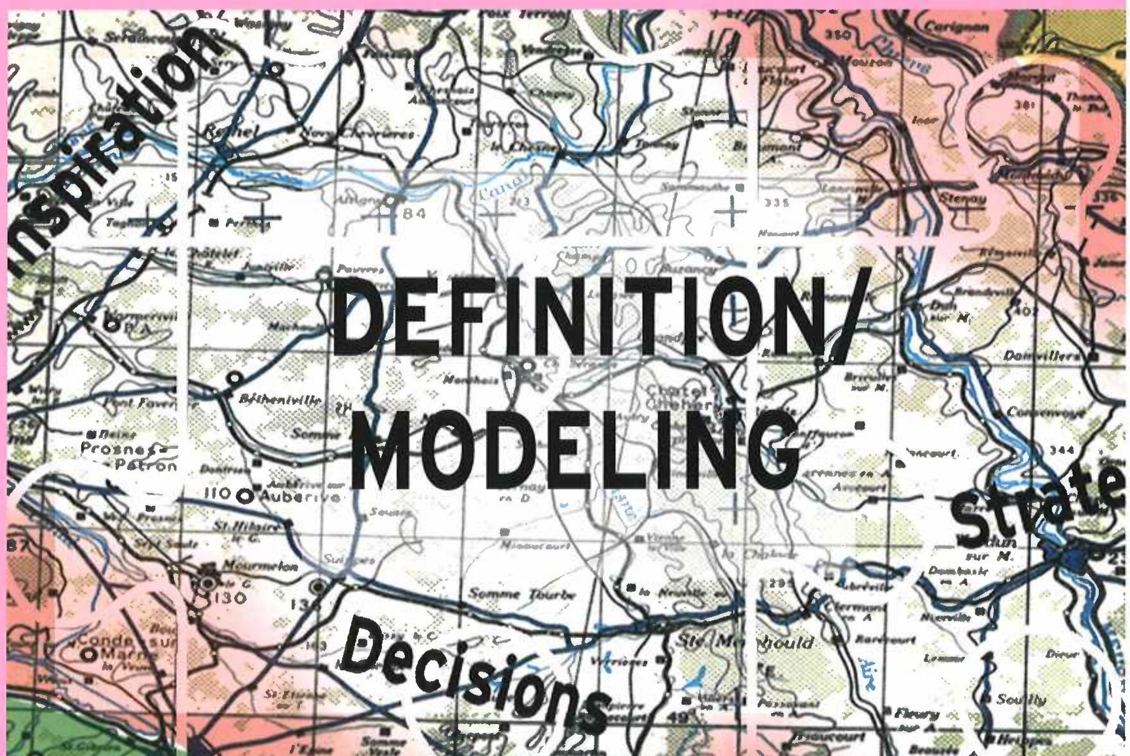
Stage 5



OBJECTIVE

This chapter explains the hierarchy of needs in design and identifies the types of decisions involved in fulfilling those needs. Also discussed are the concerns of modeling designs, from both a practical and perceptual perspective. You are encouraged to explore approaches to creating models for your designs and plan the creation of a concept model. Finally, you have an opportunity to revise your design thesis with any new developments that have occurred.

KEY CONCEPTS

- A design is inevitably less perfect than its concept. Designers can offset this tendency by paying attention to details.
- For the design to be a satisfying solution it must fulfill certain needs, determined by a definite hierarchy.
- Modeling can be an efficient exploration tool and should not be thought of as an end in itself.
- Modeling, like sketching, is a method that conveys the effect and intent of a design; its meaning is shaped by the methods and materials used.
- The design process becomes so detail oriented at this stage, the designer may need a new dose of inspiration.

MAKING IT REAL

This chapter explores the steps you need to take to move your project from the exploration stage to a more definite embodiment in the physical world. The concept must become an object. We must transition from exploring to deciding what it is exactly and sometimes even deciding what it is precisely not, the emphasis being very much on *exactly* and *precisely*. Some people would say that this decision-making process is the designer's primary function. Indeed, the designer must make choices that keep the idea intact, while respecting the parameters and constraints outlined at the beginning and keeping in mind the possibilities and limits of the manufacturing process. You must eliminate as many unknowns as possible before you reach production or prototyping, where redoing becomes costly in both resources and time. It's time for designers to take their concepts and define their realities as fully as possible and in as much detail as they can. Now you must make sure that the decisions you made about constraints at the exploration stage are still valid. It is this definition that characterizes this stage and leads to the need for a model of the design.

Reality is tricky. We have conceptualized our idea so that it seems pretty solid and ready to be used in the world. But at this point, more often than not, our concepts can be seen only out of the corners of our eyes, like ghosts. When we turn to look, they fade back into the shadows. In trying to visualize the "real" object of our design, we find that our grasp of the idea, clear as it may be, may not include enough detail or functional thinking for us to be able to fully realize its image in a physical embodiment. We must begin defining our idea in as much detail as possible and create a model to bring it into the world.

THE BASIS OF DECISIONS: WHEN IS "GOOD ENOUGH" ENOUGH?

> *It is common sense to take a method and try it. If it fails, admit it frankly and try another. But above all, try something.* —Franklin D. Roosevelt

The first thing to do is to look at the constraints and specifications to see that everything has been addressed. Do we have specific solutions for each problem? Do we have the time and resources to solve whatever problems remain?

It is important to weigh your concept on the balance of "making it perfect" versus "getting it done." Every designer must deal with the constraints and compromises of practicality and production. For example, you may want to hold out for an ideal material, but the budget won't allow it or the manufacturer can't wait for the delivery time required. Perhaps your design requires a certain technical proficiency, and you need to figure out what level of expertise is good enough. Perhaps you are just asking for too much: You can never hope to see perfection, but rather the best possible outcome. In fact, the satisfactory completion of a design often becomes a question of defining what "good enough" means in terms of the overall concept and purpose of the design.

As a result, there is always a sense of regret after a design is complete, as illustrated in this description of the architect of the new addition to the Museum of Modern Art in New York.

Yoshio Taniguchi is a pessimist by nature.

Each time Mr. Taniguchi, the architect, visits one of his buildings, he sees every compromise he had to make, every flaw he would like to fix. As he strolled recently through the newly expanded Museum of Modern Art, his first project outside Japan, it was no different.

Visiting the fifth-floor painting and sculpture galleries, Mr. Taniguchi stopped and ran his fingers over a seam in one of the metal panels that separate one room from the next, mourning the undisturbed surface he said he would have preferred there.

He lamented having had to cut back on the number of skylights because of budget considerations. He worried that a wall of windows near the second-floor bookstore reading

Figure 5.1 The atrium of the Museum of Modern Art in New York City may seem like the image of polished perfection, but to its architect it is both a collection of compromises and flaws and "nearly perfect." This kind of professional regret is typical of the designer's hindsight. "Good enough" may not always seem good enough, and yet: There it is.

room would pull the focus away from the building's atrium. He questioned the placement of Henri Matisse's "Dance" over a staircase connecting the fourth and fifth floors, and the elevation of Claes Oldenburg's "Geometric Mouse" in the sculpture garden.

But as Mr. Taniguchi, 67, stood there surveying his soaring yet understated temple of granite, marble, oak, aluminum, and glass, he admitted to a rare moment of gratification. "I think I'm quite satisfied," he said.

"It's nearly perfect," he added. "I'm not supposed to say that because I'm Japanese. I'm supposed to sound humble."

So, how good is good enough? The answer to that depends very much on the context of the needs and constraints of your designs.[1]

THE HIERARCHY OF A DESIGN'S NEEDS

The psychologist Abraham Maslow is known for establishing the hierarchy of needs theory, writing that human beings are motivated by unsatisfied needs and that "higher" needs cannot be satisfied until certain "lower" needs have been seen to.

Needs connected to designs have a hierarchy of their own that parallels Maslow's. A design will be found at a certain level depending on what needs it fulfills.[2]

Examine which needs are met by your design. If you find that you are stuck or missing a level, perhaps there is something in your concept that can change to bring it up in the hierarchy. Designs must meet these needs in succession. Skipping levels only invites a design that is less than successful in fulfilling its promise. The following needs are listed in the order of priority.

Level 1: Functionality

The hierarchy begins with a simple question: Does your design do what it's supposed to do? This most basic of questions may seem almost absurd at first. However, a quick look around will suffice to remind you that not everything that is manufactured or built does what you expect it to. For example, I purchased the thermos on my desk to transport the liter of tea required to get me through a day of teaching. I expect it to be a fairly well-functioning object. After all, the functional mission is fairly straightforward: the design thesis may read, "Keep the tea warm for an afternoon. Don't leak. Be easily transportable."

The thermos fails in two out of three respects. The interesting thing about this thermos is that it has no insulation capabilities beyond any other metal canister. As soon as the tea is poured into it, its exterior immediately heats up to the temperature of the tea, indicating that the heat loss is enormous. This also makes it very difficult to carry until the tea has cooled down, which it does fairly quickly. One may think that someone would have noticed this at some point, but clearly the design was never tested. Worse still, perhaps someone decided that it didn't matter whether it actually worked because people would still buy it.

It may seem obvious on paper, but don't assume that your design works. Before committing to your final choices, check and check again whether your assumptions are correct. Does it fulfill the most basic requirement of functionality? A "thermos" that doesn't keep anything warm is just a can. What is your design if it doesn't function?

