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A VALIDATION CASE STUDY IN AFFORDANCE BASED DESIGN

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ABSTRACT

In previous work the authors have explored various issues associated with the broad application of the idea of affordance to engineering design. Building on an extensive investigation of the theoretical basis for the application of affordance to design, the authors recently introduced several practical methods for using affordances in design. As with any new design method, the validity of affordance based methods is of course questionable until their efficacy has been satisfactorily shown. Building on recent work by other members of the design community, the authors have adopted a general validation strategy focused on the implementation of case studies of past documented industry design projects. Accordingly, in this paper, we explain the validation methodology implemented, and then present one case study in affordance based design: the design of the Oxo Good Grips Bottle Stopper/Opener. Key insights explained in this paper include 1) the notion of differentiating between example problems and case studies, and 2) the outputs to be expected from the execution of a design case study: namely the building of confidence in the method, advantages and disadvantages over extant methods, and feedback into the method itself.

1 INTRODUCTION

Tate and Nordlund's (2001) recent assertion that design science is still in a "pre-paradigm" state suggests that design researchers will have to fundamentally come to grips with the issue of validation of new theories and methods for many years to come until the field matures significantly. The particular theory of what the authors are now terming "affordance based design" has been developing for the past several years. In the beginning stages of the development of such a theory, it is important to focus on the basic theory itself before developing practical methods. After all, any method developed is only as good as the theory on which it is based. Having flushed out many aspects relating to the application of the theory of affordances in general to the field of design (Maier and Fadel, 2001 2002, 2003b), the authors recently introduced several simple methods implementing the idea of affordance in various design tasks including decomposition, embodiment design, and reverse engineering (Maier and Fadel, 2003a). The reader is referred to these existing papers for a thorough explication of the idea of affordance and its potential ramifications for design.

For the present discussion, therefore, only a brief review of the most salient characteristics of affordances need be presented. First, in terms of history, we note that the concept of affordances was introduced by the psychologist James J. Gibson (Gibson, 1979). Since its introduction, it has been involved as a central concept in the field of Ecological Psychology; it has been applied to the field of childhood development (Gibson, 2000), the development of artificial robots (Murphey, 1999), control room interfaces (Vicente and Rasmussen, 1990), and as a component of the design for usability of some everyday objects (Norman, 1988). However, up until the authors recent work, the idea of affordance had not been applied to the design of artifacts and systems in general.

Second, in terms of definition, we reiterate Gibson's original definition, which is that,

> The affordances of the environment are what is offers the animal, what it provides or furnishes, either for good or for ill. The verb to afford is found in the dictionary, but the noun affordance is not. I have made it up. I mean by it something that refers to both the environment and the animal in a way that no existing term does. It implies the complimentarity of the animal and environment. (Gibson 1979)

So, for example, since a door handle affords grasping, it possesses the affordance of "grasp-ability". The basic assertion of affordance based design is that such affordances can be designed into or out of an artifact deliberately by the designer. Affordance based methods for design guide designers as to how they can design such affordances. Among the various methods discussed by the authors in recent work (Maier and Fadel, 2003), the only method that will be investigated in this paper is the high level method for affordance based design shown in Figure 1.

