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Integrating 'Rapid Prototype as Design': A Case Study in Product Design Education

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ABSTRACT

The integration of 'rapid prototype as design' (RPaD) methodologies in the new product development (NPD) process, combined with effectively utilising virtual and physical rapid prototyping technologies, increases the potential for producing superior, better optimised products, and in shorter developmental timeframes. It is essential that education about RPaD methodologies is integrated into the curriculum of product design and engineering programmes in universities and tertiary institutes. The paper outlines background to RPaD and presents a case study of product design projects undertaken by students at AUT, University, in which RPaD was used as a key design methodology.

INTRODUCTION

Prototyping is one of the oldest product development techniques and has been used by artisans for centuries. Artisans created proto-types of their ideas, to ensure that they worked, before making the planned primary artifact. Prototypes were also useful in producing one-of-a-kind projects by eliminating some of the formality of the traditional 'stage-gate' engineering design processes.

The integration of physical, three-dimensional prototypes in the new product development (NPD) process, i.e. 'Prototype as Design' has been an essential and effective way for evaluating form, ideas, testing function, individual parts and for optimising products for intended users for many years. For example with the front end of the NPD process it is often impossible to precisely specify functional and user requirements. According to Mulenburg (2004), even if possible, it may be undesirable to do so. Further to this Singh & Vijayaraghavan (2001), go on to discuss that this often makes a strategy where the use of 'prototype as a design' critical for success, as it is a highly interactive, integrated process that allows multiple iterations of complex aspects of a product to be quickly evaluated and adapted into a properly functioning whole.

I. RAPID PROTOTYPE AS DESIGN

With the increasingly complex nature of contemporary products, and the sophisticated expectations of buyers and users, the use of 'prototype as design' to optimize products during the design process is becoming ever more important. The advent of the latest rapid prototyping, CAD, computer aided engineering (CAE) and computer aided manufacturing (CAM) technologies has added a new dimension to the traditional 'Prototype as Design' methodology. It is now evolving into a 'Rapid Prototype as Design' methodology.

The new generation of software and hardware tools now 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 an essential role in NPD as they are a means of demonstrating scale and realism in a way that paper drawings and CAD models cannot. According to Broek, Sleijffers, Horvath, & Lennings (2000), the translation from two dimensional to three dimensional representations is a key stage in NPD. The progression of prototypes can be seen as going from two dimensional to three dimensional on-screen, to three dimensional physical models. However there are large differences in perception between a user seeing a CAD model and then seeing a real physical working model. According to Krar and Gill (2003), the additional tactile, haptic and true three-dimensional perception produces two completely different responses in the user.

The overall generic design process can now be described as follows: Initial conceptual sketches are still usually undertaken in 2D, both on paper and on the computer. More advanced conceptual design and engineering design models are then usually 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.

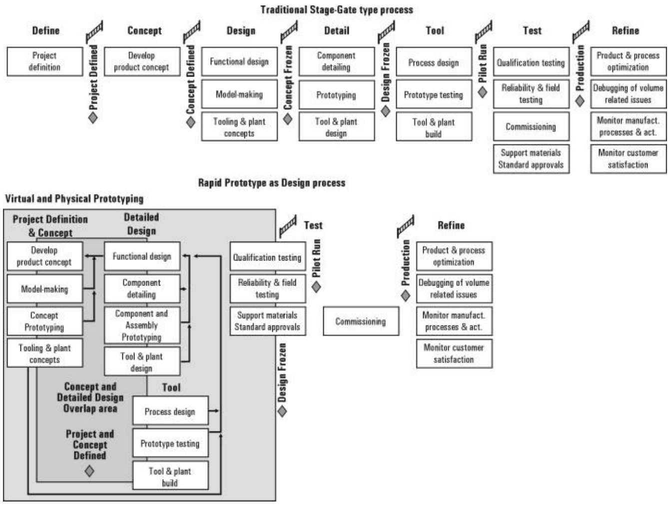


Fig. 1: Comparison of Traditional and RPaD Processes

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 (Chua & Leong, 2003).

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. Wohlers, (2009) presents a good outline of how the technologies may differ for each method in terms of the materials they use to build the part, and the process used for creating each slice of the model.

Some of the earlier rapid prototyping processes, which were only able to make plastic-like parts, are now producing metal parts in aluminum, titanium, and even stainless steel. 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 simulating the behavior and performance of electronic circuits, and 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.