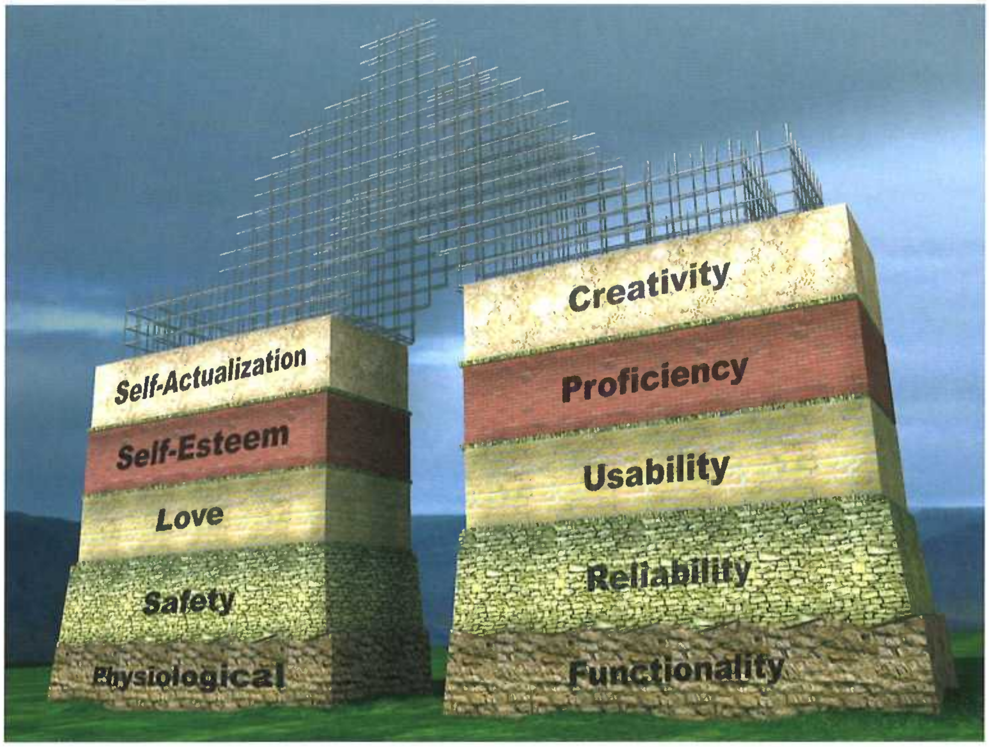


Figure 5.2 Two hierarchies of needs, developing from bottom to top with an increasing level of fulfillment. On the left: Maslow's hierarchy of human needs. On the right: a hierarchy of design needs (adapted from Lidwell, Butler, Holden. 2003.) Although simplified, these can be seen to describe a fairly accurate picture of experience. Just like a human being needs to achieve certain levels before becoming a fully realized individual, a design must achieve levels of basic accomplishment before being perceived as creative and paradigm altering.

Level 2: Reliability

Assuming that functionality is in order, the reliability of a design would be measured by the *consistency* of its performance. The microwave oven in which I reheat my tea, for example, is always consistent. A cupful at 75 seconds will always be comfortably warm. This may seem to be a fairly trivial example, but consider a parent who needs to heat a baby's bottle. If the microwave weren't consistent and made the milk lukewarm one night and boiling hot the next, this could cause an unpleasant accident. As reliability goes hand in hand with safety, this is a very important aspect of designing. Given that a design functions, we would like it to do so consistently and predictably.

Examine your idea by questioning all the things that could go wrong, whether they are seemingly trivial or important. Are there vulnerable points in the design? Remember Murphy's Law: Anything that can go wrong will. However trivial the problem may seem, if the reliability of a design is in question, you will have an irritated and unhappy user.

Figure 5.3 If the design of a thermos does not allow insulation of temperature, or a phone will not allow easy communication, then the designs have failed, and no polish or aesthetics will change that.

Level 3: Usability

Usability is about the *experience* of the design. How easy is it to use? How does it become a part of the user's life *over time*? In the past decade, usability has become a loudly chanted mantra in website and software design, but the principle applies everywhere. Ease of use is relative, but generally speaking, we should not need to relearn how to use something each time we need it, and we should be able to make mistakes without causing catastrophic consequences. I don't have to press a sequence of buttons on the microwave oven to make it work. There is a series of buttons, each one clearly and legibly marked with a setting for a typical household need. There is no real doubt about what to do. I can still manage to push the wrong button, but I have a "cancel" button and therefore have more than one shot at getting what I want.

It can be easy to fall into the trap of thinking that we are designing for one idealized user—someone exactly like us. But we are not. We're designing for other people, and if those people are going to like and use what we create, we need to understand who they are and what they need. By spending time researching those needs, we can break out of our own limited perspective and see [the design] from the point of view of the users.[3]

Level 4: Proficiency

At this level, the designs actually *improve* the user's experience, allowing things to be done better than before or in ways not previously possible.

One aspect of the designer's job, especially when breaking new ground, is to design not only the product, but also the system in which the product will operate. Defining needs and constraints is an initial step toward realizing this. The design process and the design might be addressing needs way beyond the actual operational aspects of the designed product. This is clearly necessary in situations such as the introduction of sustainable practices, where the end user must operate under a different set of principles or expectations from before, but also in cases where design is brought to bear on social and political issues. Change makes people nervous, especially when it applies to their basic needs and behaviors. Therefore any designers that attempt to achieve a larger goal by altering the user experience to a significant degree must speak to the overall needs and situation of their intended client.

For example, the nonprofit One Laptop per Child, created by faculty members of the MIT Media Lab, is dedicated to creating a child-sized laptop that will bring learning, information, and communication to children in developing countries. Governments purchase the laptops directly and distribute them to their schools.

Figure 5.4 The creators of the XO-1 laptop computer, a child-sized laptop for children in developing countries, found a way to improve on an existing design by adding new technology or challenging existing views of how things are and should be.

The OLPC laptop, called the XO-1, was designed for children and challenging conditions. As such, its design ensures that it is resilient, easily portable, and energy efficient. Because most of the laptops are going to remote places with limited or no infrastructure, and electricity very likely coming from alternate energy sources or costly (and polluting) generators, the XO-1 requires only a fraction of the power of an ordinary laptop, making the addition of a hand-held (cranked) power source an option.[4]

OLPC's mission is primarily educational, and the design of the laptop is part of an overall mission that they describe as follows:

> By giving children their very own connected XO laptop, we are giving them a window to the outside world, access to vast amounts of information, a way to connect with each other, and a springboard into their future.[5]

The system they've designed has five principles, and the machine is designed to uphold each of these:[6]

1. **Child ownership.** The laptop is low cost (between $100 and $200). It is robust enough to stand up to the challenge of being in the hands of grade-schoolers and designed to look friendly. The battery can work for many hours, and it can be charged in special gang chargers in a school or by mechanical or solar power. The display is bright to allow for use under a bright sun, enabling work outside the classroom or at home, in the wild or in any public open place.
2. **Low age.** The XO is designed for children of ages 6 to 12. It is easy to operate and navigate. Knowing how to read or write is not necessary to play with the XO. OLPC operates on the theory that playing is the basis of human learning and that digital activities will help the acquisition of writing and reading skills.
3. **Saturation.** The OLPC commitment is with elementary education in developing countries. In order to attain this objective they aim for "digital saturation" in a given population, whether that is a whole country, a region, a municipality, or a village. Operating under a strategy similar to vaccination efforts, the main point is that every child owns a laptop as a step toward lifting the education level of all.
4. **Connection.** The laptops in the community are all connected to each other, even when they are off. If one laptop is connected to the Internet, the others follow. The children are permanently connected to each other and to the world.
5. **Free and open source.** OLPC views the children not as passive consumers of knowledge, but as active participants in a learning community. With all the software open source and free, children quickly learn to create their own computing and learning environments.

Find a way to improve on an existing design by adding new technology or challenging existing views of how things are and should be. Designing a new product can take years at this level, as exploration and experimentation are at the center of activities, with many layers of problem-solving going on at once. Design products, but think of the system in which your products operate, and consider how your design can improve the whole system. This is design that *changes how lives are lived.*

Level 5: Creativity

Finally, there is the level where all other needs are satisfied, and the design goes into new territory, changing perceptions and experiences. At this level one can experience a crossover between disciplines, and designing is about much more than just making more stuff. Consider for example the wide variety of events and inventions listed in Appendix 5: Zeitgeist and Design. At the beginning of his book *By Design*, Ralph Caplan writes:

. . . design at its best is a process of making things right. That is, designers, at their best, create things and places that work. But things often do not work. And making things right is not just a generative but a corrective process—a way of righting things, of straightening them out and holding them together coherently.[7]

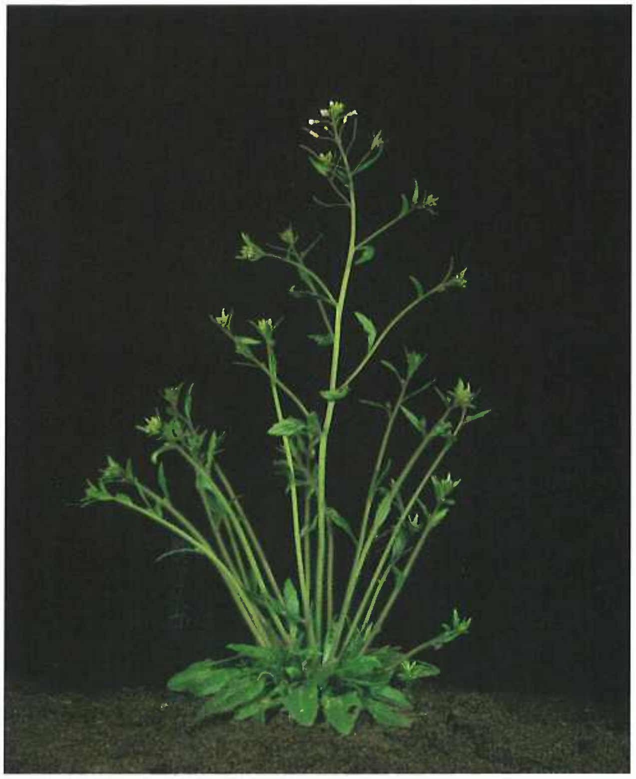


Figure 5.5 Design at its most creative level changes how we approach the world and its challenges. Re-engineering a common flower, the thale-cress pictured here, to detect landmines is a startling example of such out-of-the-box thinking.