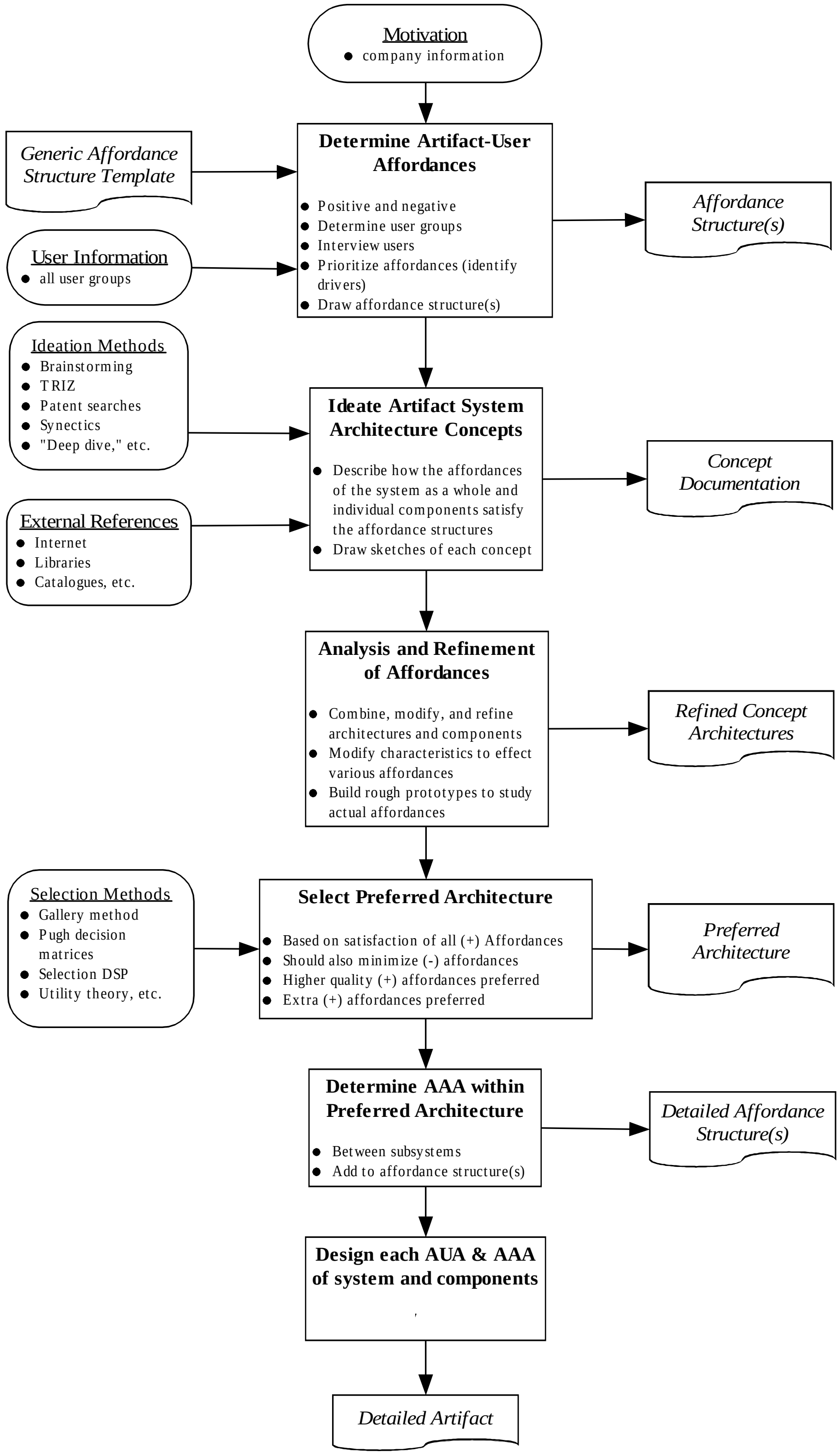

Figure 1. Overview of the affordance based design process

The affordance based design process begins with motivation—a perceived market need, a novel idea, a scheduled product redesign, etc. The parent company, if there is one, would typically provide this information and initial product cost targets, schedule targets, marketing targets, etc. to the designer or design team.

In affordance based design, the first task for the designer(s), is to determine the artifact-user affordances that the artifact should have and not have. To wit, because of polarity, the designers should identify both positive affordances and negative affordances. And because of complementarity, the affordances will depend on different users, so the designer(s) must identify the different users, perhaps grouping them as convenient, and then interviewing various users to determine wanted and unwanted affordances. Following the methods presented by the authors previously for creating affordance structures (Maier and Fadel, 2003a), the affordances should then be prioritized (the highest priority affordance can also be considered the design drivers), and finally one or more affordance structures can be constructed.

The second task for designers is to ideate to generate concepts for the artifact's overall architecture and components. Various established ideation methods can be used here, such as brainstorming, TRIZ, patent searches, Synectics, IDEO's "deep dive" process (Kelly and Littman, 2001), etc. External references may also be consulted for ideas, such as the Internet, traditional libraries, industry catalogues, etc. Sketches of each concept are typically produced using these ideation methods, however these sketches are particularly important for affordance-based design, because each concept should be analyzed for how well it satisfies the desired positive affordances with reference back to the affordances documented in the affordance structure(s) created in the previous step. The sketches made for each concept are important for analyzing affordances since we know theoretically that affordances are form dependent (cf, Maier and Fadel, 2003a). It is generally recommended (cf, Kelly and Littman, 2001) that concepts should not be criticized in the ideation process, so that the positive affordances of each concept should be described, but negative affordances should not generally be analyzed until after a large number of concepts have been generated.

The third task for designers is to analyze and refine the affordances of the concepts generated in the previous stage. This involves modifying the characteristics of concepts in order to modify their affordances, as well as analyzing the negative affordances of each concept, and modifying their characteristics accordingly to remove those negative affordances. Concepts from various architecture concepts can also be combined, switched around, and refined in order to modify the affordances of the overall artifact. The construction of prototypes of concept architectures or components may also be needed in order to better understand the affordances of each concept, which again are form dependent.

The fourth task for designers is to select a preferred architecture. Various selection methods can be used in this process, including the Gallery method, Pugh decision matrices, a Selection Decision Support Problem, Utility theory, etc. However, the decision should ultimately rest on how well each concept satisfies the desired positive affordances while eliminating or minimizing undesired negative affordances, giving preference to concepts with higher quality affordances, and preference to concepts with extra positive affordances. Note that affordance based design does not suggest a preferred selection method, but it does inform the criteria to be used in the decision-making process.

