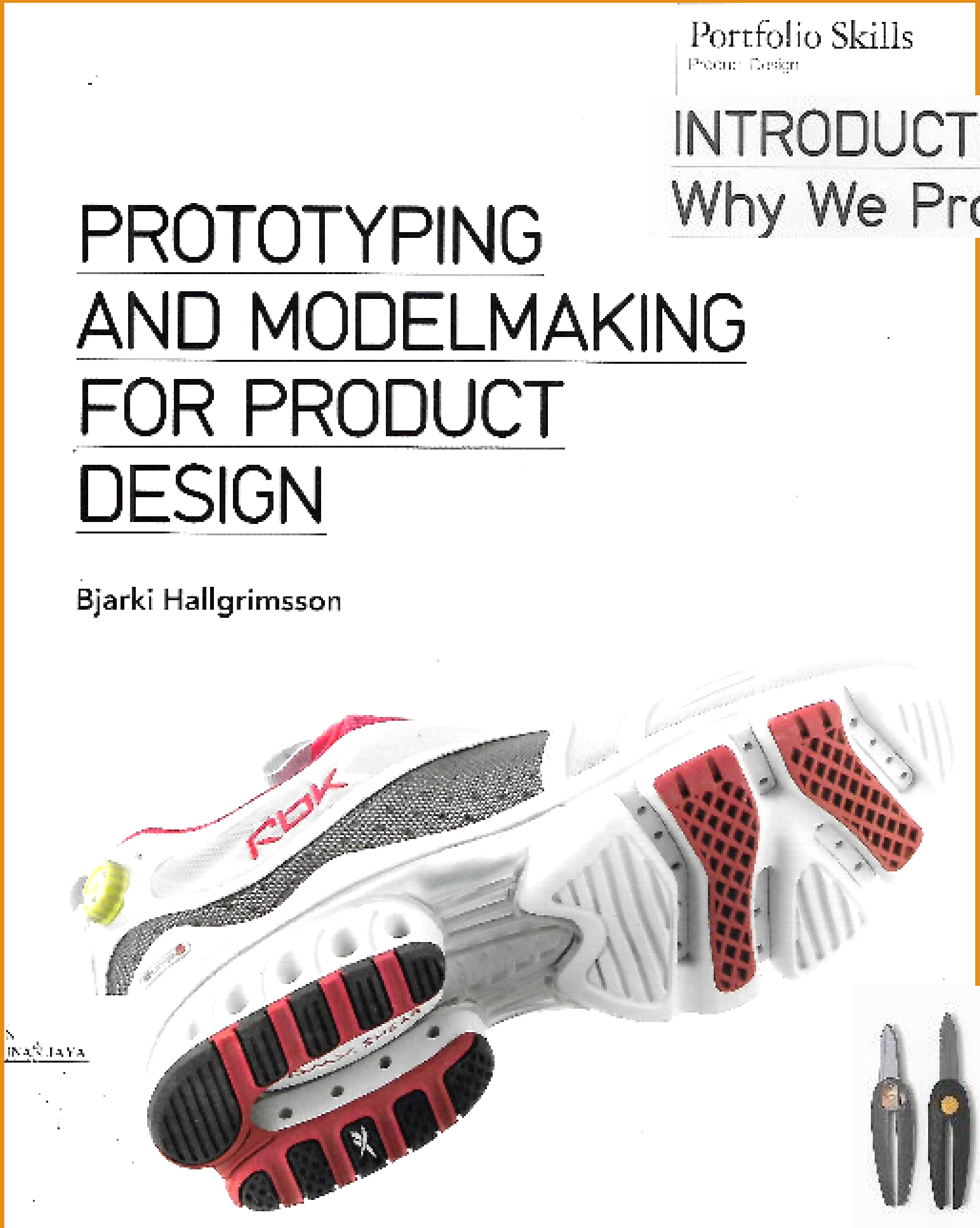
PRO 204 – Modeling Prototyping

WHY WE PROTOTYPE



Portfolio Skills
Product Design

INTRODUCTION
Why We Prototype

Behind every successful product design is a story of numerous refinements and much hard work. The fact is that the transformation of an idea into a real product takes a great deal of work, involving more than simply creating pictures on the computer. Product design is a complex activity, which involves working with other people and disciplines, coming up with creative and useful ideas (that hopefully are also sustainable) and slugging through all the iterations of making something work and look good at the same time. One method that has always been used by designers, and continues to be embraced, is that of physical prototyping. The primary message of this book is that building and testing in 3D is a continuing and critical component of a successful design process. Whereas 3D Computer Aided Design (CAD) has made it easier to visualize, analyze and implement product solutions, physical prototypes can still be played with and scrutinized in a way that is not possible on screen. As a result they precede and complement most of the computer rendering and animations that happen in real-life projects. Just as the computer helps integrate interdisciplinary activities on screen, physical prototypes draw people together in face-to-face discussions that lead to a different level of interaction between clients, designers and end users.

