Improving Product Design through Rapid Prototype as Design

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Abstract

Design teams are often expected to produce physical prototypes that demonstrate the working principles of the products they are designing within tight time-frames. The use of a 'rapid prototype as design' (RPaD) methodology, combined with the ability to effectively integrate the many existing and emerging virtual and physical rapid prototyping technologies into the development process increases the potential of producing new high technology products in shorter timeframes. The paper presents a set of case study projects, undertaken by product design students at Auckland University of Technology, in which extensive use was made of RPaD.

***Keywords**: Rapid Prototype as Design, Rapid New Product Development, Student design projects*

1 Introduction

Traditional project management tends to focus on the areas of Cost, Time, and Quality (which is usually defined by the technical requirements of a project). With global commerce supported by technology and communication made possible by the internet, time is now 24/7 and cost and technical challenges are addressed on a global basis using team members in different countries, with different cultures, time zones, methods, and even languages. In this changing world, Time is rapidly becoming the most critical factor to project success. High-tech products that come to market six months late but on budget will earn 33% less profit over 5 years. In contrast, coming out on time and 50% over budget cuts profit by only 4% [1]. Companies that develop products on budget, but in shorter times, develop commercial advantage and increased flexibility. -Prototype as Design shows significant success in simplifying and speeding up the development of unique research hardware with large cost savings. Prototype as Design is a means of using the old artisan's technique of prototyping as a modern design tool. Prototyping is one of the oldest product development techniques in the world and has been used by artisans for centuries. These artisans created proto-types of their ideas, to ensure that they worked, before making the planned primary artefact. Prototype as Design is useful in producing one-of-a-kind projects by eliminating some of the formality of the traditional 'stage-gate' engineering design processes. It is often impossible to precisely specify requirements at the fuzzy front end of a project. Even often makes Prototype as Design critical to projects, as it is a highly interactive, integrated process that allows multiple iterations of complex aspects of a R&D product to be quickly evaluated and adapted into a properly functioning whole [3]. The need for using this new/old process in NPD companies is largely due to the proliferation of highly functional and easy to use Computer Aided Design (CAD) tools to skilled and versatile engineers. Prior to computers, designers who often were not engineers, converted engineering sketches into finished drawings for manufacture. While doing so, much design detail was added to not only meet manufacturing's needs, but also to ensure the end user's satisfaction. Computers have gradually eliminated the designer's role, leaving a gap that engineers are often not trained to fill: making the design manufacturable and optimizing its desired usefulness. One development in calibrating and optimising virtual product and process designs has, for example, addressed this gap in an automotive industry application, creating millions of dollars in savings in design lead time, product quality and performance [4]. For many high tech products, design time can be saved and rework eliminated during fabrication by using Prototype as Design. Barkan & Insanti [5] advocate prototyping as a core development process. Mulenburg [6] sees lack of prototyping as a major contributing factor in the 70~80% of projects that never make it through if possible, it may be undesirable to do so [2]. This complete development, or fail in the marketplace because of compromises made during development that reduce content to save cost and schedule. Mulenburg [6] sees one of the major contributors to problems, during the traditional linear design process, as being an attempt to make every part as effective as possible. Trained in design, many designers try to optimize every portion of a product to create an optimized whole, which is exactly the opposite of what is required for both speed and parsimony in design. The result is sub-optimization adding both time and cost to the design process without optimizing the final product. The desired product must meet the needs of the intended user, and these needs must be agreed upon and defined as early and as clearly as possible. Reality is that things are often optimized simply because they can be; not because they need to be. When only a few units of a product will be built, for example, is anything achieved by a lengthy comparison of which fasteners to use in order to optimize the highest quality with the lowest cost when only a minimum order quantity will be purchased anyway? If the functional requirements can be adequately met by an early choice, it is more important to make the selection and move on to more complex aspects of the design that may need extra time to ensure they meet the desired needs. In new product development, time truly is money.