The fifth task is to determine the artifact-artifact affordances (AAA) that should exist between the subsystems in the preferred architecture. For example, the transmission of forces, heat, fluids, electricity, and information between subsystems must be afforded. As these individual AAAs are elucidated, they should be added to the affordance structure(s) previously created.

The sixth task is to design individual affordances. There are artifact-user affordances (AUA) and artifact-artifact affordances (AAA) and because of polarity both AUA and AAA can be either positive or negative. Accordingly, in other work the authors have developed methods for designing positive AUA, negative AUA, positive AAA, and negative AAA respectively (cf, Maier and Fadel, 2003a). These methods must be executed on the preferred concept architecture and components in order to specify detailed artifact characteristics such that the detailed artifact does indeed posses all the desired positive affordances and does not possess any of (or at least minimizes) the undesired negative affordances, as articulated in the affordance structure.

But how can we be confident that such a method works? And moreover, what does the efficacy of such a method tell us about the validity of the theory on which it is based? These are questions of validation, and must be addressed using a consistent validation strategy, which is the subject of the next section.

2 VALIDATION STRATEGY

Several authors have studied the issue of performing validation of prescriptive methods. Yin (1994) suggests the use of a case study protocol consisting of: project objectives, field procedures, case-study questions, and report guidelines. An important note is that such a protocol must be applied consistently if there are multiple case studies involved in a validation exercise. Yin also provides a concise technical definition of what a case study is, which bears repeating.

> A case study is an empirical inquiry that: investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used. (Yin, 1994)

So why use case studies in design? For starters, in design we are forced to examine "contemporary" phenomena, i.e., recently designed artifacts or artifacts that are still in use, if we are to learn anything meaningful about the application of our new methods to artifacts to be designed in the near future. Second, since real design problems are situated within larger corporate and economic environments, we cannot isolate a design problem from those contexts and reasonably expect results from such a controlled environment to be indicative of what would happen in the real world. And along those same lines, the sources of information available to designers are not easily controlled either, because of the variety of inputs both at the technical and human levels available to designers; this in the language of Yin blurs the line between phenomenon and context. Finally, the best case studies are those in which multiple sources of evidence are available, i.e., interviews with the original designers, inspection of design documentation, examination of the resulting artifact, and its performance in the marketplace.

A separate and more focused issue is that of validating methods in particular. This has been investigated by Laudan (1996), who recommends: “Find evidence that the means proposed in the rule [method] promotes its associated cognitive end better than its extant rivals.” The search for such positive evidence, i.e., advantages of the proposed design method over other design methods—to the extent that they address similar design issues—is therefore a key goal to be pursued when conducting a validation exercise, such as a case study. It is worth noting that the goal of a case study, as opposed to many controlled experiments, is not to show that the new method is better in a quantitative sense than another method. The goal is rather to elucidate the advantages and disadvantages with respect to other methods. Similarly, Tate and Nordlund (2001), after an analysis of progress and validation in science in general, summarize the validation task as follows:

> Do not look at individual critical experiments, but rather evaluate the overall success of the research program [method] relative to its competitors. No theory is ever going to be ‘proven’ inductively from empirical evidence, so in program evaluation, the questions become these: Which program does the evidence support more? Which program holds more promise for continued good results (correlation with reality) and for improved knowledge (new problems solved)? (Tate and Nordlund, 2001)

Pedersen & coauthors advocate a similar validation approach:

> Validation is seen as a gradual process of building confidence in the usefulness of the new knowledge [method]…we further suggest that the validation of a method’s usefulness be done using a set of carefully chosen example problems that will support a claim of generality. The example problems that we are speaking of are synonymous with case studies from Yin. (Pedersen, et al., 2000)

At this point a critical distinction should be made between the use of case studies in design validation, and the more commonly used example problem. A case study is backward looking and accepts the vagaries of the past as necessities of design in real-life. In contrast, an example problem is a contrived problem of the present, that excludes the complexity of the real world so that a method can be clearly illustrated. Such an exercise demonstrates how a method can and should be executed, but because of the very limited nature of example problems, cannot attest to the utility of the design method in question in the real world. Certainly, both example problems and case studies are both necessary, but at different points in the development of a design method. Early on, it is necessary to test and to illustrate a method in order to ensure that the method is consistent, for example, and to help others understand it. Later, for validation, it is necessary to perform case studies in order to learn about the method’s usefulness in the real world.

In order to comply with Pedersen’s suggestion of using a carefully chosen set of case studies to support a claim of generality, the validation researcher must consider the domain of application of the method, and select case studies carefully to represent the domain. In the case of design methods with intentionally very broad application, such as affordance based design, this task becomes even harder. However, the choice of case studies is severely limited by the relatively small amount of available literature on how existing real world artifacts were designed and a commensurate lack of access to designers, driven by companies’ very reasonable desire to protect both their own proprietary technology as well as their own unique design process.