Definition of Prototyping and Modelmaking

The terms *physical prototype* and *model* can be used interchangeably to describe a preliminary three-dimensional representation of a product, service or system. In recent years the use of the word 'prototype' has become favoured as it is more encompassing. A wide range of physical prototypes is used throughout the design process to simulate different aspects of a product's appearance and function before it is produced. This book will show why physical prototypes are essential to the design process, and how they are used to solve a range of problems associated with new product development. Each new version of a prototype or model is known as an iteration.

Prototyping and *modelmaking*, although inherently related terms, actually refer to different activities. Prototyping is a design method that uses physical prototypes to study and test how a new product will be used, and how it will look and be manufactured. Modelmaking, on the other hand, is the step-by-step method of producing the prototype. For this reason, this book has been divided into two sections: Prototyping and Modelmaking. The first section, Prototyping, describes what physical prototypes are and how they are used in product design and development. The second section, Modelmaking, specifically addresses the many issues regarding materials and options for construction. By being mindful of the reasons why we prototype, we should be able to make better choices about how we make prototypes.

Prototyping Is a Form of Problem Solving

Prototyping is a key problem-solving activity in product design. It starts right from the beginning of a project and continues right into production. Given the complexity of product development, it is critical to take as much of the guesswork out of the design process as possible, and prevent surprises from showing up later in a project. It is much less expensive to solve problems early in a project than later, when tooling may have been started and sales commitments made. Prototypes evolve along with the design process; simple prototypes serve as initial three-dimensional sketches and are then replaced by iterations of successively more refined versions.

The more complicated the product, the more disciplines will be involved and the more prototypes typically needed. Physical prototypes enable teamwork and collaboration, since they serve to gather team members around for discussion and reflection. The prototypes oblige the team to deal with real issues, which are more easily ignored in memos and verbal discussions alone. Prototypes are also used to study and compare alternative approaches. This includes testing everything from technical requirements of construction to usability.

Modelmaking

The rich design tradition of developing sensitivity to materials, manufacturing and workmanship is based on the idea of learning by doing, which goes back to the beginning of product design. We actually learn different things from making the prototype (modelmaking) than we do from using the prototype (prototyping). Material properties do not have any real connection to the world we live in unless we first inform our senses in a hands-on way. By experiencing real materials and processes, the material qualities gain meaning. The sensibility and experience attained from this process form the basis for intuition and are therefore essential for conceptualization.

Physical and Digital Prototypes

Product designers need to have competency in several skills, including sketching, CAD and modelmaking. These are all critical tools and should be used effectively and not exclusively. A workflow that shifts back and forth between different skills expands the creative possibilities and is more balanced.

