The Good, Bad, and Ugly of Using Rapid Prototyping in Academics.

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Authors:
William M. Leonard, David M. Street

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Rochester Institute of Technology, 78 Lomb Memorial Drive,
Rochester, NY 14623

Abstract

Rapid Prototyping (RP) in academics is a powerful tool used to enhance design visualization by generating parts and assemblies from CAD files. However, RP machines can also capture a student's interest (and faculty for that matter) as well as any video game and can easily be used as a retention hook for new students to advanced undergraduate research projects. Quite often, only the machine itself and not the whole process is considered, thus leading to difficulties in its implementation. This report focuses on the application of the technology and the problems experienced implementing a Fused Deposition Modeler (Dimension BST from Stratasys) and a Powder-based/binder infusion system (Spectrum Z510 color system from Zcorp). This report also addresses future outreach to academic institutions and industry through an NSF-ATE grant of which RIT is one of five institutions throughout the country promoting the implementation of RP in the design process.

Introduction

Over the past ten years there has been a surge of technology around rapid prototyping with the development of new processes along with the enhancement of existing ones. It is a welcome relief to observe the maturing of several RP systems resulting in a substantial price reduction of the machines and their service agreements. Purchase costs of several technologies are now within reach of universities and even high schools. Material for these machines still remains expensive and service contracts seem prohibitive at first, however, it may be unwise to 'go-naked' with these systems as two service calls may just equal the maintenance agreement cost. One school has a system that had failed just 30 hours after installation and had gone just outside of the standard warranty and now does not have the budget for its repair.

Student Experience

It is amazing to watch the student interaction with an RP system for the first time. You can actually read their faces as they figure out the process and calculate what parts they could build for themselves. Visualization of their parts on a graphics screen is giant leap forward from a two-dimensional paper drawing and the students yet again leap forward in visualization when they actually hold the part in their hands. Parents are also intrigued with the RP process. One of the stops during open house visits at RIT is the RP laboratory where parts are shown and the process explained. During one of those visits a parent started to ask more questions than any of the students. She asks if her son will get the opportunity to use the RP system and excitedly expresses an interest in using it herself. When told yes, she turns around and points at her son and said 'You are coming here!' Neither students nor parents select a college exclusively for RP, however, it exhibits the state-of-the-art technology of the college.

Students can now generate working prototypes and proof of concept models not only in record time but also with a surprisingly small budget. For example, a group of

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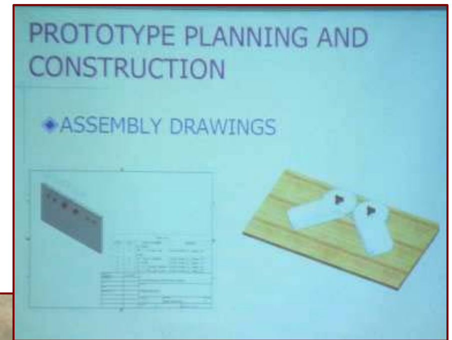
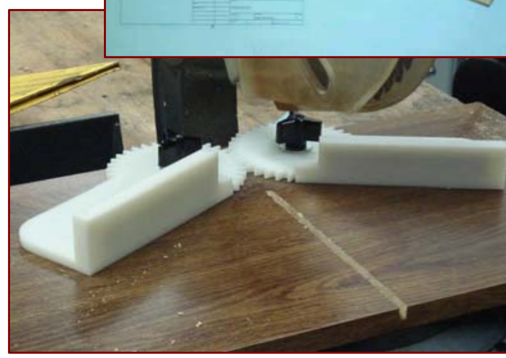
David M. Street, RIT/MET Graduate Student

students had an idea of building a better adjustable miter fence in which to duplicate cuts for any measurable angle of molding corners. This involved generating a relatively complex part that had gear teeth controlling the symmetry of the miter cut. The only reasonable way would have either been to dissect a spur gear and somehow connect it to the new fence or to possibly make the part by generating a paper rendition of the gears, pasting it onto some material such as wood and scroll cutting the gear profiles. The parts were made off a Fused Deposition Modeler (FDM) overnight directly from the CAD files and were assembled and successfully tested the next day. To the right you can see a presentation slide of an image of the CAD file assembly. Below that is the actual RP parts being performance tested in an actual miter saw. Each part took approximately 12 hours to run while consuming approximately $30.00 worth of material. The testing confirmed proof of concept and the team is exploring actual production and sales of the concept. It is interesting to note that a costly error was found on the first set that was not exposed in the CAD assembly. Some quick removal of material was all that was needed in this case.