For the purposes of validating affordance based design methods, the authors have chosen to use four example problems spanning two orthogonal dimensions of the broad design space: technical domain of the artifact, and size of the artifact. For technical domain, we consider a purely mechanical artifact to be simpler than an artifact of multiple domains, i.e., mechanical and fluid, electrical, thermal, chemical, etc. Meanwhile, we are quantifying size in terms of number of parts, considering a small size artifact to be less than 10 parts and a medium size artifact to be between 10 and 100 parts. An artifact containing more than 100 parts (such as an automobile) would likely be too complicated to accurately handle in a case study. Based upon the available literature, four particular artifacts were chosen as case studies, as shown in Table 1.

Table 1. Definition of case studies

Size (# parts) / Domain	Small (<10)	Medium (10-100)
Mechanical	Oxo good grips bottle stopper	IDEO shopping cart
Mixed (mechanical / electrical / thermal / fluid)	Incandescent light bulb	Vacuum cleaner

The Oxo Good Grips Bottle Stopper/Opener was chosen because its design is well documented in the industrial design literature (IDSA, 2001). The Stopper/Opener was an award winning design and is a part of a larger related and very successful product family of Oxo kitchen tools. It is also a purely mechanical artifact with no moving parts, requiring only a few simple steps for its manufacture. The IDEO shopping cart is also a purely mechanical artifact (ignoring an optional UPC bar code scanner), although it is composed of over a dozen different parts, many of them moving. More importantly, the design of the IDEO shopping cart has been thoroughly documented both on video and in print (Kelly and Littman, 2001).

For the mixed domain artifacts, the incandescent light bulb was chosen again largely due to the fact that its development has been widely studied, including the individual inventors and their associated patents. The same basic design continues to be used today, such that this design is still highly relevant. The final example, of the modern household vacuum cleaner, is likewise old enough to have been well studied by industrial historians while remaining largely unchanged and still in wide use. However, the changes in the design of the vacuum cleaner over time, as in any long-lived artifact, are illustrative of the design mistakes that were originally made that were later remedied.

Due to the constraints of space, and because of the nature of the authors' larger on-going research, only the first and simplest of the four case studies, a small size purely mechanical artifact, the Oxo Good Grips Bottle Stopper/Opener, is presented in this paper, and is the subject of the next section.

3 OXO GOOD GRIPS BOTTLE STOPPER/OPENER CASE STUDY

3.1 Review of the Bottle Stopper/Opener Design Process

The development of the Oxo Good Grips Bottle Stopper/Opener is documented (IDSA, 2001) as follows:

> Oxo wanted a stopper that would preserve wine once the wine bottle was uncorked. So Cyan Godfrey, the…designer assigned to the project, began…work sketching simple geometric forms for the stopper. Because it was a fairly straightforward project, she began working with foam models early. To ensure the stopper would work with most wine and beer bottles, she took neck castings of various bottles to obtain accurate measurements. She also reviewed the stoppers on the market to look at what she did—and, more important, what she did not—like about them. "Basically, I was looking for comfortable shapes," Godfrey explains. "Shapes that feel good in the hand and are easy to grip in various positions." Bulbous forms on the handle made the stopper easy to grasp. Godfrey created half a dozen foam models to show different directions the stopper could take. Some of the models had holes in them; others did not. "I saw early on that the forms that worked best had holes in them," says Godfrey. "The addition of a hole in the handle gave another grip position. A finger could be hooked through to gain extra pulling grip. [See Figure 2] "Then, when I was making models [see Figure 3], I realized that the hole could have additional functions." This was the beginning of the idea for the stopper/opener…Oxo liked Godfrey's suggestion and gave her the go-ahead to explore it [see Figure 4].
>
> She again searched the housewares aisles… "We looked at the stoppers that were already on the market, and we looked at bottle openers. But we couldn't find any products that combined both these functions," says Godfrey. From that point, the design process was relatively short and straightforward. Godfrey made hard models of what was now a stopper/opener, adding rubber to the molds to test the bottle stopper and opener functions [see Figure 5].
>
> Her explorations showed that a rubber conical ring worked well as an opener on twist tops of various sizes. The angle and depth of the conical ring was [sic] refined to fit the most popular twist-off bottle tops, from the smallest to the largest. Further informal testing of prototypes was done with colleagues as Godfrey refined the product's form to get just the right feel for different hand sizes and shapes, as well as for the various sizes and shapes of bottles. The result is a multipurpose kitchen tool that can be used to seal bottles, pry off metal caps, and twist off metal [and] plastic caps of almost any size. The patent-pending design blends with Oxo's line of Good Grips Kitchen tools…at $2.99, the Oxo Good Grips Stopper/Opener does more than the competition. (IDSA, 2001)