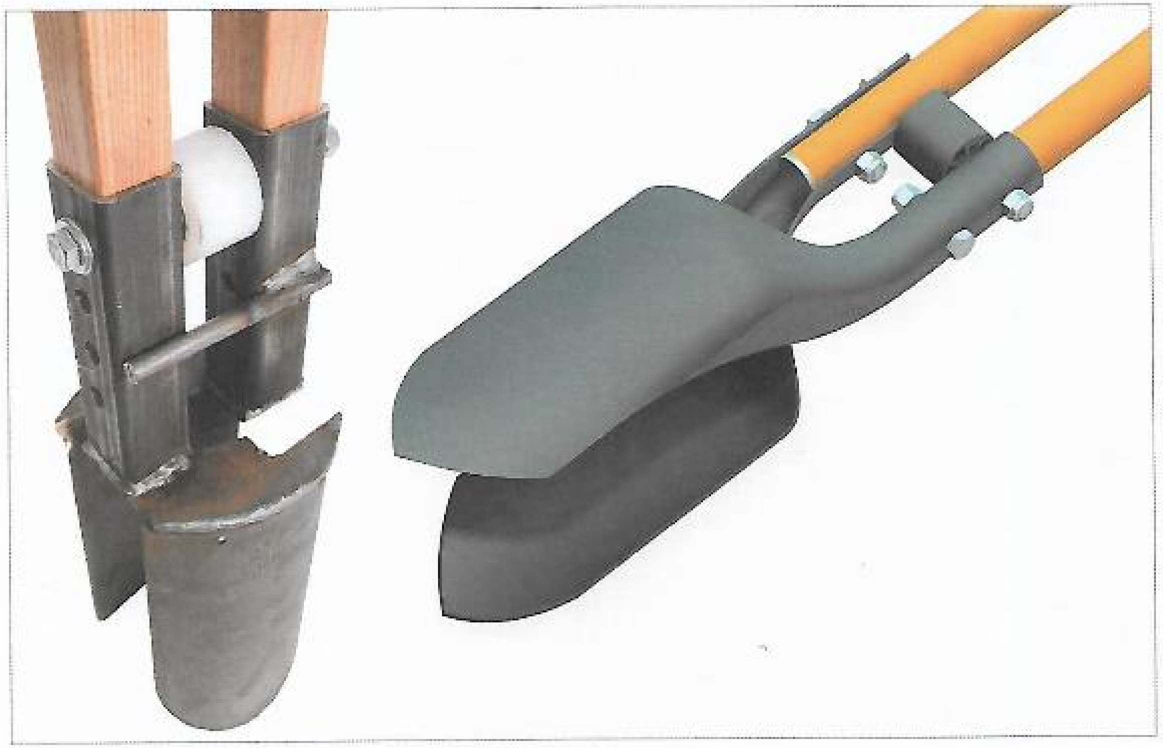
Computer technology has completely changed the way in which products are conceived and developed. Virtual computer models allow us to visualize the product, see how parts fit together, calculate the weight and carry out performance simulations along the way. Physical prototypes, on the other hand, answer questions that are hard or impossible to address on the computer alone. These questions usually have to do with the qualitative human aspects. Whereas computer simulation can be used to verify many technical requirements, physical prototypes can be placed into real environments and have tangible qualities, such as weight, size and texture, that can be experienced at first hand. Experienced designers build a great many physical prototypes along with virtual computer models. It is not a question of physical versus digital, but rather a matter of how the two approaches complement each other best. The tutorials in this book show workflow that involves sketching, CAD and physical modelmaking used in a complementary fashion.

Building by Hand and Using Computers

All physical prototypes used to be built manually by hand. Nowadays, as will be shown later in this book, new digital technologies enable 3D computer files to be output to automated computer-controlled prototyping machines. This may create the impression that prototypes no longer need to be made by hand at all, but that would be far from the truth. As will be shown in the case studies in this book, early ideas are actually explored faster by hand. What starts as sketches and quick handmade models gradually migrates to the computer and eventually from there to rapid prototyping or CNC machining.

Chapter 7 discusses how manual and digital ways of working complement each other and how new technologies such as laser scanning help designers reverse-engineer handmade models into CAD. There is, in other words, a convergence happening between traditional hand skills and computer skills. The computer mouse is probably going to be increasingly displaced by more natural and fluid input devices, which electronically simulate the sketching and sculpture-making process. This has already happened with the digital sketching pad, where the stylus is now the input device. Similarly, 3D haptic devices allow for hand-forming digital models in space. Modern design process is evolving, requiring designers to have one foot inside and one outside the virtual world every step of the way.

The Fiskars post-digging tool was first made by hand and tested (left) before creating a 3D computer model in CAD (right).



New interfaces are changing the way designers work. Products such as the Cintiq® interactive pen display (left) and the PHANTOM® haptic (force-feedback) device (below) blur the lines between analogue and digital methods of working.

Organization of this Book

The first chapters of the book explain why prototyping is so important to the design process. The many uses of prototyping will ultimately be shown in the context of several comprehensive projects by some of the world's leading design firms.

The second part of the book is an introduction to the typical materials used by designers in their prototyping efforts and how to work with them. In all cases the approach is to use digital and manual tools in a complementary and effective fashion. Tutorials were specifically developed for the book that underline the back and forth of digital and manual ways of working. The emphasis is on the kinds of construction that can be done by the designers themselves. Health and safety is stressed in terms of personal responsibility and awareness. As students leave their universities, they are likely not to have access to some of the world-class facilities to which they may have become accustomed. Being able to create models in simple materials in a healthy and safe manner will be important.

CHARACTERISTICS OF PROTOTYPING

1

Successful prototyping requires thinking about building and making in a way that is different from the way we think about manufacturing and fabrication. First and foremost a prototype is not a final product. Before going into detail about how prototypes are used and before getting into the specifics of working with materials, it is worthwhile discussing some of the important characteristics of prototyping.