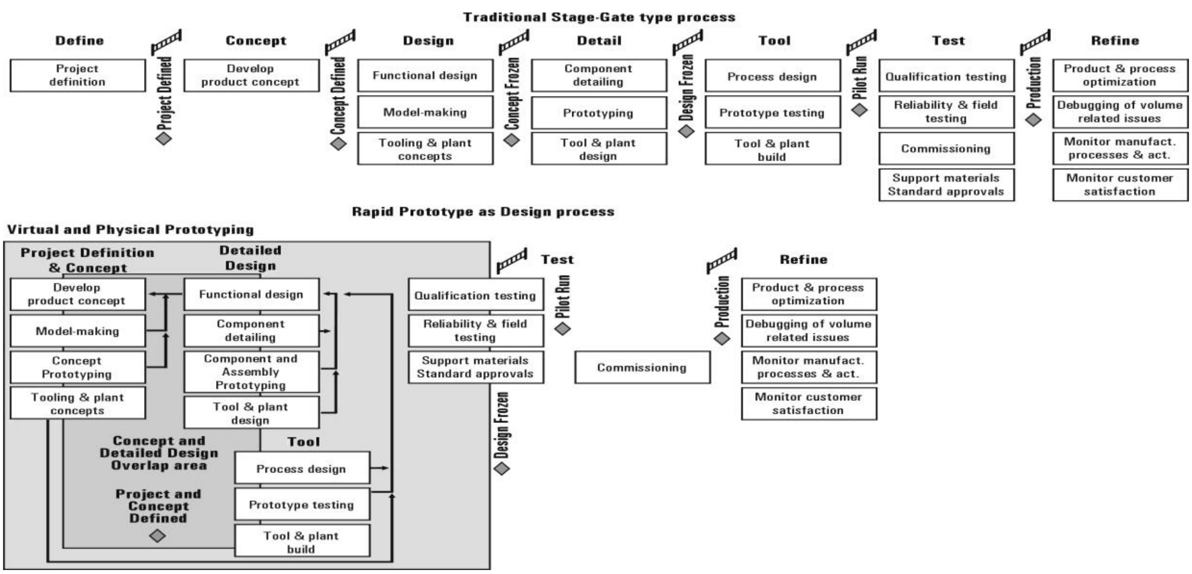

Figure 1: Comparison of Traditional and RPaD Processes

2 Rapid Prototype as Design

The advent of the latest rapid prototyping, CAD, computer aided engineering (CAE) and computer aided manufacturing (CAM) technologies has added a new twist to the traditional Prototype as Design process. It is now transforming into a 'Rapid Prototype as Design' process. This new generation of tools allows engineers to perform complex finite element analysis (FEA) on their products, to test for any thermal or structural problems, or to simulate how plastic may flow through an injection molding tool during manufacturing. Physical prototypes play a great role in NPD as they are a means of demonstrating scale and realism in a way that paper drawings and CAD models cannot. The translation from two dimensional to three dimensional representations is a key stage in NPD [7]. The progression of prototypes can be seen as going from two dimensional to three dimensional on-screen, to three dimensional physical models. Only a three dimensional physical model can effectively achieve the real suitability of a physical product [8]. There are large differences in perception between a user seeing a CAD model and then seeing a real physical working model. The additional tactile, haptic and true three dimensional perception produces two completely different responses in the user [9]. The overall design process now looks somewhat as follows: Initial conceptual sketches are still often done in 2D, both on paper and on the computer. More advanced conceptual design and engineering design models are then produced using 3D CAD software. This produces a virtual model that can be rotated, zoomed in on, measured and manipulated on-screen. From this 3D Computer model, a physical rapid prototype can be produced. Traditionally, the only way to produce a real, physical model was to either use a subtractive technology such as Computer Numerically Controlled (CNC) machining or to produce expensive tooling into which the part could be injection molded. Both these methods were time consuming and expensive. The latest generation of rapid prototyping technologies, such as stereolithography (SLA), Selective Laser Sintering (SLS), Fused Deposition Modelling (FDM) and 3D printing now allow physical prototypes to be produced within hours rather than days [10]. The rapid prototyping process begins by taking a 3D computer generated file and slicing it into thin slices (commonly ranging from 0.1mm to 0.25mm per slice depending on the technology used). The rapid prototyping machine then builds the model one slice at a time, with each subsequent slice being built directly on the previous one. The technologies differ mainly in terms of the materials they use to build the part, and the process used for creating each slice of the model [11]. Some of the earlier rapid prototyping processes, which were only able to make plastic-like parts, are now producing metal parts in aluminium, titanium, and even stainless steel [12]. Not only is the choice of materials and processes increasing, but the last few years have seen a significant reduction in the cost of these technologies. Systems are now also available for not only simulating the behaviour and performance of electronic circuits, but also for rapid prototyping complex double-sided (and even multi-layer) through-hole plated circuit boards. These technologies mean that it is now possible to construct highly advanced virtual prototypes, and then working physical prototypes almost as fast as they are designed, thus allowing many more iterations of a design within a shorter timeframe. This, in