in rapid prototyping classes.
- Over 500 private companies have been contacted regarding the advantages of using this technology.
- 400 private companies have contracted with the Center to receive employee training, technical assistance, or for production of models (with the work being done by student interns).
- 1,200 private business people have been involved in supporting the Center by participating on industry forums, advisory councils, and ad hoc committees.
- The Executive Director and Director have made 21 presentations in forums ranging from local area classrooms to international conventions.
- The Executive Director and Director have published 11 papers or articles on the technology, as well as numerous case studies in the field.

*Partnerships*

National Center Partners:

**Portland Community College** is focusing on incorporating Additive Manufacturing Technologies into their Subtractive Manufacturing program and is producing bridge activities. They are also conducting regional workshops exposing K-16 institutions to the new manufacturing technologies and how they incorporate with existing manufacturing technologies.

**Honolulu Community College** is working with the architectural community in developing processes to utilize Additive Technologies in model making for Architecture. They are also working with all community colleges in the islands in incorporating this new technology into the career technical programs. As part of their effort, they are developing specific processes for transferring CAD data from new architectural programs with an STL extension so that solid models of structures can be produced by Additive Manufacturing Technology equipment.

**St. Louis Community College** is focusing on processes and techniques for reverse engineering and producing solid models of the part/product. They are also working with Boeing Research and Development in providing technician training for the St. Louis location.

**Edmonds Community College** is incorporating Additive Technologies into their Materials Science center programs and working with ASTM and SME to develop standards and testing methods for Additive Technologies. MATED is also conducting regional workshops starting this summer to assist regional K-16 institutions in adopting the technology for manufacturing and engineering students.

***Affiliates:*** University of Louisville
Milwaukee School of Engineering
Georgia Institute of Technology
Central Maine Community College
UC Davis
NCATC (167 higher education institutions)
Centers for Applied Competitive Technology (14 in California)

***Industry:*** 3DSUG, Boeing Phantom Works, Disney Corporation, Proctor and Gamble, Ford Motor Co., Airflow Systems, Hester Studios

RapidTech Goals & Objectives:

**GOAL 1 Cultivate a leadership position by creating synergistic interactions among faculty members nationally for additive manufacturing and related technologies as an enabling technology for ideation.**

**1.1 Objective:** Support opportunities for the integration of rapid prototyping and tool as an enabling technology for creative conceptualization for community college faculty members and their students
- 1.1.1 Develop and implement concepts to utilize rapid prototyping as an enabling technology by diverse industries.
- 1.1.2 Identify and support opportunities for community college faculty to interact with other disciplines
- 1.1.3 Encourage the development of pedagogical interactions with all engineering and technology disciplines

**1.2 Objective:** Identify opportunities for community college faculty to interact with other disciplines beyond engineering and technology
- 1.2.1 Present case studies and publication at national conferences supported by RapidTech's web presence as a way to foster creative and innovative ideation and dialogues that encourages collaboration for development via NSF or other funding sources
- 1.2.2 Identify potential funding sources for creation of interaction among various disciplines

**GOAL 2 Disseminate appropriate rapid and related technologies regionally and nationally**

**2.1 Objective:** Develop an effective paper based as well as web presence to support dissemination of curricula, case studies, events, as well as the latest innovation in additive manufacturing and related technologies
- 2.1.1 Create web site with appropriate content and link to support national dissemination.
- 2.1.2 Create a FAQ section based on individual RP technologies and update repeatedly
- 2.1.3 Create a case study section and update continually with support of faculty involved in summer workshops
- 2.1.4 Create a list serve of faculty involve with RP and related technologies in order to help with the exchange of ideas, trouble shooting tips, helpful suggestions, and curriculum.
- 2.1.5 Evaluate user interaction with RapidTech web site using Google Analytic.
- 2.1.6 Produce two annual newsletters which will be distributed by mail and posted on the RapidTech website.

**2.2 Objective:** Provide for posting of relevant curriculum materials
- 2.2.1 Posted learning objects, modules, case studies, machinery specification, and equipment operating manuals.
- 2.2.2 Post or link to relevant curriculum materials at other locations: ATE centers and project as well as related sites such as related journals e.g. Time Compression Magazine
- 2.2.3 Cross link to other relevant websites such as COT-RCNGM, TIME, MatEd, and NCATC.

**2.3. Objective:** Ensure that the web site acts a conduit for sustainability by creating a variety of revenue streams.
- 2.3.1 Curriculum materials will be available for purchase e.g. machine manuals, training guides, post process documentation, as well as curriculum modules.
- 2.3.2 Provide original equipment manufacturers with instruction

materials and specifications to support new equipment introduction.

2.3.3 Create a comparative rapid prototyping machine and finish comparison chart for sale.

2.3.4 Provide production and consulting services on a fee basis to industry.

2.3.5 Develop and provide technical seminar for industry.

2.3.6 Generate revenue for credit and non-credit courses as well as from lab fees.

2.3.7 Establish a functional business model that evaluate sustainability based on incoming revenues vs. expenses and determine if it is sufficient to maintain center.