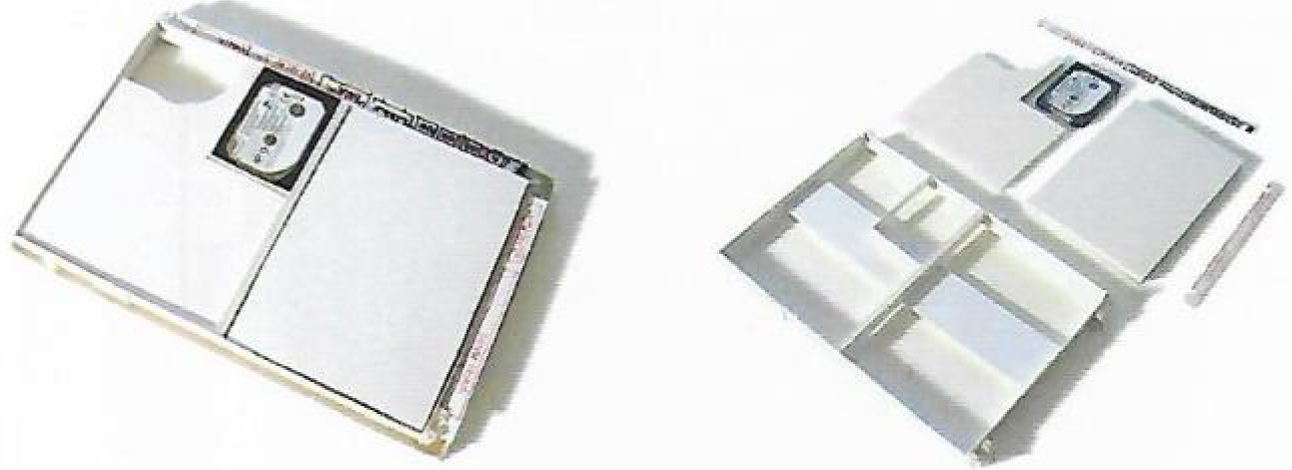
The Difference between Prototyping and Manufacturing

Prototyping and manufacturing are separate activities. Mass-manufactured products achieve their economy of scale through tooling. The time involved and the cost of making various types of tooling and setting up an assembly line, is a huge capital investment. Products have to sell in the thousands before this investment starts to pay off. Prototypes serve many purposes in order to reduce the risk associated with that level of investment. Since prototypes are built only in small numbers, they do not typically require any tooling and can be produced in a completely different fashion. At the early stages of a project, the focus may not even be on manufacturing at all, but on figuring out basic configurations and how the product will be used. As the design gets closer to production, it will be necessary to prototype all parts before tooling is made.

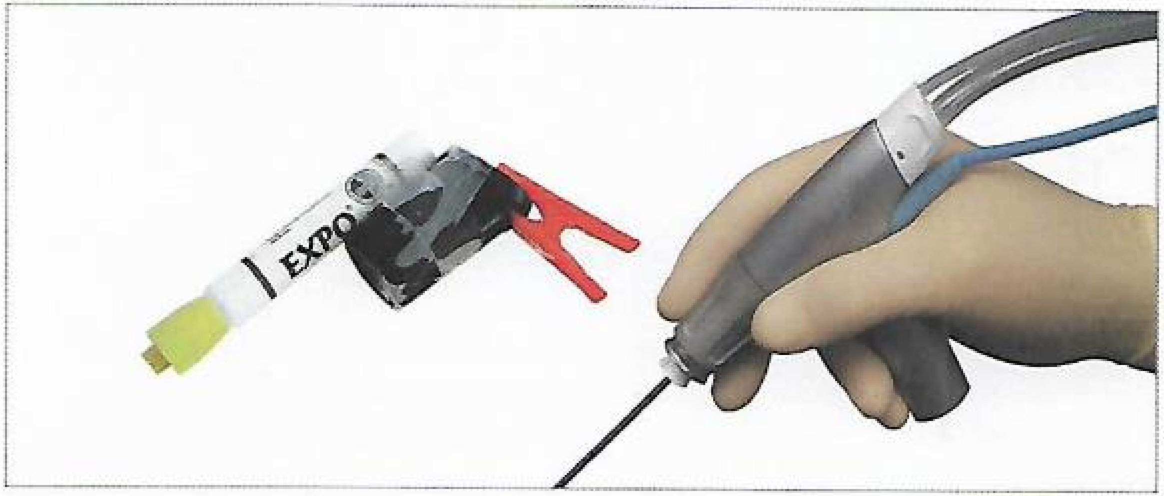
Material Substitution

Early on in a project, it is typically more cost- and time-efficient to substitute softer materials in place of production materials. Polyurethane foam, for example, is frequently sculpted to study the shapes of injection-moulded plastic parts, while a sheet of plastic can be painted in metallic pigment to look like sheet metal.