turn, allows for products that are even better suited to their intended users in even shorter times [10]. It is important to remember that a product prototype includes more than just its mechanical parts. Many products also include electronic and software components which must also be prototyped as part of the process. It is vital to understand that the mechanical, electronic and software systems are closely related to each other and that the design of one should therefore affect the others. This is why it is so important that all disciplines work as a single unit rather than as simple parallel activities. Some of the tools that can effectively be used for software prototyping include visual development tools such as Visual Basic or C# which allow complex software systems to be prototyped relatively quickly as they remove much of the time needed to produce Graphical User Interfaces (GUI). Tools for programming embedded system devices and micro-processors have also improved over recent years, making it possible to quickly program a working electronic system. The same goes for electronic design, in which an ever increasing arsenal of electronic design and simulation tools makes it easier to design working virtual and physical prototype electronic systems.

3 Case Studies

Second year product design students were required, as part of their studio project, to design a set of medical devices that improved the quality of life of the users. The students had a total of less than 12 weeks in which to design the product from initial ideas to proof-of-concept prototype and put on an exhibition and create a product plan and report.

In order to achieve this goal within such a tight time-frame, the students were advised to use RPaD as a way of testing any of their ideas as soon as they had them. They were required to use the prototyping method that best suited the idea or concept they were trying to test. In some case this was just done as a cad model. In others, relatively crude card or foam mock-ups were used, and when more complex ideas were being tested, they used laser cut or rapid prototyped models. They were strongly encouraged to use their prototypes as a way of thinking about the problems they needed to overcome to reach their goals. The first project was for a moon-boot cast for broken ankles. The student team first undertook a detailed analysis of users and, from the information gathered, identified that current moon-boots were unwieldy and bigger than they needed to be for a large part of a user's convalescence. After brainstorming to generate a number of design concepts, most of which were quickly prototyped, they came to a final design for a modular moon-boot in which sections could be removed as the user progressed through their recover, thus making the user more comfortable and therefore more likely to recover faster. From the start of the project, the students tested all of their concepts and ideas with prototypes. They generally started off with relatively crude cut card prototypes then, after starting to virtually prototype in CAD and physically prototype in parallel, they progressed to laser-cut polypropylene prototypes and finally 3D printed plastic prototypes made on a Dimension FDM machine. One of the challenges faced by the students was in learning to decide which type of prototyping was most effective in achieving the purposes of any particular challenge, be it communicating and idea or testing an engineering or manufacturing principle.

The prototype moon-boot shown in the figure below is comprised of a mix of plastic 3D printing and laser cutting and is a fully functional proof-of-concept model.