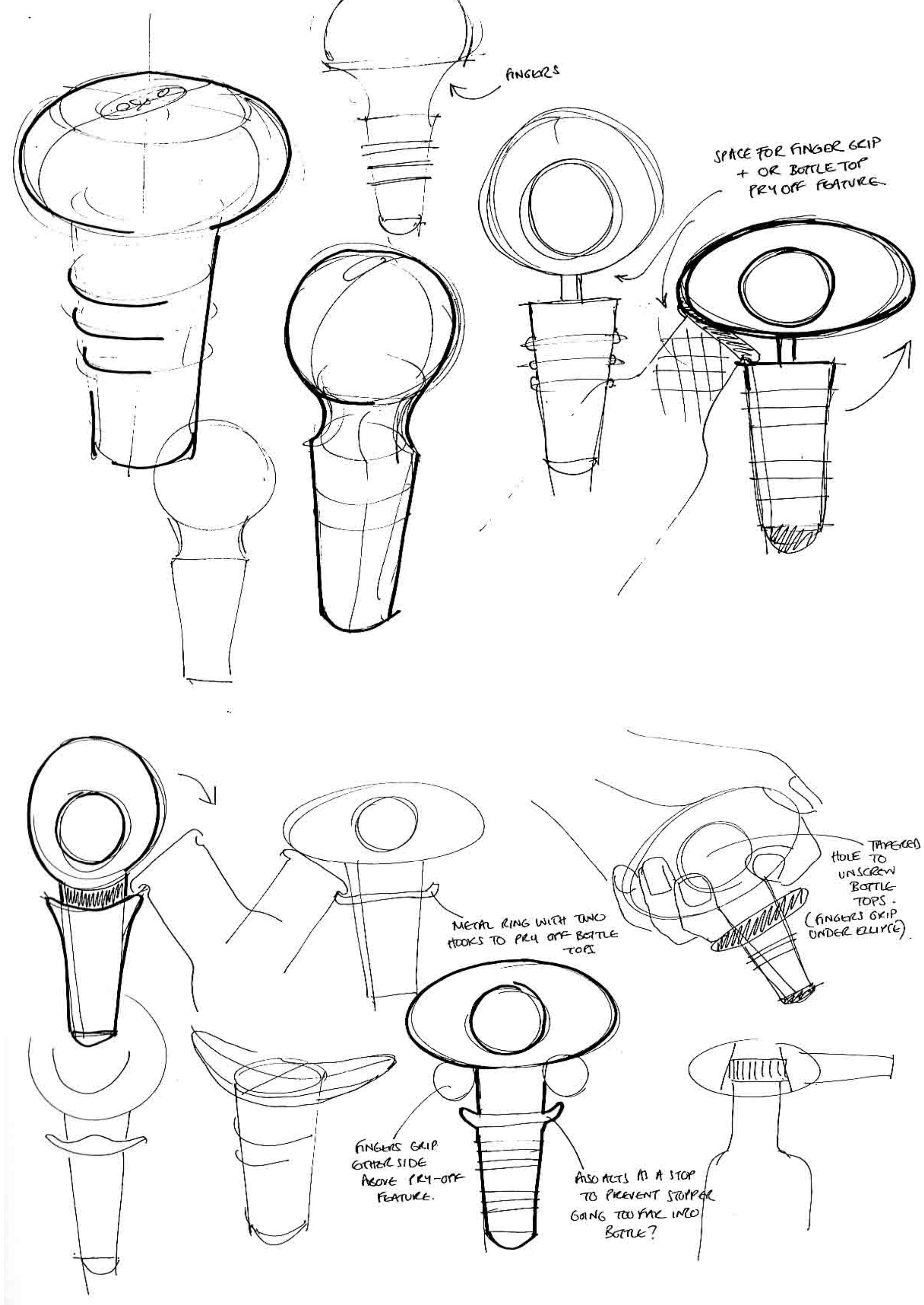

Figure 2. Early concept sketches of Oxo bottle stopper showing development of the stopper from no hole (upper left), to the introduction of a hole for grip (upper center), to the idea of using the stopper as an opener (upper right and lower left) , and finally penning the idea that the hole could be used as an opener (lower right) (IDSA, 2001)