Functional configurations can also be simulated very quickly with simple prototypes. This is really useful when designing products that have internal components, as it allows the engineers and designers to play around with component placement in an effective and dynamic way.



A simple foamboard mock-up allowed engineers and designers to study internal component placement for the Motion Computing J3400 computer.



The Gyrus ENT surgical tool was developed by IDEO. The simple model on the left was quickly fashioned out of found materials during a meeting that paved the direction for the final design shown on the right. This shows the importance of trying things out early, even in simple found materials.

Iteration

The iterative aspect of prototyping is key. It is simply impossible and foolish to try to get everything right the first time. At one of the world's leading design firms, IDEO, the phrase 'fail often to succeed sooner' is used to describe how 'failure is the flip side of risk taking' (Kelley 2001). By discovering a failure in a prototype, something useful is learnt. That is critical to making sure that the product will work as intended. Being afraid of failure is really nothing more than taking unnecessary risk. The important thing is to subject the prototypes to enough evaluation and testing to expose possible failures beforehand. The sooner these problems are discovered the easier it is to accommodate changes to the design. Simple prototypes will expose obvious problems or show that an idea is viable.
Every project has time and money constraints. These dictate the quantity of prototypes and iterations to be made. Physical prototyping does not have to be expensive, and, unlike computer simulations, can be used to get real information from real end users. Iteration is a major benefit of prototyping as many alternatives can be studied and compared.

Fidelity

The *Oxford English Dictionary* defines fidelity as 'the degree of exactness with which something is copied or reproduced'. Some materials, such as foamboard or polystyrene foam, are inherently low fidelity, as it is hard to get a lot of detail out of these soft materials. They are, however, easy and fast to work with.
A high-fidelity model would be more exact and would typically have to be made in a harder material, which also takes longer to work with.

The idea of iterative product development involves solving big picture problems first, as opposed to fine details. Issues such as overall shape and size can therefore be studied first in low-fidelity materials, allowing for more speed and iteration. Examining the many iterations of the Oral-B toothbrush below, it is

Looks-Like and Works-Like Prototypes

Design students may find that as they start working on complex products and experiences, they quickly become overwhelmed. At that point, prototyping may seem daunting, as there are so many things to test and understand. The case studies and examples in this book are meant to help illustrate how to break these larger problems into smaller, more focused prototyping exercises at the right level of fidelity. This is also a function of identifying the context: who is using the product, where and how?

Understanding how people interact with products is critical to framing the design and hence prototyping objective. Technological issues and human interaction aspects have to be looked at separately to some extent. This is because the human-use issues can become extremely clouded by technical assumptions and parameters, which in turn can limit any real innovation. When building prototypes it is therefore useful to distinguish between *looks-like* and *works-like* prototypes. The material qualities needed to explore form versus function are also different. A hard material may be needed for strength in the works-like prototype, whereas a softer material lends itself better to the sculptural complexity of the looks-like prototype. It is often much faster to build separate prototypes for this reason, and any necessary changes will be easier to implement.

In the development of the Oral-B CrossAction® Toothbrush, Lunar Design, Palo Alto, made many models of body shapes as part of the iterative prototyping process.

This hairdryer project, by Wataru Watanabe (Carleton University, Ottawa) illustrates how prototyping progresses from low to high fidelity. It also illustrates the importance of getting the idea right before spending too much time on fine-tuning appearance. The idea behind this product is quite simple. It is to include a concentrator in a folding travel hairdryer. The design problem was that a concentrator, although a valuable feature for many users, adds extra bulk to an otherwise compact product.

During conceptualization, sketching was complemented by simple low-fidelity prototypes in paper and polystyrene foam. This showed that the concentrator could be fitted over a hairdryer handle with a wrapped-up cord. The low fidelity was appropriate as the focus was on the exploration of ideas. The pictures show how configuration issues such as overall size and storage compare to a more standard folding hairdryer.

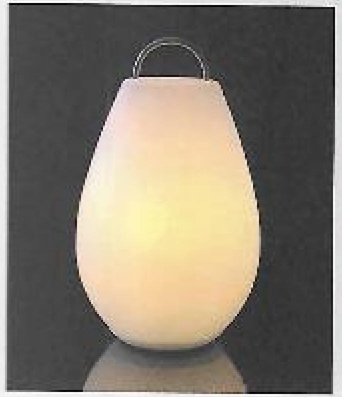
The next step was to observe other people to see if they would find it easy and convenient to use the product as intended. This would necessitate a more robust low-fidelity prototype to allow people to perform the required tasks without breaking the prototype. A simple script was presented to participants (classmates in this case) and they were then photographed and interviewed to see what they thought. The outcome was important in deciding that in this case the handle should be thinner than competing models because that made it easier to roll up and fit the cord under the concentrator.