RP has opened up a new experience to RIT's Mechanical Engineering Technology Department, where the laboratory resides, in that it is providing service to several colleges on campus such as Mechanical Engineering Science, Industrial Design, Graphics Arts, and even the Biology Department in the College of Science by developing parts and offering technical advice on a frequent basis. It has certainly increased the exposure of Engineering Technology on the campus. Industrial support is also of strategic value and is discussed in a later section. The recognition of recruitment and retainment, campus exposure, and internal support of courses is of anecdotal strategic importance at this time. It is difficult to measure the impact of RP on these issues but it is clear by the frequency of use and engagement that it has become an important and strategic factor within the department.

RP Implementation Issues

Certainly the cost of the machine is of a major concern not to mention the maintenance and material expense incurred through use. Some machines cost as low as $18,000.00 with the material running approximately three to five dollars per cubic inch. (*Prices change frequently and need to be discussed with the retailer for actual costs at that time*.) However, other factors such as noise, contamination, and complexity of process must be considered before a successful implementation of RP can be achieved.

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Every machine and its related technology has hidden difficulties that are exclusive to itself. For example, when a machine claims to be able to run in an office environment, it may not apply to an academic setting. One of the machines at RIT was installed in the CAD laboratory where there is open lab time along with course lecture time. It was found that even the quietest machine was annoying enough that fifty percent of the faulty would complain of the disruption by the motor and fan noise. Sometimes, the machine was found to be shut off (Something that you do not want to frequently do!) the next morning. Not only is it more efficient to batch and queue parts at night but some parts simply require the time to run overnight. Hence, the batch of parts is not recoverable and must be restarted after resetting the machine with a complete non-recoverable loss of material.

Level of process complexity is another issue that must be addressed. A powder-based system can not be handled practically without some sort of infiltration process. This process requires the immersion of the part into a strengthening agent such as wax, cyanoacrylate, epoxy, or wood hardener all of which requires some level of accepted risk by the user. Most all infiltrants are either highly flammable or toxic enough to be of concern to a trained operator. Health and safety are of concern here. Getting past the carcinogenic nature of the materials will lead you to the mess factor. Infiltrating a part with highly viscous cyanoacrylate requires attention from the person doing the application in order to not glue everything in the room together not to mention the part to either their hands or clothing. Fused-Deposition-Modeling (FDM) is not without its risk. The support material of the FDM is either of a soluble or non-soluble variety either of which is picked off in some fashion from the build material. (The soluble variety technically does not need to be picked away from the desired part but is usually done in order to reduce the soak time or amount of waste fluid wash.) The most effective tool to pick this material off is either a dental pick or similar device which, if not used properly, will require a box of band aids and some sort of a wound sterilizer.

To the experienced user, part orientation during build can mean a successful part or one that may be dimensionally inaccurate, missing features, or simply too weak to handle. Each of the two processes discussed here have unique characteristics that must be adhered to. For example, thin-walled cylindrical parts must be vertically oriented in the FDM in order to give the greatest strength whereas, if practical, the powder-based system also prefers to be built vertically but for a different reason. A powder compaction phenomenon is observed during a horizontal cylindrical build causing a depth-compaction of the powder resulting in an out of round or oval part.

Material management is another issue which can be costly. The way a part is built in the FDM determines the amount of support material required. For example, if you wanted to build a coffee cup, you would build the cup as you would place it to fill it whereas if you built it upside down then support material would be build up on the inside in order to make the bottom or base when it came time. In the powder-based system, unused powder is recovered during part removal from the build cavity. Not all of this material is recoverable as you run the risk of leaving broken pieces in the powder thus contaminating the build material. It is recommended that you do not recover all of the spilled or used material as it is supposed to change the material properties. At approximately one dollar a cubic inch it is simply too expensive to throw a portion away as is suggested by the company. It is up to the user to accept the risk of using recovered material.