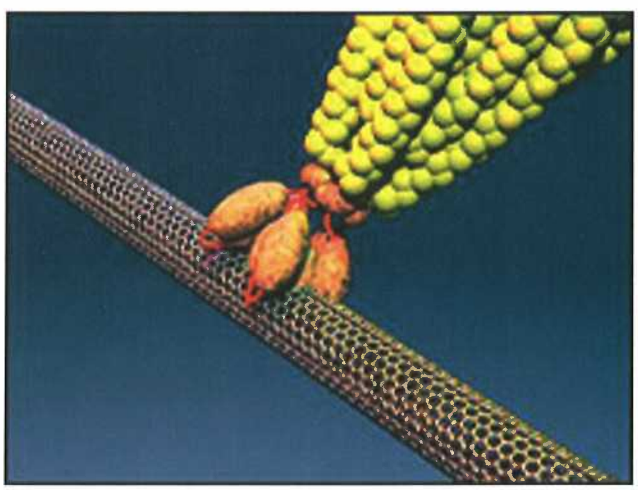


Figure 5.6 Another example of radically innovative thinking comes from MIT: a genetically modified virus that latches onto a nanotube and creates an electrical grid to make an environmentally friendly battery.

With this in mind it is hard to beat the paradigm shift attempted by Aresa Biodetection, a Danish company. In 2004, the company announced that it had, by genetic modification, produced a new variant of thale-cress, a small flowering weed. The new strain turns red, not in the fall as it would normally, but when growing in the presence of nitrogen dioxide, a gas commonly emitted by the explosives inside a landmine after the mine has been in the ground for a while. Now there would be a new way to detect landmines left over after a war: seed a suspect area, wait a few weeks for the thale-cress to grow and where they turn red, there's your danger zone. In 2005, the concept was proven in tests with the Danish Army, and in 2008, large-scale clearing of mines was planned in Croatia and Serbia.[8]

Instead of machines, dogs, or slow, laborious, and highly dangerous detection by human hands, the bombs would be sniffed out by flowers. A killing zone would not only be removed but greened at the same time. Sadly, this very creative concept could not compete commercially with machine-based solutions and so has not been put into wide use. But trust the Danes to come up with a solution straight out of Andersen's fairy tales.

Another example of such radically innovative thinking also involves genetic engineering. In April 2009, a team of scientists at the Massachusetts Institute of Technology, led by Professor Angela Belcher, published a study showing that they had genetically engineered a virus to make an environmentally friendly lithium battery.

The engineered viruses, which are not harmful to humans, first coat themselves with iron phosphate, then grab hold of carbon nanotubes to create a network of highly conductive material. Because the viruses recognize and bind specifically to certain materials (carbon nanotubes in this case), each iron phosphate nanowire can be electrically "wired" to conducting carbon nanotube networks. Electrons can travel along the carbon nanotube networks, percolating throughout the electrodes to the iron phosphate and transferring energy in a very short time.

The new type of battery could come in the form of a thin film and would be capable of charging laptops, music players, and cellular phones. The prototype is packaged as a typical coin-cell battery, but the technology allows for the assembly of very lightweight, flexible and conformable batteries that can take the shape of their container. The implications for the design and manufacturing of small electronic devices are enormous. According to the research, not only would the biovirus battery perform as well as or better than the standard lithium ion batteries available on the market today, but they would also be a much more environmentally friendly alternative. Not only are all the materials that go into the battery nontoxic, but the process itself has no harmful elements.[9] Because the viruses are living organisms, the process entails only water-based solvents, uses no high pressures and no high temperatures. Said Professor Belcher, "We're using a biological template that's already on the nanoscale."[10]

It is this kind of cross-disciplinary creativity in innovation and design that will be the key to sustainable living in the future. A shift of this kind can be made by putting new technologies to unintended uses or by combining components that otherwise would not function in the same environment.

Figure 5.7 The biovirus battery looks like a simple battery, but is cleaner and stronger. It requires no toxic materials or harmful elements in its production. This kind of creativity will be key to our sustainable future.

What can you do to bring your idea to this level? Think of the problem you are solving with your design. How would you approach it in another way? Can you remove the problem altogether? Attack the cause rather than the symptom. Build batteries using organic processes. Do something unexpected, and don't be afraid to be weird or engage in magical thinking. People love creativity but are often resistant to—or even scared of—change. Show them that your change is fun and beneficial. Sow flowers instead of Kevlar-clad warriors with dogs and bristling machines!

ANATOMY OF AN IDEA

An understanding of anatomy is essential to anyone who wants to know how an organism functions. To fathom how well an idea would grow and survive, you need to approach it with an anatomist's eye before you grant it a physical existence. By taking this approach, you will gain great insight into your idea and how all of its components fit together, which allows you to explain it to clients, manufacturers, and others, and also to field their questions *or* criticisms. Look at your idea and break it up into its constituent parts: What are they, what is their purpose, and why are they there? Begin by asking how much of the idea deals with the actual physical representation and how much deals with philosophy or the intangible, emotional response. In other words, break your idea up into its actual physical parts and the perceived effect of these parts. For instance, you can have two fairly ordinary but highly contrasting materials (e.g., driftwood and steel). Each material has a specific quality that can be powerful and clear. Putting them together in a structure causes an effect that is greater than the effect of each individual material. Our reaction to the juxtaposition of colors and textures has an emotional quality that is created at this point. The idea contains more than just a shopping list of things; it is greater than the sum of its parts. You need to consider what the statement is in each case. What is the purpose of each entity in relation to other elements and to the whole? How do they affect, contrast, and complement one another? Then consider whether there is any way each part could be made more effective. Does it serve the idea as well as it can?

Ideas evolve, and the evolution of an idea often means that the concept has been approached several times, tinkered with, and tweaked. Things have been added and taken away, in both a physical and philosophical sense.

When complex entities evolve, parts lose their importance and perhaps even stop serving any purpose at all; yet, they remain if they are not in the way, until something—usually something problematic—draws attention to them.

Examine your idea for unnecessary additions. Make sure every element the design contains has a purpose. Any purpose may do: Practical, decorative, humorous, or sentimental—it is up to you as the designer to make the case. But if you can look at some element of your design and say that it really has no purpose, take it out. Finally, one might say, as physicians do in their oath, "First, do no harm." Examine your idea for ecologically unsound elements. Look at its entire life cycle, from the harvesting or gathering of components to its eventual reuse, recycling, or disposal. Whatever needs to be altered to minimize the environmental impact must now be changed.

DETAILS

Before we look at the actual modeling of a design, we must consider the details and how they come into play. Details can be aesthetic and surface-oriented, as in the decorative details of apparel or interior design. They can be subtle and integrated, as in the application of techniques and finishes on furniture. Details can also be functional in the sense that they can involve the use of very specific components, as in the choice of certain components, chips, or electrodes. Details may involve a choice of materials for ecological purposes or be references to other eras and art forms in their aesthetics, contexts, qualities, or material content. For modeling purposes it is good to identify details as either functional or decorative, if possible. (The grey area of the "functionality" of decoration must be evaluated on a case-by-case basis.) This distinction will inform the level of functionality of the model, as you will decide how much detail the model needs to show.

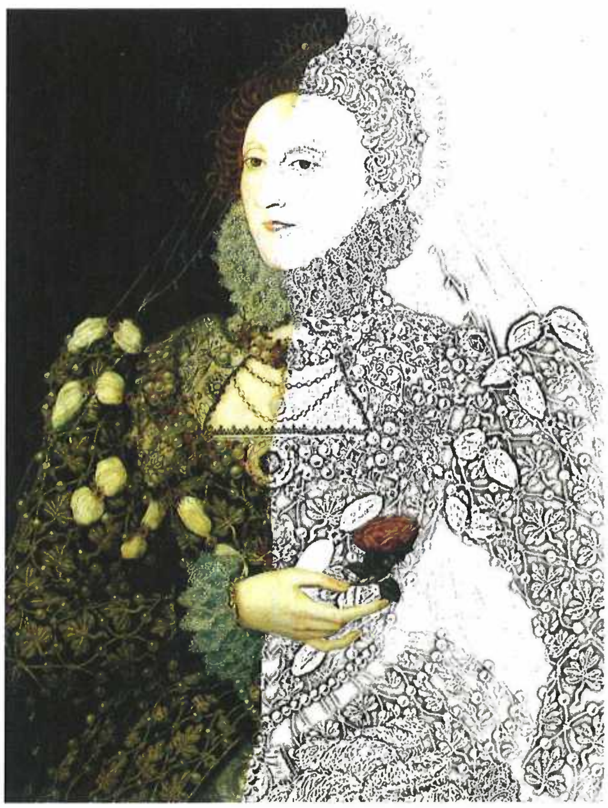


Figure 5.8 How much detail you need is entirely dependent on what you are trying to convey to your audience. For some, the overall form will be important; for others the finer detail and texture will matter most. What you present, either way, must maintain a consistent relationship with the reality of the design. Make sure that the big picture and outlines conform to the same world as the more-detailed picture. Here, the left and right represent the same design, but each has a very different approach to the information.