Once the design parameters were better understood it was time to start focusing on the appearance and detailed shape. Eventually the design progressed toward the final high-fidelity prototype.

Foam and paper are used to explore the idea of a folding hairdryer with a concentrator. The prototypes show how the concentrator is stored on top of the handle.

A more robust wooden prototype was used to test the new configuration with end users. At the same time polystyrene foam models were made to study form (above)

With the configuration well tested, it is time to refine and finalize the design, again starting with low-fidelity materials, and progressing into a final detailed high-fidelity prototype.



The Candela Luau™ is a sophisticated LED lantern designed with many uses in mind.

The convex cylindrical shape of the main body evoked the right visual semantics for the product's many uses. In order to achieve the hollow convex shape, the product would need to be blow-moulded. This presented some production challenges and needed to be verified. By working closely with the offshore supplier, the tooling and the production process were eventually worked out. It is important to realize that if this had not been the case, another design approach or design would have had to have been pursued.

A Styrofoam looks-like prototype was used to determine the proper size and overall shape in the context of different environments and uses. It was also possible to study the placement of the lantern on the base and its removal.

When designers Stefane Barbeau and Duane Smith of Vessel created the Luau™ portable LED lantern for OXO, they wanted to create a portable lighting product that could be used both inside and outside the house.

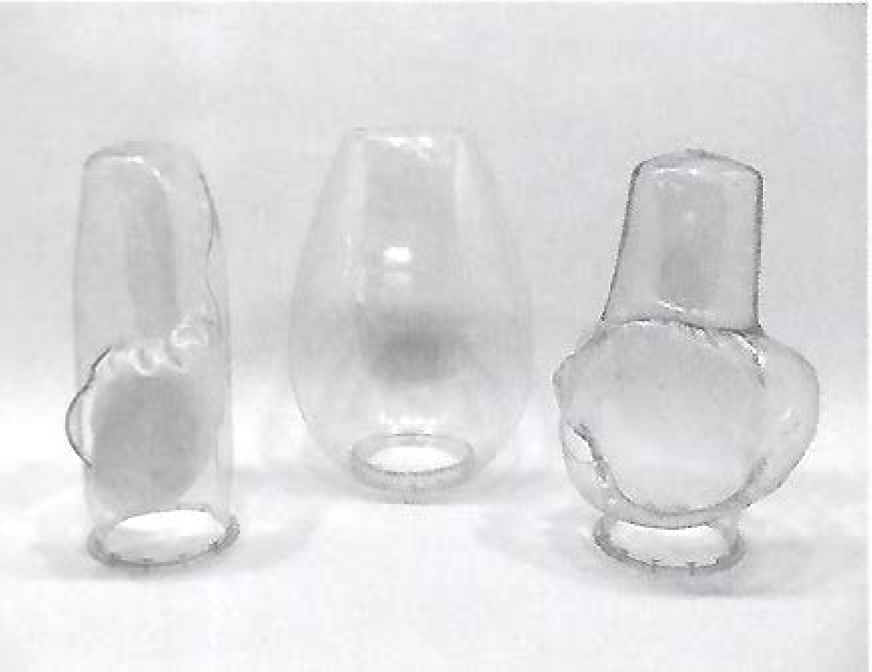
Some of the key features for the Luau™ were explored and confirmed through simple early prototypes that could be used to act out the scenarios that were important to the success of the product. A very simple works-like prototype was used to examine the idea of incorporating a dimmer into the bottom of the lantern, so that it could be dimmed by simply twisting it on the ground or while holding it. Stefane Barbeau says, 'we wanted to investigate if we could use the form of the lamp itself as an interface in order to simplify the action'. The placement and shape of the handle therefore became very important.

Although such a simple model was useful in exploring the basic functionality, the lantern itself needed to be explored more formally. It had to have a suitable aesthetic for indoor as well as outdoor environments. The shape also had to be comfortable to carry and easy to place on a charging base. Establishing overall form and proportion was done with a low-fidelity handmade looks-like polystyrene foam model. This model could be carried and placed in the relevant environments for evaluation by the design team.

The learning that was gained through these simple prototypes allowed the design team to start designing the product in 3D CAD with a sense of confidence. Once the 3D CAD data existed, it made sense to produce a more detailed prototype through rapid prototyping means. The levels of refinement and attention to detail now converged toward detailed design decisions and implementation.