**2.4. Objective:** Disseminate the latest in additive manufacturing and related technologies e.g. laser scanning.

2.4.1 Publish and post annual trends via the Wohlers Reports

2.4.2 Publish and/or post pertinent technical articles related to RP from manufactures and educators from a variety of web based resources.

**GOAL 3 Provide faculty development opportunities for high school and community college educators**

**3.1 Objective:** Foster sensitivity to issues of diversity in all activities related to faculty development as well as curriculum development.

3.1.1 Provide regional and national diversity training

3.1.2 Provide ongoing analysis and feedback based on diversity training sessions to be coordinated with inside evaluator. Use results from this analysis to modify curriculum, faculty development, and projects as needed.

3.1.3 Support the development of two projects annually that encourages or provides the opportunity for culturally diverse solution

3.1.4 Design concepts will be reviewed and critiqued by diversity expert based on a specified rubric.

**3.2 Objective:** Provide summer workshops for a variety of rapid and related technologies for faculty members

3.2.1 Provide summer workshops on the latest in rapid and related technologies

3.2.2 Provide opportunities for faculty to compete in rapid technology design contests.

3.2.3 Develop and create a national design contest to challenge students' proficiency and imagination using rapid prototyping technologies

**3.3 Objective:** Evaluate the diffusion of rapid technology and its effectiveness as a pedagogical tool.

3.3.1 Survey faculty use of rapid prototyping in their courses.

3.3.2 Identify barriers that limit rapid prototyping full potential and utilization by faculty members and students.

**GOAL 4 Develop curriculum as well as outline technician competencies for rapid prototyping**

**4.1 Objective:** Faculty members will be provided multiple opportunities for curriculum development

4.1.1 Faculty involved with summer workshop will produce one case study for dissemination on the RapidTech website.

4.1.2 Industry partners will be encouraged to submit case studies based on their

**4.2 Objective:** Develop standards for certification in rapid prototyping.

4.2.1 Identify technician competencies for existing and emerging technologies

4.2.2 Develop short courses and/or modules to ensure that existing as well as the latest advances are available to educators and industry personnel.

4.2.3 Validate curriculum via subject matter experts in industry.

**4.3 Objective:** Identify new competencies based on the emergence of emerging technologies

4.3.1 Identify new student learning objectives that are appropriate for these emerging technologies.

4.3.2 Verify student learning objectives with industry.

4.3.3. Utilize these learning objectives to facilitate the development of appropriate curriculum materials as well as support faculty development efforts.

## IV. FUTURE DIRECTIONS

Rapid Technologies are currently at 20% growth rate globally, and with that comes new applications, new materials, and new equipment for additive processes. Within a few short years, Direct Digital Manufacturing (DDM) will become the standard process for product development and manufacture. Most of the current research is in the materials side for DDM which will enable the end users of the technology to utilize the technology for new applications. It should also be noted that AM is considered a green technology, as this manufacturing process reduces the carbon footprint when compared to traditional subtractive manufacturing. There is less waste material generated in the process when the comparison is made. Additionally, with the development of new materials, focus will be placed on green materials for product development. Of particular early stage green material usage will be in replacement of traditional plastic products.

The adoption of these technologies is also increasing the need for engineers and technicians to be familiar with the design process for AM. To meet this future need, Universities and Colleges will need to incorporate theses technologies into their educational programs. In the United States, this is happening on a large scale to meet the needs. It has also become increasingly important to introduce students at a younger age to the field, so RapidTech has expanded its efforts to include high school faculty and students to be integrated into the field.

In the near future, all institutions of higher learning will need to adopt Rapid Technologies to prepare Engineers and technicians to work in the expanding global market place.

## V. CONCLUSIONS

Given the wide and increasing usage of Additive Manufacturing and the growth of the field, it is imperative that higher education institutions expose future engineers and technicians on “Design for Manufacture “ utilizing rapid technologies including rapid prototyping, rapid tooling and reverse engineering.

Future engineers and technicians will have to be familiar with these technologies to assist in enabling their companies to be competitive in a global marketplace. This enabling technology allows manufacturing companies to be competitive in mass customization for manufacturing and allowing them to accept contracts for manufacturing smaller while maintaining a good profit margin. This will be especially import for smaller manufacturing companies who have not been competitive in bidding for jobs against the Asian manufacturing companies.

It is not necessary to make the capitol investment in equipment for all the different technologies in this field, lower priced 3D printing equipment and scanners can be valuable in teaching the concepts in this area without making large expenditures. One of the roles of our National Center is to provide assistance and counseling guidance to companies and higher educational institutions in the decision making process on equipment purchase. RapidTech will assist you in that process if you wish. We are a neutral entity and will discuss the different technologies and advantages/disadvantages of each technology. We can also provide assistance in curriculum development to assist in incorporating the technologies into your instructional programs.

We can be contacted through our Web page; www.rapidtech.org

## ACKNOWLEDGMENTS

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