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.

II. Product Design at AUT

The three-year undergraduate product design programme at AUT University is a relatively new programme, developed in 2007 and launched with the first intake of students in 2008. In 2011 the programme will have 80 students across the three years as well as eight students studying at postgraduate level. The programme is centred on project/problem-based learning in which students are given a studio space to work in over the year, and access to workshops and prototyping facilities. Over the three years of undergraduate study the students work through a number of NPD projects ranging from short i.e. two week, through to full semester i.e. twelve week projects. Expectations range from conceptual outcomes i.e. ‘blue sky projects’ through to product outcomes as close to realization as possible.

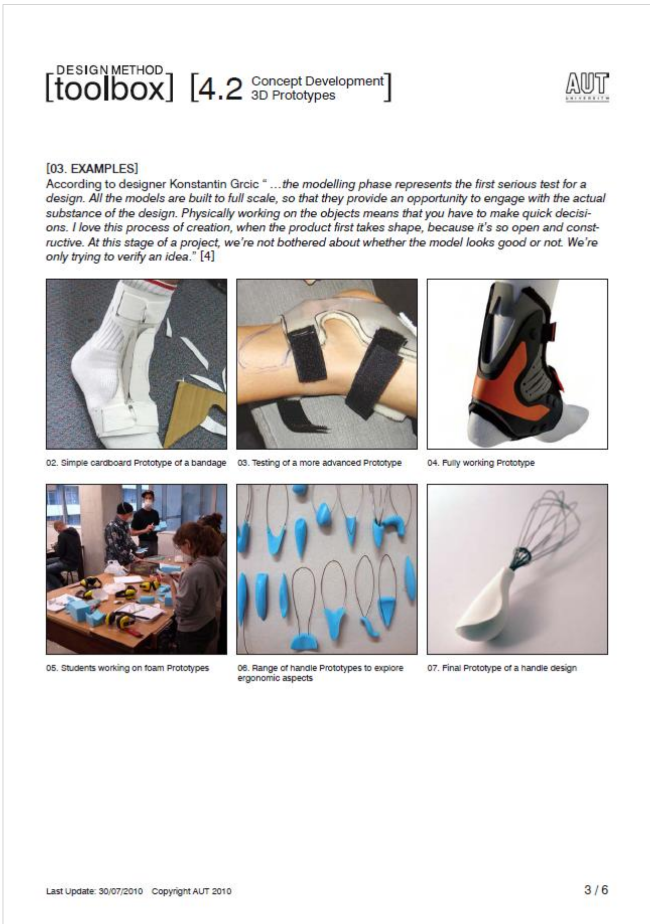
While the development of a new academic programme provides many organisational and operational challenges, it also presents a unique opportunity to develop new approaches to teaching and learning and without the constraints of institutional history and tradition. An innovative pedagogical approach to product design is currently being developed in the product design programme at AUT that focuses on integrating emerging, contemporary design methodologies and processes. The concept of ‘Rapid Prototype as Design’ is seen as a key methodology for the product design programme.

III. Integrating ‘Rapid Prototype as Design’

Traditionally product design schools have focused on the specific use of drawing and CAD as the primary creative methodologies, and a model or prototype was something that was usually created at the end, not something generated throughout the process.

Given the traditional use of design methodologies, it is essential for the successful integration of new methodologies such as ‘Rapid Prototype as Design’ to get student ‘buy-in’ and a ‘culture change’ away from the traditional approaches i.e. to a more hands-on process, using quick, effective and many generations of prototypes to test and evaluate ideas. Further to this, to get students to understand and independently select the most appropriate prototyping methods for a given context.

To achieve this at AUT, a number of key strategies have been utilised to teach and integrate RPaD into the programme. This includes the development and delivery of key lectures and discussions to engage students in a discourse around the broader issues of the use of prototyping, hands-on workshops with a variety of prototyping processes from low-tec to high-tec, case studies of professional projects, physical examples previous student’s project outcomes, and the use of other resources such as videos, site visits and access to online resources.