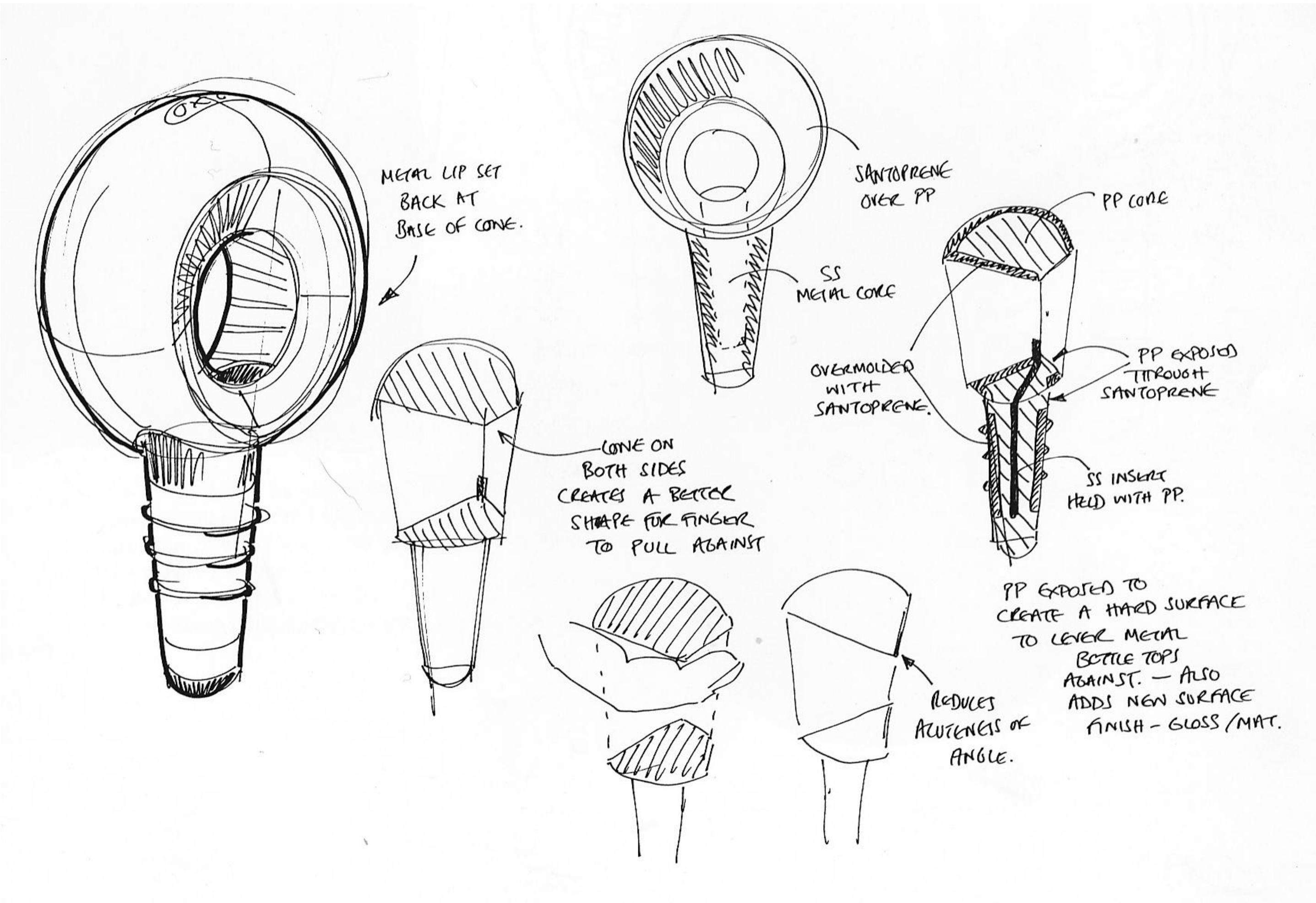

Figure 4. Later concept sketches exploring details of the stopper/opener design (IDSA, 2001)

Figure 3. Early foam models that led to the realization that the hole in the stopper could also be used as an opener (IDSA, 2001)

Figure 5. Hard prototypes made exploring various materials and shapes (IDSA, 2001)

3.2 Application of Concepts from Affordance Based Design to the Bottle Stopper/ Opener

Gibson's original theory of affordances posited that animals (users) perceive their environment (artifacts) in terms of their affordances—what could be done with the artifacts, not what the artifacts themselves did. In other words, Gibson predicted that users perceive artifacts in terms of their affordances, not their functions. Yet, as the authors have discussed in prior work, the current design methods are steeped in the language of function (Maier Fadel, 2002). So it is no surprise in this case study to uncover some apparent contradictions. The original designer, Ms. Godfrey, as well as the authors of the original text, speak of the stopper/opener as having "additional functions," combining two functions, and doing more than the competition. Yet the artifact itself does nothing. It is an inanimate object; but it can be used for a variety of purposes. In this case the stopper/opener has two primary purposes, to be used as a bottle stopper and to be used as a bottle opener. However, the artifact does not stop bottles or open bottles by itself.

Rather, it is the affordances of the physical artifact that make the behaviors of people using the artifact to stop bottles and to open bottles possible. Ms. Godfrey's key observation was to notice that the hole that afforded an extra grip position also afforded prying off bottle caps. However, for Ms. Godfrey, that observation was simply a matter of serendipity. While playing with the foam prototypes, it dawned on her that the hole could be used to open bottle caps. This was not a product of systematic evaluation of the prototype's affordances, as it would have been under a conscious application of affordance based design. Nevertheless, the hole had multiple affordances, and with the prototype in hand, in accordance with classical Gibsonian perceptual psychology, Ms. Godfrey perceived the extra affordance, and voilà, the idea for the stopper/opener was born.

Now let us examine the methodology at work here more closely. It appears from our discussion so far that Ms. Godfrey is consciously using the language of function but may unconsciously be working with affordances. She is not following a textbook function based method, but rather seems to be executing somewhat of an ad-hoc method enabling her to work with the affordances of the object at play. For comparison, the Pahl and Beitz (1996) framework for systematic function-based design is shown in Figure 6. The steps that Ms. Godfrey actually executed are shown in black, while the steps she did not execute are shown in grey.