Figure 2: Student Design moon-boot

The second project was for an ambulatory blood pressure monitor. This is a blood pressure monitor that is worn continuously by the patient for 24 hours and which takes readings at preset intervals. Current models are worn on the belt and have air pipes leading up to the cuff which is wrapped around the upper arm. This makes it difficult for patients to wear at night as the tubes get in the way, and can stress patients to the extent of affecting their blood pressure. After prototyping a number of different concepts, the team settled on a design in which the entire monitor was worn on the arm. The electronics and pump became an integral part of the cuff. One of the prototyping methods used by this particular team was in the reuse of existing components, a very useful prototyping method that often gets ignored. All internal components, pump, solenoid, circuit boards were reused from an existing blood pressure monitor. This reuse of components drastically shortened the teams' development time on the technology front.

Figure 3: Student Design for ambulatory blood pressure monitor

Two of the other projects were for portable Chronic Obstructive Pulmonary Disease (COPD) devices that would allow patients full mobility so that they could leave their homes for short periods of time. After examining the problem from a patient's point of view, the two project teams came up with different solutions. One team decided on a head mounted device that was worn on the back of the head in a manner similar to some music headphones. The other team opted for a belt-worn or pouch-worn device. The head-mounted team went through a series of prototyping exercises, first using foam and card, then moving on to clay and vacuum-forming, and their final model rapid prototyped in plastic on an FDM machine. The belt-worn device team, in particular, approached their design cleverly. They designed for ease of prototyping. Their entire product was made through laminated laser cut sections. This meant that, right from the outset, they were able to very quickly, from their CAD designs, create laser cut sections of card, then MDF, then acrylic to create extremely professional looking prototypes.

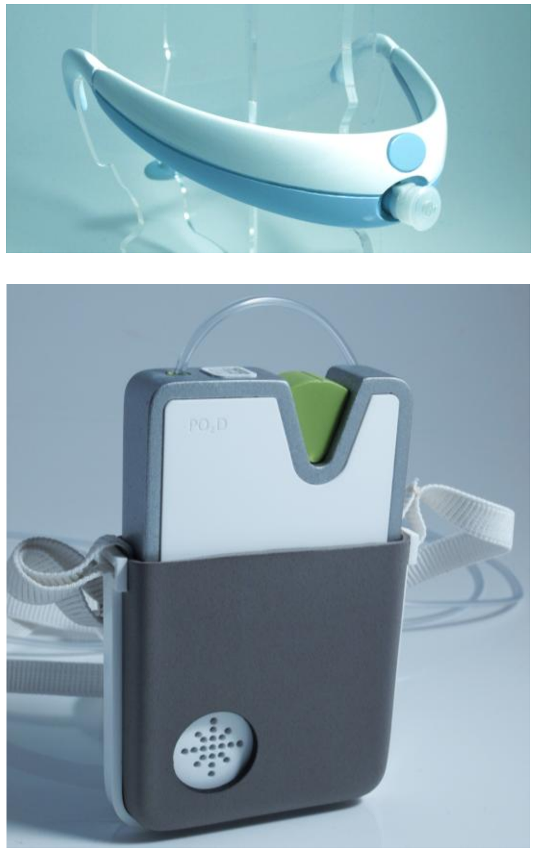

Figure 4: Student Designs for COPD portable breathing device

4 Conclusions

As newer virtual and physical rapid prototyping technologies emerge, the way in which we use them to more effectively manage the NPD process must evolve in tandem. Indeed, the traditional NPD processes must evolve into Rapid New Product Development management processes. The combination of rapid prototyping technologies, not only in the mechanical area, but also in the electronic and software areas can be used to reduce the product development cycle if they are used effectively. Not only can the project time be reduced, but more desirable products can often eventuate as more design iterations can be gone through, thus more closely meeting the needs of the users. The paper then presents several case studies of students who used RPaD in their studio projects. All four teams came up with extremely innovative solutions which not only met the user's needs, but were also relatively easy to manufacture. Most of the teams created between twenty to thirty prototype iterations for their projects (ranging from crude cardboard and foam concept models, to CAD prototypes to highly polished plastic or laser-cut final product prototypes), which allowed them to develop their ideas in an efficient manner. As they prototyped every idea they had, the idea was automatically tested for validity through the prototype. The biggest learning the students got from the project was about which was the most appropriate type of prototyping to use depending on what they were trying to achieve.

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