The correct treatment of these details, whether functional or decorative, is crucial at this stage. Their definition and treatment will not only influence the outcome of the final design, but their presence or absence in the model will also present your idea in a certain context. As your model is the first impression your clients and colleagues get of the design's physical manifestation, a false or inadequate impression can be quite harmful. It will stick, as first impressions do, and when you present your next iteration of the design, there could be great shock and surprise if the implications made by the first impression were now seen as being incorrect.

Through sketching and concept mapping, you should now have a fairly well-defined sense of which details are important and how they come into play. Having separated them into functional and decorative, consider which are essential to the true representation of your idea. Remember that the model you are going to build is a conceptual one and should not necessarily have to arrive with all the bells and whistles of the final design. However, your model needs to tell the story, even if it is abbreviated, and the story must give all the details and hint at all the implications.

How will you create or represent functional details? Will they actually function in a way the final design needs, or will you imply and explain the action? How will decorative details be represented? This decision may not always be easy, especially if the scale is small. Here is where you must begin to consider the language of your model, much in the same way you began establishing a language with your sketching. Regardless of how small or large it is, how functional or not, the model must be coherent and present to your audience its inherent reality, maintaining a point-to-point connection with the physical reality that the design will eventually inhabit. In other words, each element of the model has a direct reference to one, and only one, element of physical reality. Just like spoken and written languages maintain a clear individual meaning for each of their words (for the most part), the language of your model should be clear and allow for no ambiguity in terms of which model element represents what real texture, material, and so on.

CREATING MODELS AND SAMPLES

It is worth noting that the word *model* is used here in its widest possible application, meaning any kind of sample, mock-up, or attempt at physical representation of an idea, ranging from a standard architectural model to a sample garment on a mannequin. The creation of models and samples at this stage of any design is an attempt to bring the idea into the real world and help us understand how the design will function there. But why now? Why not wait until the idea is more developed and create a final model in one go, rather than one that will very likely only be a temporary representation of the design?

Modeling can, like sketching, be a very efficient way of exploring a design. There are huge benefits to making one at this point, but also dangers. Creating a model is the best way to become acquainted with the possibilities your design contains in regard to textures, functionality, and manufacturing techniques. Not only can you use the model to show what your design

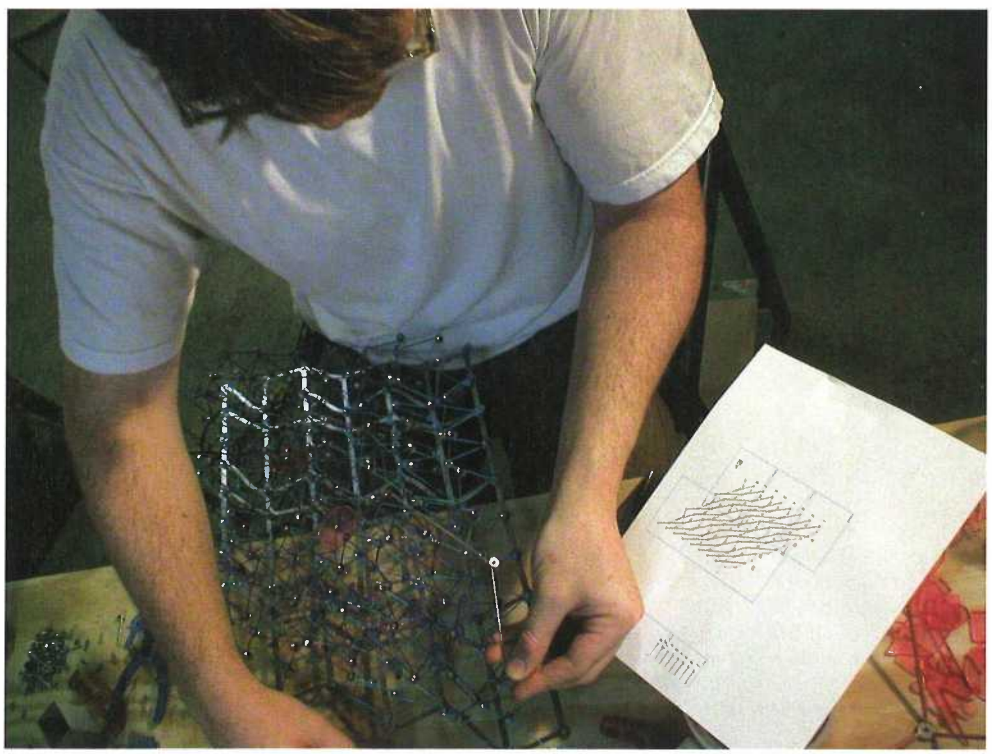


Figure 5.9 Creating a model allows an exploration of textures, functionality, and manufacturing techniques. Use the model to show what your design can do, but also experiment during the model building process with issues of functionality, construction, finishes, textures, and techniques.

can do, you can also use the model building process to explore and solve issues of functionality and construction. The model will also allow you to try out different finishes, textures, and techniques.

There is a trap that is easy for all designers to fall into. That is to think of a model as a sacred object, created once and observed with reverence thereafter. Don't be precious about your models: Realize that you can use models as sketching exercises, to experiment and explore. Make models for different purposes and from different materials. In the same way you would sketch on a napkin with a ballpoint pen, you can create sketch models from available materials and scraps.

Creating a model brings the design into the world. No matter how good the drawing or diagram, there is a different perception of an object we can touch and view from different angles. Even when viewing virtual models on a computer screen, we are still looking at two dimensions. Animated virtual models approximate the sense of space, but there really is no substitute for substance. As soon as something is in the world, taking up space, open to touch, and very much *there*, we perceive it differently. We are beings who live in space and time and take a different view of things that share all our dimensions. Even if it's just sitting around, the model is *in the world* and will develop its own presence and character for you to explore as well.

The Model Is Real, But It's Not the Real Thing

The realized model is extremely valuable in demonstrating the design to clients. You may have lived with the idea for some time and feel you know everything about it, but the client may not have seen anything yet and may not be good at visualizing or understanding sketches. By bringing in even a very basic model, you are anticipating that problem and fixing it for your client before the client even realizes it.

Another reason could be that everyone enjoys a work in progress. Watching someone at work is informative and often entertaining. Bringing in a model invites your client to come inside your process. However, this may also invite some issues. You may find that the client buys the ingredients, but not the recipe. In other words, the client may focus on the individual elements of your model or your methods of construction but not approve the sum of the parts. If you create a conceptual model, the client may mistakenly believe that because the model doesn't work that the final design won't work either. Perhaps a client will expect too much because you made a model look so good and it's not immediately clear that the end result will work. This is especially problematic with computer design, whether it is graphic or three-dimensional. Graphics pop on a computer screen, as the screen is a light source, and you can achieve colors on a screen that most printers cannot duplicate. The key is to keep reminding yourself, and the client, that the model is not the real thing. (This can be subtly done by maintaining a level of "unreality" in the CAD model by simplifying backgrounds or using wireframes to form surrounding objects.)

Figure 5.10 Bringing in a model in progress is a way of letting your client inside your process. Allow them to engage with your creative process and see the work from the inside. They will appreciate the work all the more for it.

You must be careful when presenting a mock-up that your meaning is clear. What exactly are you presenting: the look, the function, or both? Perhaps you are only presenting a part of the whole idea. Declare this up front and the confusion (yours included) will be lessened.