As can be seen in the figure, roughly half of the steps in the Pahl and Beitz process were not executed. There are several reasons for this. First, the design of the stopper/opener was much more of an industrial design exercise than an engineering design exercise, yet considerations of both aesthetic and engineering value were necessary. The design of the stopper/opener could perhaps be better described as an exercise in product design, yet the product design textbooks, such as those by Otto & Wood (2001) and Ulrich & Eppinger (1995), use function based methods adapted from Pahl & Beitz, and there is no industrial design textbook.

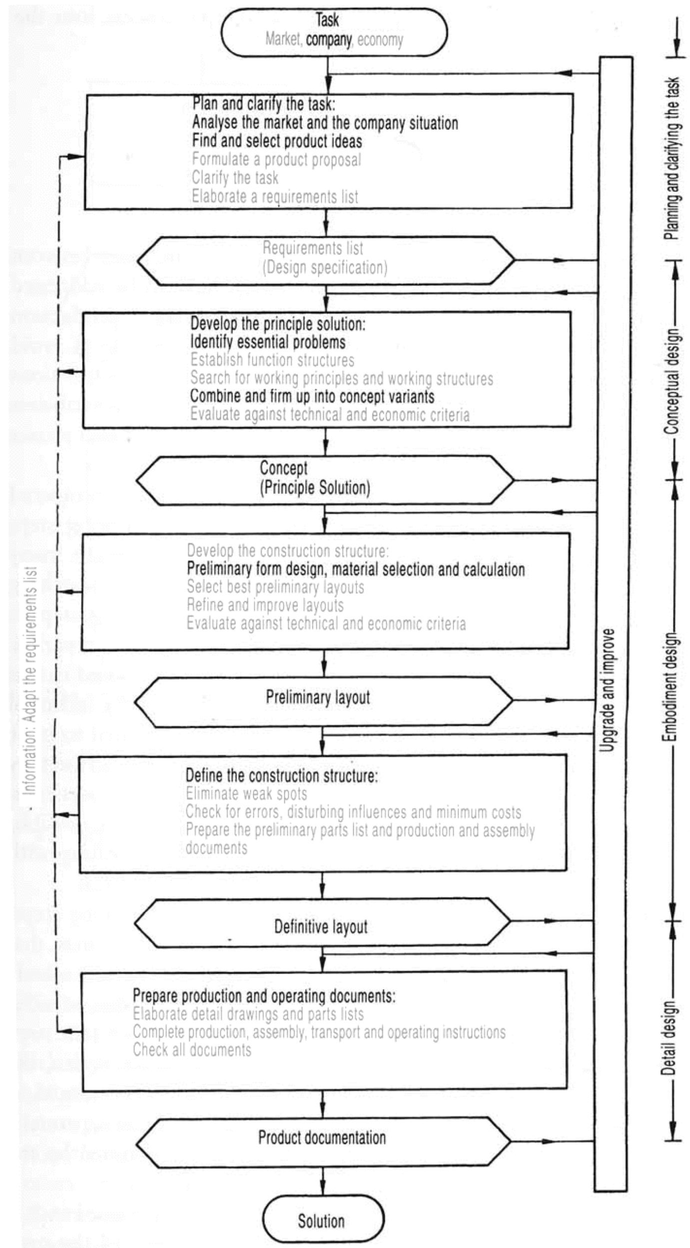

Figure 6. Steps of the Pahl and Beitz systematic engineering design process used in the design of the stopper/opener (from Pahl & Beitz, 1996)

Another explanation for why so many steps in the Pahl & Beitz process were not executed is because the stopper/opener is a relatively small, uncomplicated system, whereas coming from heavy machinery backgrounds, Pahl & Beitz formulated their design method with larger, more complicated systems in mind. However, there are certain steps that were omitted that are not readily explained either by the fact that this was a consumer product or by the fact that the product is relatively simple. In particular, notice that no requirements list was generated, and no function structure was generated, and no working principles were explored. Rather, the first thing the designer did was to start “sketching simple geometric forms” without first having considered an abstract “form-independent” function structure. Interestingly, such behavior has also been noticed by the authors among engineering design students.

Such a quick leap to consideration of physical form is, however, exactly what we would expect in affordance-based design. Therefore, for comparison, in Figure 7 a flowchart for an affordance based design process is shown. As in Figure 6, the steps actually performed by Ms. Godfrey are shown in black, and those not performed are shown in grey. Again, roughly half of the steps are not performed. In this case, since a formal affordance based design process was not being followed, it is understandable that no affordance structures were drawn, nor were positive or negative affordances considered explicitly. Rather, the primary affordance, of stopping an open bottle, was already specified by the parent company. No documented formal methods of ideation or selection were used either, which is not surprising given the ad-hoc nature of the overall design process used.