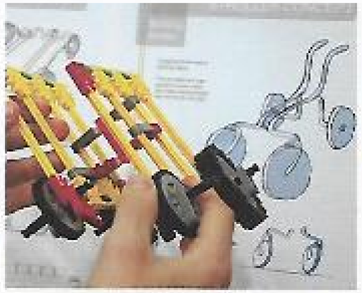
Sometimes a design presents manufacturing challenges. In these cases, it is important to verify that the shape can be made. Establishing that the Luau™ lantern body could be blow-moulded required some manufacturing experimentation.

A discreet indicator on the charging base changes from orange while charging to green when fully charged. The lantern illuminates automatically when lifted or during a power outage. Such subtle features were important to the quality and spirit of the design and required further detailed design development.



HOW PROTOTYPES ARE USED

Physical prototypes are used in myriad ways to solve problems and develop a better understanding of design requirements. In conjunction with sketches and other design methods they aid in: idea exploration, user testing, communication, design verification and standards testing. A single prototype often has more than one function: for example, exploration often involves some simple user testing as well. The following categorizations are not meant to be prescriptive, but rather draw attention to the many uses of prototypes.



Carleton University students, to complement some of their early concepts for a new baby stroller design, used quick explorative prototypes. Kinex, foamboard and found objects were among some of the different approaches chosen by the students to help communicate the ideas.

Explorative Idea Generation

Just as brainstorming and sketching are fundamental to ideation, the physical dimension allows materials to be experienced in a hands-on, playful way that is not possible through two-dimensional visualization alone. Explorative prototyping involves rapid and sequential modelmaking to supplement sketches. This quickly helps to gauge whether an idea is worth pursuing and may even lead to fruitful unexpected insights, and hence to more innovative products. A low level of fidelity is often enough to serve as a proof of concept. Different organizations will have different names for explorative prototypes. The term breadboard or mock-up is often used to describe a low-fidelity works-like prototype, whereas low-fidelity looks-like prototypes are often called sketch or massing models. In this book the term 'explorative' is more encompassing as it describes any quickly made prototype for examining alternative emerging ideas. Functional exploration is usually highly experimental and rough. Sometimes products are taken apart and recombined into new functional creations. Mechanisms or other elements of the product may even be built in Lego® to get a feel for how it works, which in turn provides a foundation for the next iteration.

Exploration has everything to do with curiosity and discovery. Exploring new materials or technologies is just as important as exploring form and function. The famous Finnish architect Alvar Aalto developed his innovative laminated birchwood furniture through an extensive prototyping approach. This is even more important today, given new technologies and emphasis on sustainable design. For example, the Nike Trash Talk shoe evolved from designers at Nike exploring how to produce a quality athletic shoe using leftover materials so as to reduce its environmental impact.

Exploration of form (sketch or massing models) usually starts in low-fidelity materials such as foamboard, cardboard or polystyrene foam. The approach is often to work directly from a quick sketch rather than to create exact drawings. Speed is of the essence in order to examine different options effectively before committing to a particular design direction.

Professional product designers build many early prototypes to generate and explore ideas in conjunction with sketching and computer work.

In the development of the ball-flinger dog toy, Mixer Design Group generated explorative models to visualize and evaluate ways in which to throw and pick up the ball. By building a set of early works like prototypes they were better able to evaluate different ideas and approaches quickly and effectively.

Mixer Design Group developed the StarMark disc-shaped fetch toy for dogs through a process that involved a series of explorative prototypes in addition to sketching and computer work.

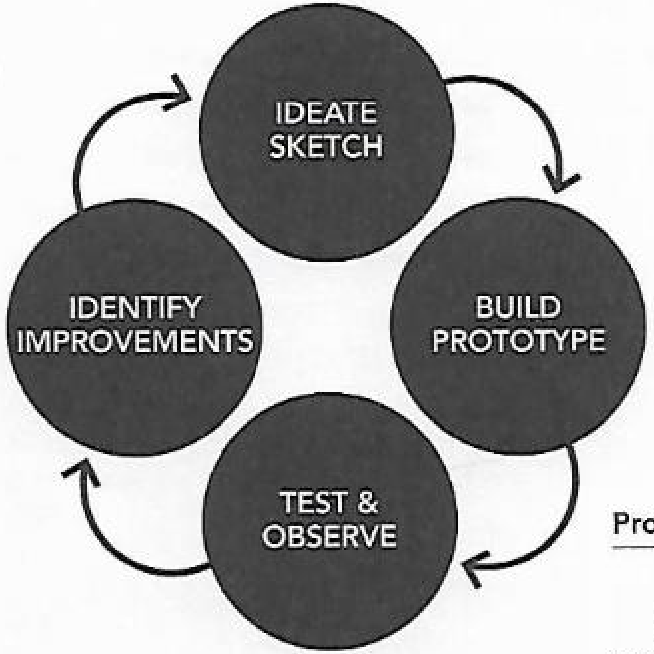
An explorative prototyping approach informs the designers' thinking and often leads to unexpected insights gained from experimentation and testing. These insights in turn lead to more innovative products because the designers learnt something new that could be incorporated into the design.