In addition to having to deal with the issue that the model is not the real thing, there is also the issue that the model will not

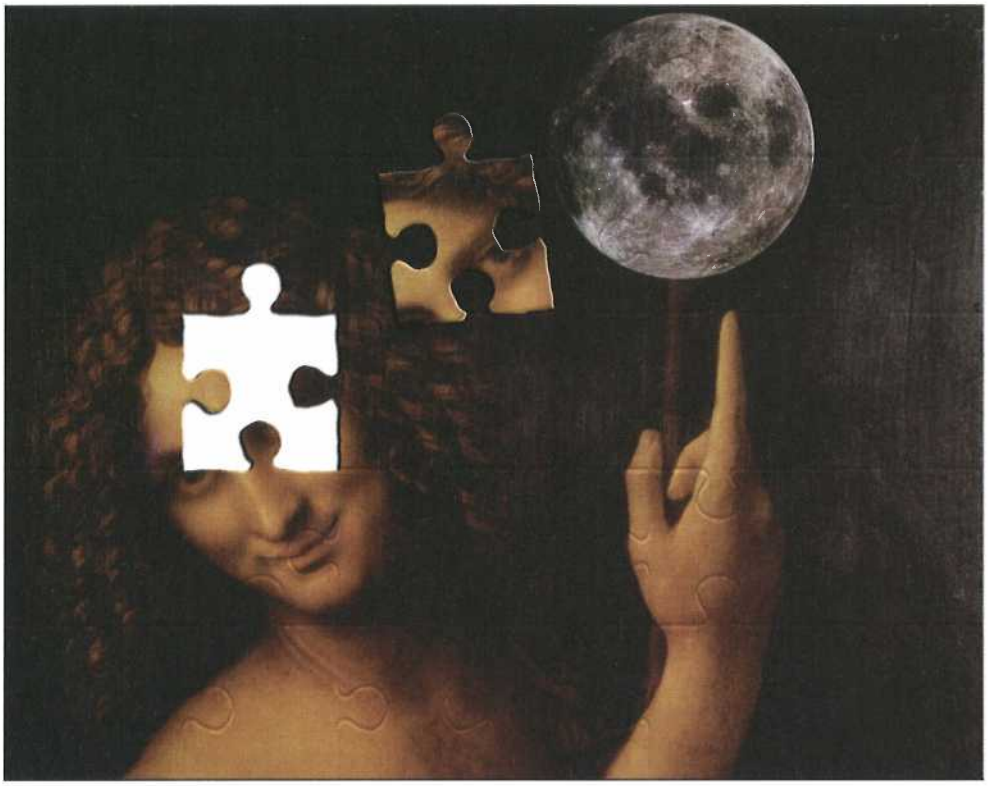


Figure 5.11 An old proverb says that when a hand points at the moon, a fool looks at the finger. Make sure you do not make fools of your clients by allowing them to make this mistake when observing your designs. Your presentation must not become the focus—make sure the designs, ideas, and concepts are at the center of everyone's vision and not how clever your model is or how masterful your illustrations are.

actually live in the real world and not be subjected to the daily grind. Therefore, certain problems that will develop over time will not be observed.

More often than not, a model is made from substitute materials and cannot be subjected to all the rigors of existence—a problem that becomes even more acute when dealing with virtual models. Since the virtual world does not contain any temporal or environmental forces, unless they are carefully programmed in, we may assume that the design will survive out in the real world. The better the simulation on the screen, the easier it is for us to suspend our sense of reality.

The solution is to try to envisage the object in full contact with reality. Use rough models to imagine situations and carry out as close a simulation as you can. Do the math, get the experts, do whatever you can, but above all, try *something* rather than just assuming (and hoping) that all will be well.

Scaling Problem

A dangerous aspect of modeling is that behavior, both human and natural, does not scale well at all. Something that works perfectly well in miniature may not work at all when scaled up and vice-versa. The problems can basically be divided into those of *forces* and *interaction*.

Force problems are concerned with the effect of the environment on the object, most notably gravity (load) and any kind of impact (friction or stress). For example, architecture requires knowledge of what is known as the *square-cube law*. While strength is proportionate to the square of the linear dimension, mass is proportionate to the cube of the linear dimension.

Strength, however, is dependent on the cross-section of the object. Using the block example, a single block has a single face pressed to the ground. However, the cube two blocks high has four faces pressed to the ground. (It's composed of two levels of four blocks.) This is the cross-section, and it is the square of the linear dimension. A building with twice the thickness of girders, compared with another one, is therefore four times as strong—but if the building is also twice as tall as the other, the weight pressing down on those girders is eight times as much. So architects need to give large buildings proportionately stronger supports. (This is why large animals tend to have thicker legs than those of smaller animals.)

In apparel design, if a sample is created to scale, similar rules apply to fabric and yarn. A small piece of fabric is harder to tear than a large one, as the stresses increase geometrically, and the load-bearing strength of yarn and thread is also subject to the square-cube law.

Beware if you are using your model to describe in any way loads, forces, and movement. We could happily go along and create a model using the materials planned for the finished object, and at the scale we're modeling, everything holds up. But then later, we build a full-scale version and it cannot hold itself up, or an object that moves around lightly in a scaled-down version may just hang there, or worse, crash to the ground.

Interaction problems come into play when a designer assumes that users and the environment will interact with the object in the same way in larger scales as they do in smaller scales. I have witnessed this problem myself in theatrical design on more than one occasion, especially in the case of onstage stairs. Viewing a model with stairs in it, no one would usually comment on them. I learned to very carefully discuss possibilities of this sort at presentations, so the reality represented in the model would be clear to everyone. I would even warn the actors, "This is going to make you nervous when you see it onstage." Despite warnings, the full-scale reality would still come as a shock to some when the set appeared, and the purpose of the design would have to be explained again. This is not a problem of your audience's intelligence or the clarity of your model's information. This is a problem of perception and how people internalize information. A model is a model, regardless of how much is said. It requires a mental journey on behalf of the audience, and you, the designer, must help your audience make that trip. That is why you are there.

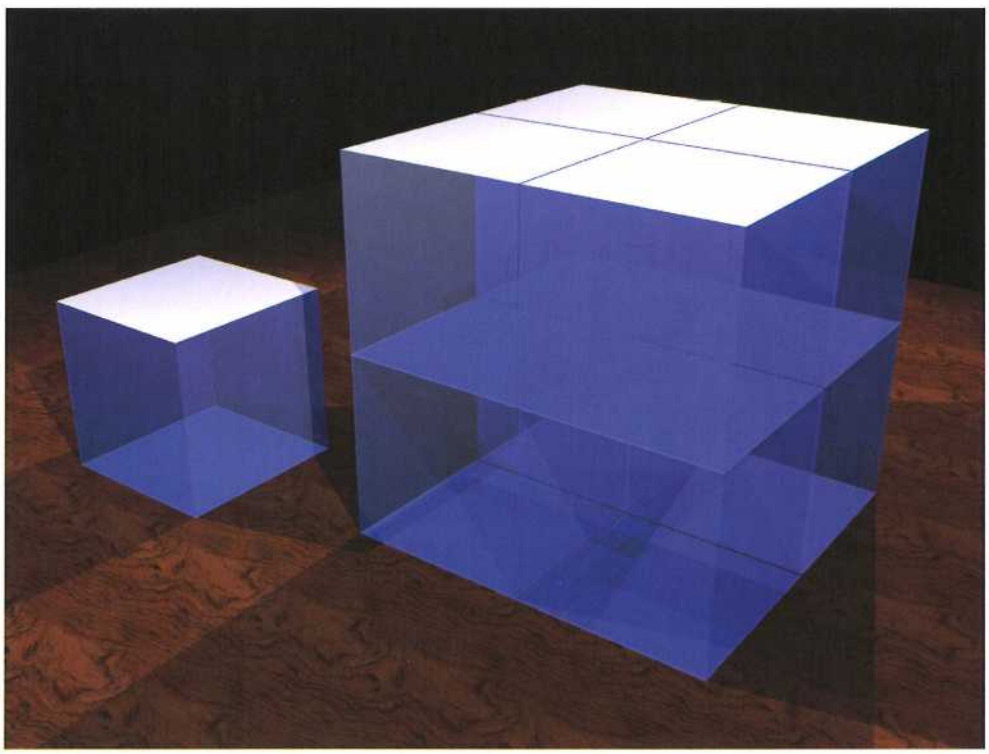


Figure 5.12 A problem of scaling is well illustrated by these blocks in a simple illustration of the "square-cube law." Strength is dependent on the cross-section of an object. Here, the single block has only one face pressed to the ground. However, the cube two blocks high has four faces pressed to the ground. An object with twice the linear dimensions has four times the surface in cross section but eight times the volume or mass. This rapidly requires a rethinking of the strength of the material to be used.

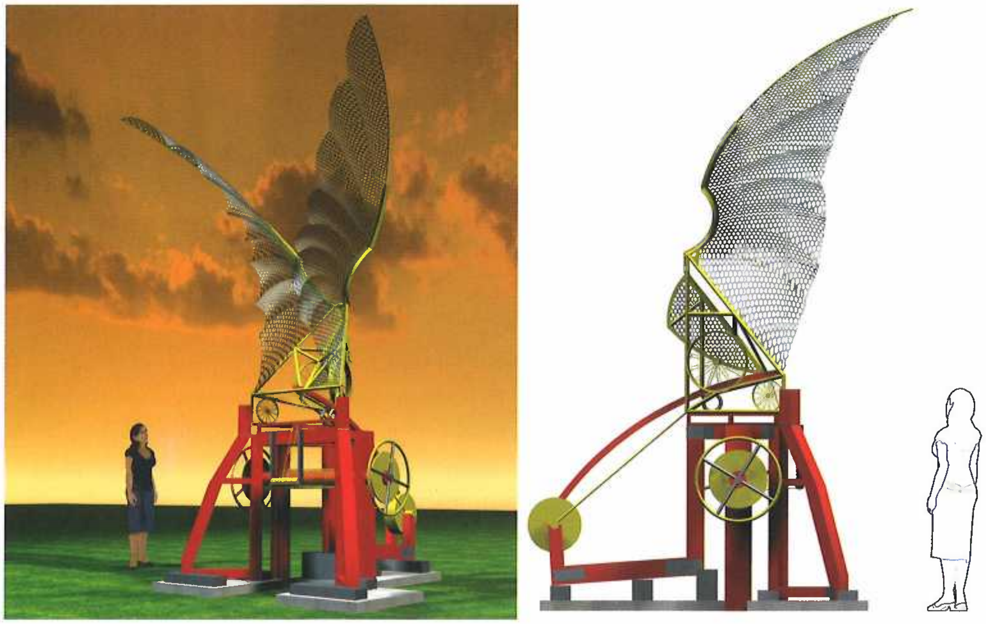


Figure 5.13 Without the human figures, there would be no way of assessing the scale of the object. Even though the dimensions are not included, we all have an innate sense of the approximate size of a person.