Application of technology

When the product life-cycle is considered there are four areas in which RP parts can be useful. These are:

1. Concept phase – Cosmetic parts
2. Design phase – Form, fit, and function
3. Pre-production phase – Alternate production parts
4. Production – Direct parts.

Cosmetic parts are critical during the concept phase including marketing analysis. No amount of graphics can replace a three-dimensional part in your hand. The 'touchy-feelies' are critical in decision making especially in industrial design and product design.

Parts showing form, fit or function can be very useful in certifying proof-of-concept models or assemblies. Gear mechanisms or mechanical linkages can be invaluable for identifying interferences in mechanisms or even assembly procedures. For example, a unique pump had been designed as a senior project and was quite difficult to visualize for manufacture as the part required a five-axis CNC machining process. The assembly was produced via RP resulting in a greater understanding of design and manufacture.

As products are developed there can be times that a part must be used in the pre-production phase to fix a problem right away but must wait until a tool, such as an injection mold, is made before the part can be tested. RP parts can sometimes be used as an alternative process to provide parts until the production parts come online. Parts such as fan blades or blower shrouds have been made via RP and used in this way.

When product quantities are low enough RP parts can actually be used as direct parts in some cases where appropriate. This is the holy grail of RP with part strength, speed and cost as the limiting factors.

Identifying and strengthening the RP process in these areas provides opportunities in undergraduate and graduate research. One of the issues in RP is the precision and accuracy of parts developed. Cosmetic parts do not need the accuracy nor the precision to provide value. For all other uses within the product life-cycle, part tolerance and statistical process control are central to the RP process.

The following excerpt from a report by David Street, a graduate student at RIT, is shown below as a result of scholarly activity done to investigate the accuracy of the powder-based RP system.

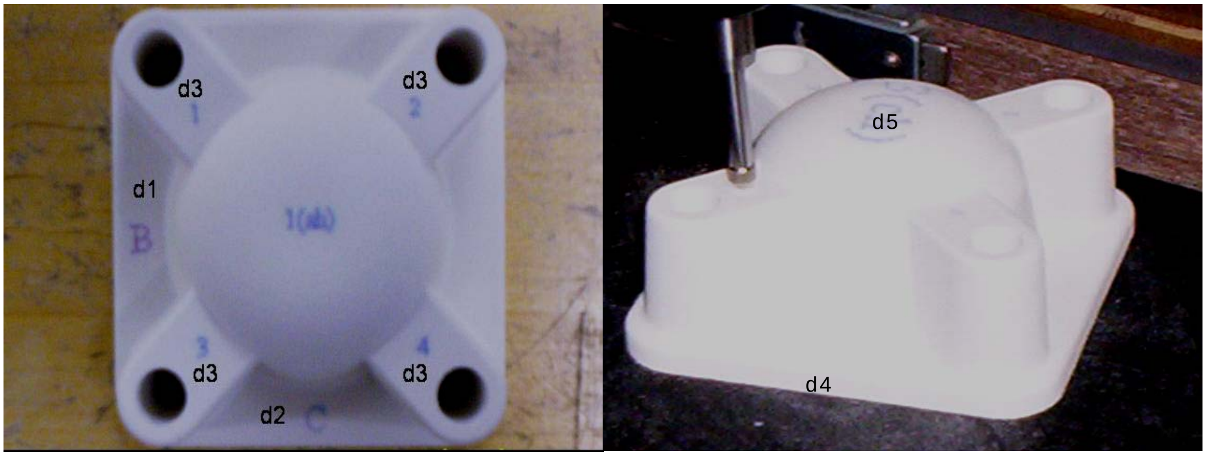

Figure 1.6 indicates that the RP 510 machine is somewhat precise but not accurate. All dimensions seem to cluster around the mean measured value and have no indication of skewing toward its upper or lower limits. The numbers seems to randomly be above or below the actual value. On the next page figure 1.7 shows the corrected process control chart. This was done by subtracting the skew of the process. By doing this it helps to indicate that the machine is capable of making parts that fall within the part tolerance. This is not always the case as in trial six the print head failed and had to be replaced immediately.