Guidelines for Exploration:

— These prototypes are mostly built for yourself, to help you understand what you are doing.
— Keep the model simple and free of details that detract from its purpose.
— Make appropriate use of materials. Also use materials to experiment.
— Build models in parallel to explore different issues, for example, works-like versus looks-like prototypes.
— Think of the prototype as disposable. This is an experiment to answer questions: try to learn from the model.

User Testing

A modern design approach involves ongoing research into how people interact with a new product, interface or service. Designers use prototypes to look at what people can and want to do, instead of making assumptions about their behaviour and preferences. By doing this early on in the design process, the observations form a framework for user-centred design requirements. This has become one of the most compelling and significant uses for physical prototypes because it is impossible to test the user experience of a physical product through the computer alone. Prototypes are thus used to test a range of ergonomic considerations, including human fit and size as well as cognitive issues.



Prototyping

The testing cycle consists of building a prototype, testing it with real end users and then observing the outcome of this interaction. This type of ethnographic research is greatly aided by prototypes and includes videotaping of participants to uncover obvious problems or to verify that the design is proceeding in the right direction. Testing can lead to some interesting and unexpected design opportunities. The more alternatives that are investigated, the more will be learnt.

The starting point is often simple handmade prototypes in low-fidelity materials. Sometimes the entire environment of use may need to be prototyped, for example the interior of a car or aeroplane. By focusing on people and their interactions, the prototypes can be kept simpler in construction. This allows more options to be explored and changes to be made. Paper prototyping is a technique for testing a screen-based interface with a series of paper templates that mimic the software.

Simple low-fidelity prototypes in cardboard, in conjunction with paper prototypes of the screen interface, establish the interaction sequence and overall design requirements for this student project for a post-office kiosk.

The post-office kiosk was user-tested with a full-scale low-fidelity prototype (right). Once the product configuration and architecture had been completely tested, the final design detailing and manufacturing considerations had to be taken into account. The final design was communicated through a third-scale appearance prototype (far right).




Full-scale prototypes help to finalize task flow and design requirements. The fidelity is gradually increased as more details are resolved.

Participants

Choosing the right participants is an important consideration. Whereas classmates might be useful for pilot studies, it becomes important to enlist the right end users in order to make the correct observations. This is also an opportunity to address a more inclusive design process by considering universal access issues in regards to people with disabilities. Suggested further reading is listed at the end of this book. Consider the rights of the people participating in your testing. If the information is to be published or shared, then privacy rules apply. Fortunately there are many good resources for conducting ethical studies, and universities require that all studies involving participants have ethics approval. Common sense obviously dictates that participants should never be involved in something that could have any adverse effect, especially regarding safety. User testing is only for the purpose of seeing if people can easily use the product: the prototypes are never to be used in testing strength or any other aspect that could potentially put the participants in harm's way.

Guidelines for Usability Testing:

- Be clear about the test and the tasks and build the model for that specific purpose.
- Obtain guidance on participant selection or refer to books on usability testing.
- Consider universality by including people with disabilities where necessary.
- Explore use from a general context into a more specific context. The overall experience and purpose is the starting point, as opposed to how the buttons should be arranged.
- Observe and document all interactions.
- Make sure to obtain ethics approval before testing with participants.
- Use electronic prototyping toolkits to prototype the experience.
- Never make prototypes that in any way expose the participant to any possible harm. If in doubt do not proceed and instead get expert help.

Communication

Product design is inherently an interdisciplinary activity. Product designers frequently need to communicate their ideas to end users, engineers and marketing professionals, who are not necessarily looking at the project from the same viewpoint. In the film industry, storyboards visually communicate design decisions such as the setting, costumes and story in a comic-book format. A series of still photographs with participants using physical prototypes and acting out intended scenarios can be used in the same way, to show other stakeholders how the product will be used and how it fits into its intended environment. This form of interdisciplinary communication is important in order to make sure that everyone involved with a new product's design and market release is consulted.

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