Interaction can also be different for differently scaled environments. A building can be only so large before comfort demands elevators, moving walkways, large lighting systems, and so on. The maintenance required for a small garden-square is far different from that for a large park. Maintenance crews may need vehicles, which require larger paths, which in turn lead to a desire for larger shade trees, which then need more maintenance, and so on. These consequences can continue in a chain reaction far beyond any intent of the designer. Don't get so involved in your model that you forget to make the necessary calculations, and make a point of researching any similar situations and designs you can find.

OBSESSION WITH MODELING TECHNIQUES AND METHODS

A variation on the above problem, and perhaps a more common one, is to become completely obsessed with the model-making to such a degree that the actual design fades into the background behind the technical and practical aspects of the modeling. This obsession is understandable but nonetheless something to avoid. We fall easily for the fun and charm of finally creating something tangible, and if it is a scale model, our inner ten-year-old selves may take over and get lost in the delight of creativity. This is a wonderful impulse but must be kept under control.

On a more difficult note, obsessing with model creation is also a way of deflecting issues that are perhaps more serious. The model itself we can solve; the questions it raises perhaps not. Focusing on the model sometimes becomes a way of avoiding the more problematic issues at hand. It is easy to avoid a looming dilemma by focusing heavily on getting that texture right or making sure the scale is absolutely perfect. But the problem does not go away while you play with your model. On the contrary, it becomes worse by the fact that when you finally look up from the details of your model, there is now less time than before to solve the problems.

If you are aware of the design hierarchy of needs stated above, you can make sure your priorities are in order, and having solved all you can, you can blissfully hyperfocus on the detailing of your model *after* you are sure you can fulfill the needs of functionality and reliability. If not, then using the model to solve these problems is the thing to do.

STRATEGIES

Dimensionality

Deciding on the presentation method of the model gives you a framework to work inside and a clear endpoint for your modeling. The first choice is whether to make the model two- or three-dimensional. Next you consider whether you will present a functional model. Then you can decide whether you are presenting a physical or virtual model, and finally you can choose to create an animation if you have decided on functional or virtual.

In most cases, the default route for a functional model is three-dimensional, unless the project is in graphic design. However, two-dimensional diagrams can also convey all the relevant information, especially if you are modeling processes or functions over time. A three-dimensional model has the obvious advantage when depicting a three-dimensional object, but sometimes the full three-dimensionality is not the main concern of the design. Perhaps the central issues are cross-sections, silhouettes, flowcharts, or process diagrams. Think very carefully about what exactly you are showing your audience before creating your model.

Although modeling techniques have remained the same over the past few decades, the one change that did take place in the last decade of the 20th century was hugely significant: the rapid development of computers as tools for modeling and the creation of animations and rapid prototypes.

Virtual models often look fabulous and have the ability to be quickly translated into instructions for laser cutting or rapid prototyping. The inherent danger of a misperceived reality is always present, however, and I have also found that the hyperreal textures and environments of a CAD model can be distracting to an audience. The focus becomes the presentation, not what is being presented. As mentioned, I have found it to be helpful to include some element in a virtual presentation that "gives the game away." For example, a designer might follow a set of lifelike renderings and animations with a more sketchy set of images or wire frames. This reminds the audience that they were looking at a simulation. Sometimes less reality is better for allowing and even encouraging the audience to consider the designs as works in progress.

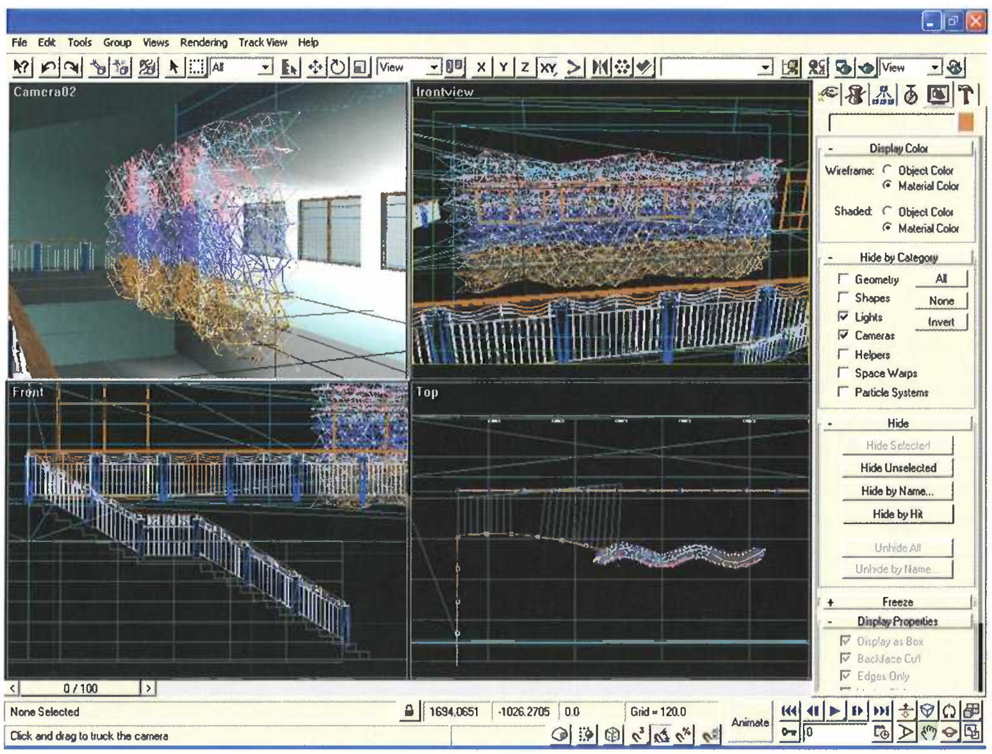


Figure 5.14 Three-dimensional renderings can have an almost "too-real" feel to them, and it is good to remind your audience that they are looking at a model.

Functionality

The dimensionality of the model may be decided by how functional the model should be. Any mechanical function immediately implies three dimensions, but there are degrees of this. Does *everything* have to be three-dimensional? Are you modeling parts, or is everything put together? Can you model only the parts that require three dimensions?

If you are designing in two dimensions, how are you going to present the design? Are you printing diagrams or showing slides or projections? If presenting two-dimensional graphics, you must decide on the printing technique and medium for printing. Choosing heavier paper for larger prints is usually a good idea and mounting on boards for display or passing around is often helpful.

Choosing a Scale

If it is left up to you to choose the scale, the best way to approach this is by considering the smallest model you can make that will still function and display the design as clearly and accurately as is necessary. Do stay within standard scales, though. Make sure you know what scale your audience is accustomed to. It can be very confusing to be presented with a scale different from the one you are accustomed to, especially if the difference is not large. I came out of college in England versed in creating set-models in 1:24 and scaled garments in 1:3 only to find myself in a theater where the custom was 1:20 and 1:4. Needless to say our scaling languages were thoroughly confused at the beginning. I would, for example, read other designers' models as if they were in 1:24, despite knowing that they were not and would instinctively feel that my own models were too large. No matter how sure we are of the numbers we are looking at, there is an experiential threshold that cannot be crossed so easily.

The problem of choosing a scale can be approached another way. We can choose a scale that affords the best use of materials to represent our object. It is interesting to note that there seems to be a "reality threshold" in the scaling of models. It would seem that somewhere around one-twelfth scale for industrial objects and one-third scale for fabrics our perception becomes much more forgiving and ready to accept the models and anything larger as real. This is due for the most part to the scaling of textures and the materials' physical behavior. Most textiles, for example, simply because of the mechanics of their weaving, need a certain ratio of area to drape convincingly. Once you get below one-third scale, the thickness of the weave takes over and the fabric looks (and feels) stiff. Architectural and theatrical models must, however, by virtue of the size of the subject matter, be at a much finer scale, and so the models are rarely made of the true materials and not experienced as "real."

Choosing Materials

Think very carefully about what materials you will need for your model. What are you looking to represent? The real materials may not scale well, so you may have to be very innovative and allow yourself time to research how others have solved similar problems. Techniques of physical model-making have not changed much in the past decades as they have been perfected through many years. A quick visit to a hobby shop can give you clues on how to represent textures to scale or how to actually build objects. There you will also find softwoods, balsa, plastic clay, and other staples of model making. But you may have to invent your own, so allow yourself time to research and experiment. New emerging technologies in 3D printing are now offering glimpses into new possibilities for model making as well as production. Once these become affordable and more versatile, there will be a sea change in the approach to prototyping and model making.

Often we must substitute one material for another, so that it will read correctly in the scale. Wood does not scale well, as the texture is so easily discernable. A solution to this is to use another wood with a finer grain, or—if the scale is relatively small—paper or plastic clay.