DESIGN METHOD [toolbox] [4.2 Concept Development 3D Prototypes]

[03. EXAMPLES]
According to designer Konstantin Grcic " *...the modelling phase represents the first serious test for a design. All the models are built to full scale, so that they provide an opportunity to engage with the actual substance of the design. Physically working on the objects means that you have to make quick decisions. I love this process of creation, when the product first takes shape, because it's so open and constructive. At this stage of a project, we're not bothered about whether the model looks good or not. We're only trying to verify an idea.*" [4]

02. Simple cardboard Prototype of a bandage

03. Testing of a more advanced Prototype

04. Fully working Prototype

05. Students working on foam Prototypes

06. Range of handle Prototypes to explore ergonomic aspects

07. Final Prototype of a handle design

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Fig. 2: Example of resource given to students

The programme team also works very closely with the AUT, Centre for Centre for Rapid Product Development, for student visits, technical advice on specific problems and projects as well as ongoing use of rapid prototyping facilities.

To illustrate the use of RPaD at AUT, a number of successful case studies are presented.

IV. Case Studies

As part of their studio programme students were asked to design a set of medical products with the goal to meet/exceed the needs of intended key users and to improve the overall experience of using the product. The students had twelve weeks in which to design the product from research, 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 specifically use RPaD as the key design methodology. In addition the students were asked to use clearly identified prototyping methods that best suited their idea or concept context. In some case this was undertaken through the use of CAD models. With other students, relatively crude but quick card or foam mock-ups were used. With more complex ideas were being tested, students 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 project goals. Overall students utilised a range of prototyping processes.

Fig. 3: Examples of student prototypes used in the project.

A. Moon-Boot

The goal of this project was to design and develop an innovative moon-boot cast for people with broken ankles. The students first undertook a detailed analysis of key 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. Firstly relatively crude card prototypes where used to visualize initial ideas, then after starting to virtually prototype in CAD and physically prototype in parallel, the students progressed to laser-cut polypropylene prototypes leading to final, 3D printed plastic prototypes produced on a Dimension FDM machine.

One of the challenges faced by the students was in learning to identify which method of prototyping was most effective in achieving the purposes of a particular challenge, be it communicating and idea or testing an engineering or manufacturing principle.

Fig. 4: CAD Model of Moon-Boot

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.

Fig. 5: Final Prototype of the Moon-Boot

C. Ambulatory Blood Pressure Monitor

In this project an ambulatory blood pressure monitor was redesigned and improved. An ambulatory blood pressure monitor 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.

Fig. 6: Prototype of Ambulatory Blood Pressure Monitor

D. Portable Chronic Obstructive Pulmonary Disease Device

These projects were based around the redesign of 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 produced through laminated laser cut sections. This ensured 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.

Fig. 7: *Prototype of COPD Concept*

Fig. 8: Prototype of Respiratory Humidification System

E. Respiratory Humidification System

This project was focused on a respiratory humidification system in conjunction with Fisher and Paykel Healthcare. The student was asked to redesign an existing product based on the findings of extensive user research in hospitals. The focus was to improve the experience of both staff and patients and to create the next generation of the product. In this case the student also challenged the existing humidification technology and proposed an alternative and potentially radical method of both generating and recycling humid air.

The project involved prototypes in the form of early concept form studies in foam, through to working prototypes for the development and testing of systems to produce humidity. This involved setting up alternative methods for generating humidity, creating air flow and the testing and comparing of each of the methods. A number of presentations of the prototypes were made to the client and to users for feedback. Once the overall form factor was developed and the system designed, the final form was refined using CAD. This culminated in the production of a final rapid prototype using FDM technology for high level communication and display purposes.

V. Conclusions

As newer virtual and physical rapid prototyping technologies emerge, the way in which they are used to more effectively manage the NPD process must evolve in tandem. Further to this, the traditional NPD processes must evolve into Rapid New Product Development 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.

It is essential that design and engineering programmes also engage students with new and emerging design methodologies and processes such as RPaD, and that they are embedded deeply into programme curriculums. This paper has presented how at AUT, the product design programme is integrating RPaD into the teaching and learning programme, and has showcased a number of student design projects that have utalised RPaD as the core design methodology. All five teams came up with innovative solutions which not only were optimised for 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 effective and efficient manner. As they prototyped every idea they had, the idea was automatically tested for validity through the prototype. The AUT students have demonstrated that RPaD, as an excellent emerging professional NPD methodology, can also effectively utalised by design students to develop innovative, new product concepts.

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