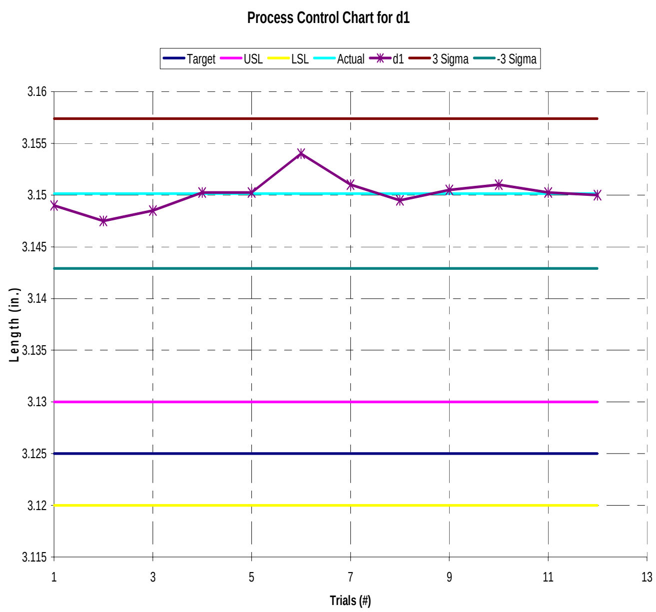

Figure 1.6 Base Control chart for the first dimension

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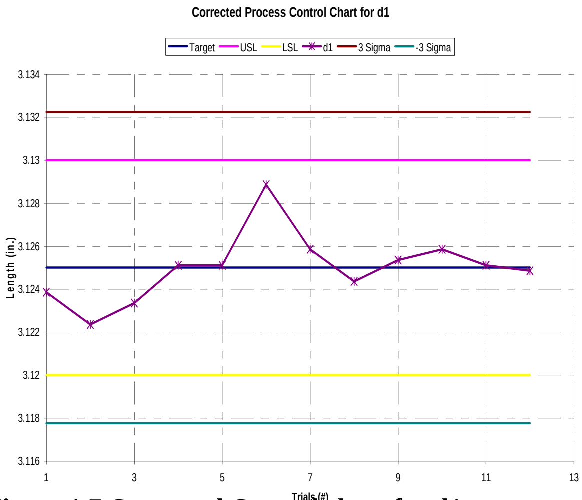

Figure 1.7 Corrected Control chart for d1

The process control chart for d2 (figure 1.8) shows a trend that is leading toward the upper control limit. This is a signal that the process is moving out of specification. These charts were repeated for all dimensions so as to convey the overall process limits of the machine. As shown by the process control charts the upper and lower specification limits are to tight for the process to meet. Which indicates the tolerance can be opened up. If left alone, trying to meet more specific specification limit then the process can provide will cause trouble and the expenditure of more time and money. As shown in figure 2.0 of the corrected d3 leg one.

Outreach Possibilities

RP machines in academics are not normally used all the time but the opportunity exists to be used as outreach to local industry or even other universities/high schools by providing parts. However, many issues need to be addressed prior to this endeavor.

Part designs are the intellectual property of the company that requests the build. The university, by its nature, is an open architecture relating to information and must be addressed prior to involvement. Non-disclosure agreements and policies must be in place before intellectual property is accepted.

The purpose of industrial outreach may be strategic, educational, or even for profit. Involving students with industry is an excellent educational experience but material expense will quickly become an issue. Collecting monies for service may violate specific grants or non-profit status of a university. Care must be taken to first understand these issues.

Even student intellectual property must be recognized and dealt with at an institute level. Design courses have to be particularly sensitive to this problem relating to student ideas. At RIT, the institute Intellectual Property Office is an integral partner in the recommendations and procedures being developed.

Conclusion

RP not only provides exceptional opportunities for students and faculty but also may offer outreach opportunities that may provide new and unique ways in which to enrich the student experience. This is a ‘work in process’ at RIT and many issues are still being discovered as RP is moving forward. Universities embarking on this endeavor need to network with others in which to better understand all the pitfalls and benefits possible.