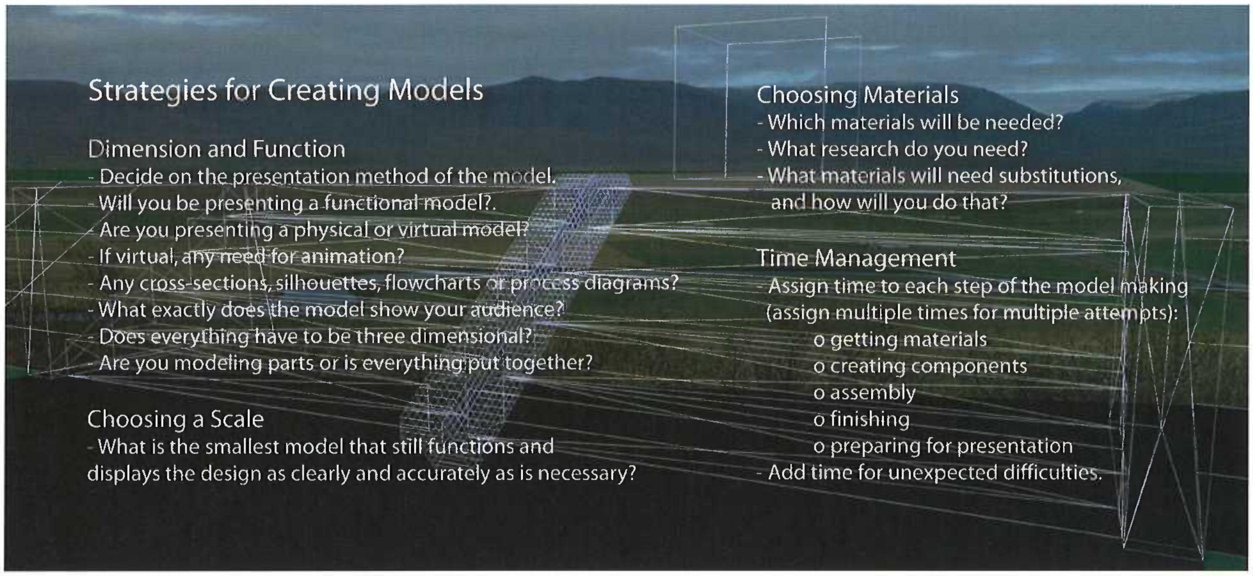


Figure 5.15 Strategies for model making.

Metals and glass scale well texturally, but not in terms of thickness. Here we find ourselves resorting to plastics, clay, or paper. The substitution then relies on a textural handling for believability, and we can apply varnish or paint and various powders to simulate textures. One danger inherent in this solution is that by distancing ourselves from the reality of the designed product, we forget to consider the environmental impact of the "real" materials. Once again, we must keep reminding ourselves that the model is not the real thing. Then, every change made to the model must be interpreted back to the final product.

Time Management

When creating a sample or model of a new design, it is very important to allow for experimentation and the redoing of things. Take a moment to think about the steps you must take to create your model, and assign time to each. You must plan time for getting materials, creating components, assembling, finishing, and preparing for presentation. Consider which elements may require more than one attempt, and multiply the time for those. Then add some time for unexpected difficulties, and you should be in good shape.

REINSPIRE

Once you get to this point of the design process, it is very possible that a bit of fatigue will set in. More than common, it is practically integral to the process. The initial excitement over the project gets buried in the practical details, the defining, and the planning. The amount of work ahead may be a bit daunting, and the way a studio usually works, you may find that a new project has come in that looks much more exciting.

You need to remind yourself why this project was a good idea and where you intended to go with it before you make the big step toward commitment. If you don't, you may be in danger of the fatigue taking over, and the designing will increasingly become an unwelcome chore since you will have to drag yourself unwillingly to do it.

Creativity is a positive act and must have a positive drive moving it forward. Doubly important, at this stage you are bringing other people into the project. Clients, colleagues, fabricators, and marketing staff will all look to you for inspiration. If you can't convincingly tell them the benefits of your work and inspire their enjoyment, you are in for a gloomy relationship with your design. So reinspire yourself. If you are feeling a bit fatigued, go back to your sources and crank up the energy level.

IAN CUNNINGHAM, DESIGN DIRECTOR

Ian Cunningham heads the Industrial Design Department for the Rubbermaid business unit of Newell Rubbermaid Inc., a Fortune 500 company headquartered outside Atlanta. Ian holds a marketing degree from Ithaca College and a master's degree in industrial design from The Rochester Institute of Technology. Prior to his current position, he amassed years of experience as a consultant, designing across consumer and commercial fields.

The whole process of developing product is really exciting to me, right from the level of identifying a problem. I just love hearing people say, "Why didn't I think of that?" The greatest inventions are sometimes the simplest.

Design is just an easy thing for me to get excited about—I guess that's why I do it. Another thing is that it's just dead interesting to see how things are made. The way technology can help us create products is really very compelling to me. I still can't believe how we do some of the things we do in our plant in Ohio. We have some tremendous injection molding equipment that is heavily automated. It's very poetic to watch these machines work. They're pulling 20 or more parts from stack tools and loading them on conveyers every 10 seconds. I just stand there and watch, and I think it's incredible.

For the most part I believe industrial designers really enjoy their job[s]. I honestly don't think I've ever met one who's said, "This isn't really what I like doing." I have a lot of friends who don't like their jobs. They watch the clock, and at five o'clock they run out the door; they can't wait to get out of there. I can honestly say that I never look at the clock. It's weird to say, but half the time I'm wishing the days were longer. It's the kind of thing where all of a sudden I'll look up, and it's seven o'clock—if I'm going to see my kids, I've got to get home. I think it's a matter of just doing what you love to do; then getting energized is almost easy. It's important to enjoy what you do.

Like many industrial designers, I came in through a side door; I really didn't know anything about industrial design. I went through a marketing program thinking that advertising seemed interesting: a little bit on the creative side, a little bit of artistic capability. When I graduated from undergrad I started doing some work with sculptors, more in the fine arts area. During that time I found out about industrial design through listening to a radio program. One day, there was a story on NPR [National Public Radio] about a consultancy that was designing garbage cans for the city of Boston. There were a lot of constraints around the can. You had to be able to see into it, but you also had to prevent people from throwing large volumes into it. You had to keep rain out, but you wanted people to be able to get trash into it easily, so it had to be covered, but not too much, and so on. All the layers that a design project goes through—that's what really appealed to me. Not long after that was when I decided to go back to grad school for ID.

I wound up going to work at a consultancy and got experience in everything from consumer goods and electronics to medical equipment. I did a lot of retail and even interior work for retail spaces. That whole consultant world was a great foundation for me. You get so much variety in what you're asked to do on any given day, from toys to industrial machinery. Every day is a different experiment in learning a new category or becoming an end user expert. I always tell young designers that although consult jobs don't typically pay as well as corporate, they pay dividends later in your career.

There really is a vast difference between the consultant's world and the corporate world. As a consultant you may spend six months studying, conceptualizing, and designing what you feel is the perfect solution. Then you hand your baby off, very gingerly, to Corporate America. It may get produced, or you may never see it again. It may die a slow death within their doors, or it may come out the other end and not look anything like what you handed off. There's always some pain associated with that process. You're not really in control, and you rarely have the ability to follow through on the manufacturing side of the business. In some cases, as a consultant, you get involved in programs where you walk things farther down the road, but it's much more the exception than the rule.

Then on the other hand, you get into a position like I am now, where you are working for a specific brand. There is less diversity, but as far as day-to-day activities go, there's a much broader spectrum of things that we get involved with. We're still doing all the front-end stuff, all the early conceptual napkin sketches, but we also travel to Asia or go to our manufacturing facilities and work through problems or opportunities with the manufacturing process. So we see many different levels and have much more opportunity for input along the way. Personally, I get much more satisfaction out of being in the corporate world. I really feel much more vested in the product. A product's success has a direct impact on my welfare and how my company is doing.

One thing a consultant background early in your career does for you is that it demands that you sketch more. I think you still have to draw a lot as a designer to get good at thinking through problems, to think about three-dimensional solutions in a two-dimensional [medium]. That's very helpful. The variety is great, too. I am always amazed at how I still refer back to products I worked on 10 years ago for inspiration on a current project. It's really just exposure to different types of materials and different types of end users that adds to your experience or your knowledge base. If you focus on any one end user group too much or entirely, you don't get the additional experience that makes you well-rounded as a designer. It's a critical component to my development as a designer to get to experience all those other demographics or lifestyles. You really do have to become a bit of an expert, if only for a day, on whatever product it is that you're designing. You're just not doing your job if you don't really understand how it's intended to be used or what the environmental conditions are that it is going to be used under. Those are things that are critical to being able to design new products.

As in any industry or company, our single biggest challenge is to have clear communication. The industrial design team is part of the engineering group here at Rubbermaid, but we spend at least as much time with our marketing counterparts. I tend to think that the industrial designers live in a gray area between marketing and engineering. I think we have to have both hats on at times, depending on what we're doing in the course of the day. We will, in many cases, be a conduit between the marketing and the engineering functions, so we have to be good communicators and be plugged into both sides.