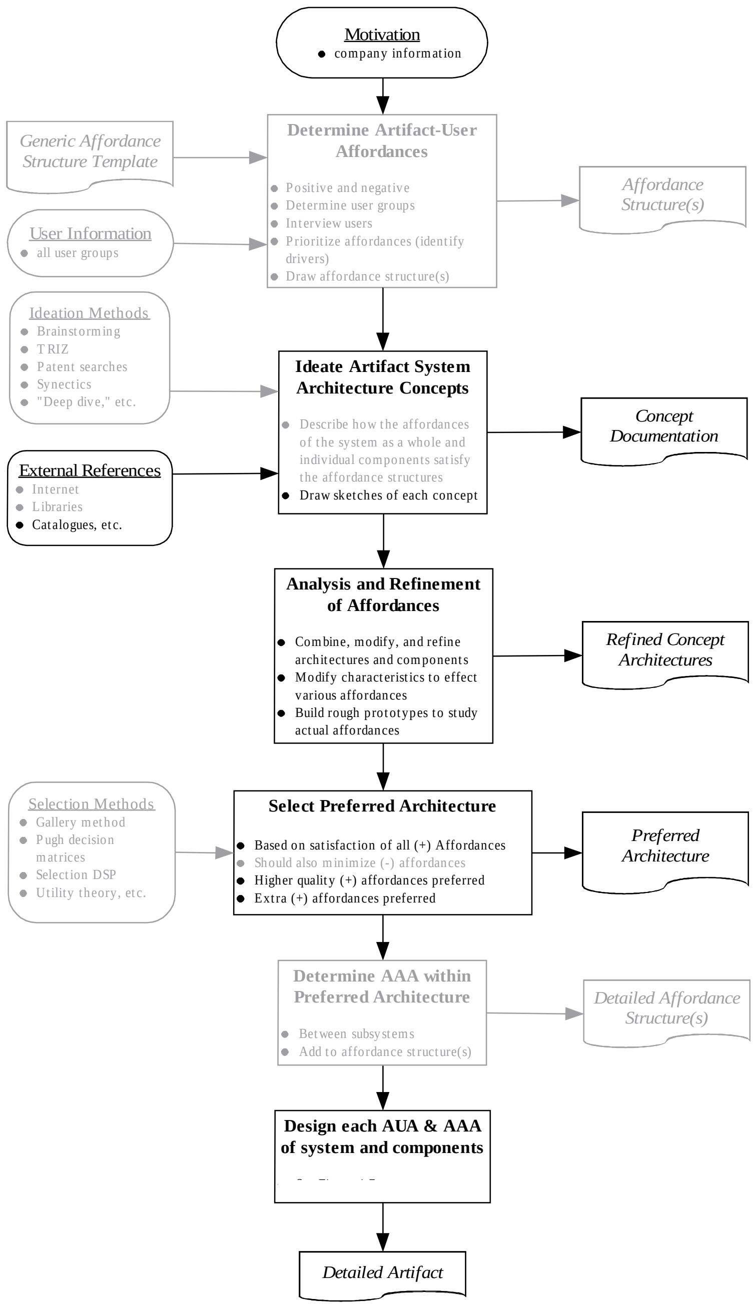

Figure 7. Steps in the affordance based design process used in the design of the stopper/opener

Now what can we conclude, based upon this case study, about the advantages and disadvantages of affordance based design—about its usefulness—with respect to existing methods, particularly function based methods? For this relatively simple and successful consumer product, neither a function based nor affordance based decomposition was used, however the simple nature of the artifact lent itself to exploration of form variants early in the design process. The affordances of those form variants determined the winning form configuration, which largely dictated the other physical parameters of the design, such as material and manufacturing techniques. Comparing the application of function based design and affordance based design to the stopper/opener, it appears that affordance is a useful concept in this case because the nature of the artifact is to afford multiple behaviors. In other words, the concept of affordance helps us to explain both how the artifact was designed and why it is successful. Meanwhile, the concept of function is not as useful in these respects, chiefly because the artifact is not transformative in nature. Moreover, the success of the stopper/opener design can be attributed to its form having two separate uses, which would immediately be recognized in Step 3 of the high level affordance based design process: the task of analysis and refinement of affordances.

4. Closing Remarks

In this paper a general validation strategy has been presented based on the recommendations from several authors who have studied method validation and case study research. The particular kind of case study validation we have suggested focuses on the examination of past documented industry design projects, and the appropriate selection of case studies from across the domain of application of the method. The general validation strategy described is further illustrated through the case study presented in this paper, that of the design of the Oxo Good Grips Bottle Stopper/Opener. The results of this case study showed the usefulness of the concepts of affordance and affordance based design in explaining the way in which the actual design process was conducted and the success of the final artifact. This illustrates the desired results from a design method validation case study, namely building confidence in the method, and elucidating the advantages and disadvantages of the method. Moreover, earlier work with this and other case studies earlier in the development of the affordance based design method studied led to significant refinement of the method, illustrating a third desired output from a case study, the feedback of information back into the method itself.

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