I believe industrial designers need to be focused on end-user needs and that we're in charge of maintaining the design brief for a project. We'll work with marketing at the beginning of a project to scope it out and make sure we're all on the same page. The constraints can be almost endless. Having good criteria established is the key to a successful program that stays on schedule. If you don't have a prioritized list you will chase leads that are not relevant to your target market, which leads to failures. Product launch failures are the only ones we are afraid of. Failures during the development process are always a great source of learning and help create strong concepts. We use ethnography, observation, participation, scientific discovery, history, and trends to fuel this learning. They'll use focus groups or observations, study a market, or just understand a consumer's behavior through what products have historically sold.

At the same time, we are working with the engineers who are going to be more concerned about the functional side of the product, the mechanical design, how it's manufactured, and if it is cost effective. We also work closely with the engineers to validate our test procedures. They are the reason our products perform to our standards. By collaborating with both marketing and engineering we develop better products than if any one group were to do it alone.

One day we may be sitting in a focus group facility with our marketing counterparts and the next day we may be talking to our factory with our engineers. That's the more physical link we create between marketing and engineering, but all along the way there are communication elements that the designers have to be involved with to help the other two groups work.

We serve as the voice of the consumer when it comes down to making decisions about what the product's going to be. We serve as an interpreter, making sure the needs of the end user are communicated into the product. The end users may not have the solutions, but they certainly can identify problems. We need to internalize and digest these problems and then produce solutions. And all along the way, we have to be communicating those solutions to the engineering group, the marketers, management, or whoever may be waiting for them.

As a design manager, I have a very similar experience to that whole process a designer goes through, except that I'm guiding more than doing. Maybe I get more enjoyment out of it, in that I can contribute on a level that is more directional than detail oriented. Making smaller contributions to the bigger picture becomes the way I get my creative fix.

That's not to say I don't still love to design. The early sketch phase is still my favorite . . . searching for the "Eureka" moment when a thought turns into the foundation of a product. Today our process has us jumping very quickly into 3D CAD systems, actually modeling the product. So in the space of 24 hours, you've gone from a little sketch on a napkin to a photo-real rendering of a product that you can show to somebody who can understand the materials and everything you're intending to use. Computers have given us such a good tool to simulate reality. We can very quickly have some kind of representation that is very valuable in getting end-user feedback or communicating internally within our design or marketing group. Not everyone is as visual as the engineers and designers, so having a realistic rendering as a tool to communicate with them is a great asset. There's usually this kind of 24- or 48-hour window in which an initial idea is conceptualized, and then we'll bring it into a more refined rendering level. That little 24-hour period is very exiting. You've got all the energy of this idea coming about and solving something, and then all of a sudden, you've got this visual representation of it, and you can make it any color you want and any texture and do all these exciting things to it. That's the most satisfying part of the job. In the matter of a day, you've created something.

STAGE 5: DEFINITION

APPAREL: DEFINITION

Modeling the jacket is done with the classical method of creating a sample garment. Using the actual materials or close approximations where needed, a full-size sample is sewn and fitted to a specific size. It is then tried out on a model to examine how it moves and interacts. The different variations of decoration and finish may be tried out on separate samples, but all questions of fit and comfort must be resolved with experiments in a "real world" situation on a person moving through space. Any problems observed are then re-worked until a suitable solution is found. For this jacket the balance between fit and motion will be exceptionally important, as will the wear-and-tear of materials.

FURNITURE: DEFINITION

The real test for furniture only arrives with the final product, but the look of the chair is examined through a CAD model and then a scale model is built. Individual components can be tested for strength and abrasion, and the finishes, paints and hardware can be individually tested for tarnishing and durability. After the scale model a full size mock-up might well be built, but as the chair is to be made from found objects, this is likelier to be done in CAD or full-scale diagrams. However, the important modeling will be in the testing of any unorthodox methods of assembly since some of the materials are being repurposed and exposed hardware is being used.

GUI: DEFINITION

Of the examples we are concerned with here, the GUI is, interestingly enough, the product least open to simulation in modeling. That is to say, the only way to test a GUI is to actually have a site to test. The method here would be to create a test site that allows a user to peruse an entire "decision-tree" going from a front page to a logical termination point of exit or checkout. This does not have to be the actual site, but has to contain all the elements a user may encounter, so it might as well be. The process may be step-by-step, modeling individual situations and then linking them together, but in the end the test has to go in front of an uninformed user who browses around making notes of hindrances, lack of clarity, and failures. These are fixed and then the model is tested again. Deliberate testing of points of user input must however also involve scenarios of deliberate errors and wrong inputs in order to make sure the site and its code respond correctly.

REVISION AND REMODELING

This exercise operates on two levels. On one hand, you are holding the current idea up to your thesis and revising either one. On the other hand, you are approaching the creation of your model. Examining the seven questions that defined the Identification stage with your current perspective will show you where you need to bear down.

1: What Will You Design?

In your design thesis, you gave a succinct description of your intended design. Most likely you can now add to that description. Does your idea, as it now stands, match the description you gave? What has changed? Most important, now that you need to create a model, what is still unclear?

1. Rewrite, add to, or edit the design thesis as necessary.
2. Create simple sketches illustrating your description with what you now know. As you sketch, keep a mental eye on the intended model, and use these sketches to help you plan its construction.
3. Consider how you would present the model and how this will affect the model's construction.
4. Choose a scale in which to create your model. Then decide whether your design is best represented in two or three dimensions and whether you should make a physical or virtual model.
5. What level of detail do you need in the model? Consider the importance of your details and how you would like to represent them.

2: What Is Its Nature?

You described the design's function and components. There may or may not be a change in the functionality, but it is almost certain that you now know more about the design's components.

1. Is your model intended to demonstrate function, aesthetics, or both? How will it do this?
2. As it now stands, does your idea do what it was meant to do? Is there any question or problem about its functionality? How will you use your model to demonstrate this?
3. Will you need to sacrifice any capabilities or performance to achieve aesthetic goals? If so, is that acceptable? What are the ecological implications of this move?
4. Make a detailed, descriptive list of materials and components and how they contribute to the design's aesthetics and/or functions. Illustrate this list as much as you can with images and samples.
5. Consider how to represent the components in a model, and create a second list of these solutions.

3: Who Is It For?

It is possible that you can now envisage your design in a wider or different context than before.

1. Can you change or enlarge the definition of the intended client or end-user of the design?
2. Can you change the environment to which the end user belongs or in which the design will operate?
3. If the answer to either question 1 or 2 is no, experiment with changing your design until the answer is yes, and sketch out your solution. Either way, compare the previous idea with this one and decide whether your design has improved. Have you learned something new about your ideas?

4: Why Is It Needed?

As a result of the previous question, you can now examine whether your idea can be expanded to solve more than one problem or a wider concern than before.

1. Have you found a satisfactory solution to the original problem?
2. Have any new problems surfaced?
3. If there are still unsolved issues, what do you need to do to arrive at a satisfactory solution?
4. How will you present your model to best describe your design as a solution to the problems?
5. Where in the hierarchy of design needs does your design stand?
6. How can you move it up at least one level in the hierarchy? If it is already at the top level, can you make an even larger creative move?

5: What Are the Benefits of Your Design?

1. In light of the preceding conversation, describe the benefits that will be derived from the design.
2. If this has not changed from the original thesis, consider what you could improve on to increase the benefits.
3. Consider again whether improvements can be made in terms of the design's environmental impact. Consider the entire life cycle of the product from the gathering of materials to the recycling stage.

6: Why Is This Interesting?

Now that you have been living with your ideas for some time, your perspective on the project should have widened and your vision become more detailed.

1. Re-examine why this project is (still) interesting to you.
2. How is it now more interesting to a client than before?
3. If you find that either of the above answers does not indicate enough interest and enthusiasm, what will you do to re-inspire yourself and/or reengage your client?

7: How Will You Proceed?

Plan the creation and presentation of your model in light of all of the above.

1. Decide on a scale.
2. Resolve how to construct the model: physical or digital?
3. Plan how the model is to be presented.
4. Choose the materials
5. Plan your time.

8: Create the Model

1. Assemble all your materials and tools/familiarize yourself with the software required.
2. Go for it!

1 "At Modern, Architect Is Content (Mostly)." *New York Times*, November 16, 2004, section E, p. 1.

2 Concept adapted from Will Lidwell, Jill Butler, and Kritina Holden, *Universal Principles of Design* (Gloucester, MA: Rockport Publishers, Inc., 2003), 106.

3 Jesse James Garret, *The Elements of User Experience* (New York: AIGA New Riders Publishing, 2003), 46.

4 MIT press release http://gizmodo.com/392060/olpc-xo-laptop-20-has-dual-touchscreens-looks-amazing-and-future+y (accessed March 2014).

5 OLPC http://laptop.org/en/vision/mission/index.shtml (Accessed March 2014).

6 OLPC Wiki http://wiki.laptop.org/go/Core_principles/lang-en (Accessed March 2014).

7 Ralph Caplan, *By Design*, 2nd ed. (New York: Fairchild Publications, Inc., 2005), 4.

8 Aresa press release, July 4, 2008: http://www.aresa.dk/landmine_plant_project_english.html (accessed April 2009, but no longer online in March of 2014. It is not clear whether these plans were carried out.).

9 MIT News Office 4/2/2009 http://web.mit.edu/newsoffice/2009/virus-battery-0402.html (accessed March 2014).

10 The Battery Times http://thebatterytimes.com/2009/04/03/bio-virus-batteries-mit-developing-eco-friendly-lithium-ion-battery/ (accessed April 2009, but no longer online in March of 2014).