INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07
28 - 31 AUGUST 2007, CITÉ DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE

IDENTIFYING AFFORDANCES

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ABSTRACT
An affordance is what one system provides to another system. Originally introduced in the field of perceptual psychology by James Gibson, the concept of affordance has been proposed as a fundamental concept for engineering design by the authors in a recent series of papers. Recently the concept of affordance has begun to attract some attention within the engineering design research community. However, due to its background in psychology rather than engineering, the concept of affordance poses unique challenges for engineers to adopt in practical usage. This paper attempts to address one such challenge, the difficulty of identifying affordances. Four succinct methods for identifying affordances are discussed: pre-determination, direct experimentation, indirect experimentation, and automated identification.

Keywords: Affordances

1 INTRODUCTION
The theory of affordances was first put forward by the perceptual psychologist James J. Gibson [1]. Although the term has its roots in concepts from Gestalt psychology [cf., 2], Gibson coined the English word "affordance" as follows (all emphases are his):

> "The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or 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 complementarity of the animal and the environment." [1: 127]

Gibson's book The Ecological Approach to Visual Perception is most concerned with how animals perceive their environment, which Gibson argues is through the perception of affordances in the environment. As such, Gibson's theory of affordances is a descriptive formulation: it describes how animals perceive their environment. Since Gibson's introduction of affordance theory and his ecological approach in general, the concept of affordance has been the subject of much study and application within perceptual psychology [see, e.g., 3-16].

A decade after Gibson seminal work, another psychologist, Donald A. Norman, took Gibson's theory of affordances and extended it into a prescriptive formulation: Norman gives some guidelines as to what certain objects should afford and should not afford. However, Norman, in his book *The Psychology of Everyday Things*, also published as *The Design of Everyday Things* [17]), is concerned primarily with, as the title says, "everyday things" and not the design of artifacts in general. Hence Norman's theory culminates in two design-for-x methodologies (design-for-usability and design-for-error) but stops short of incorporating the concept of affordance as fundamental to the design of any artifact. Norman and others have further refined his approach with respect to interaction design (which includes graphical user interfaces (GUIs) as well as human-computer-interaction (HCI) in general) [cf., 18-20]. In a similar vein, Ecological Interface Design [21] emphasizes high-level processing of data by human users and speaks chiefly to the layout and configuration of displays. Meanwhile, Warren and his students have applied the concept of affordances to design specific artifact-user relationships, such as the height of stair treads [22]. An excellent summary of the ecological approach to physical interfaces and prospects for the future is given by Pittenger [23]. A more detailed treatment is offered in a collection of articles edited by Flach, et al. [24].

Inspired by the work of Norman, some researchers in the industrial design community have also adopted the concept of affordance as a psychological tenet underpinning product semantics [cf., 25-27]. Product semantics is defined as the "study of the symbolic qualities of man-made forms in the cognitive and social contexts of their use and application of the knowledge gained to objects of industrial design" [27]. A concise review of the use of affordance in this field as opposed to its use in HCI is given by You and Chen [28].

The idea of affordance has also been applied in the field of artificial intelligence, e.g., how to design robots that recognize affordances in their environment [29]. The application of the theory of affordances to engineering design has been advocated by the present author in a recent series of papers [30-35].

The presentation of these ideas has recently sparked some debate within the engineering design research community. In a recent paper, Galvao and Sato integrate the concept of affordance with their proposed Function-Task Design Matrix "as an instrument useful for understanding the relationships between technical functions and user tasks" [36].

In another paper presented recently, Brown and Blessing [37] contrast the concept of affordance with the function-behavior-structure framework advanced by Chandrasekaran and Josephson [38] and Rosenman and Gero [39]. Brown and Blessing surmise that "one could consider the affordances of a device to be the set of all potential human behaviors that the device might allow. This, of course, is a very large set." They continue:

> "We see a role for affordances in the design process in addition to functional reasoning. Functional reasoning as proposed in particular in the German literature, assumes that the behavior intended by the designer is the actual behavior of the device, which is considered to be the behavior desired by the user. As a consequence, the focus of reasoning is narrowed down to the functions the device should have, rather than could have. Other potential positive functions, as well as negative functions, might not be identified during the design process, but only during the use phase, due to unexpected modes of employment, user intentions, or constraints."
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> "Designers need to be encouraged to think about other possible behaviors and environments, rather than only focus on securing the intended functionality. The affordance approach requires a broader, more environment-centric view that could help identify potential failures or negative effects which the other methods have difficulty identifying. In our view, considering affordances is a perspective that complements the functional view. This design approach will never provide the designer with all potential user actions, but it helps change one's viewpoint to a more reflective, critical one."
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> "Our conclusion is that while affordances, as 'possible actions', are an important consideration while designing, it isn't always easy to reason out what they are, as the search space is large. Using function helps to focus the search, as it is backward reasoning. However, once a design or a conceptual design is developed, affordances clearly have a role to play in investigating undesirable possible actions, perhaps leading to designs that are safer and easier to use." [37]

As leading proponents of function based approaches, their final conclusion that affordances are important to the design process, indeed complementing the functional view, is most welcome. However, we disagree with the assertion that reasoning about affordances cannot be done until after a conceptual design has been developed. While the affordances of a conceptual design can and should be analyzed, in affordance based design, the affordances of the final artifact, and any potential concepts thereof, can and should be determined first. The formal identification of affordances the artifact should (and should not) embody serves to guide the remainder of the design process, including generation of concepts and later detail design [32, 34, 35]. Finally, in the above quotations, emphasis has been added to several statements made by Brown and Blessing that raise a concern over how broad the concept of affordance is, and the consequent difficulty of identifying affordances in what is practically an infinite search space. Indeed these concerns are valid, and have been raised by other reviewers of the affordance based approach. This paper is an attempt to address these concerns by presenting an in-depth discussion of how affordances can be identified in theory and in practice.

2 THE TROUBLE WITH AFFORDANCES

The trouble with affordances is not that they are ill-defined. Indeed, the precise meaning of affordances has been the subject of discussion and refinement over the last thirty years [cf., 18, 9, 19, 13, 14, 20, 35]. The trouble with affordances is that they are so very broad. Other concepts, such as function and behavior, while broad enough to describe either intended or actual action of an artifact, do not directly entail the interaction with the artifact's environment, especially users. But affordances do directly entail interaction, and herein lies the conceptual power of affordances. What one system offers to another can be just about anything, depending upon the two systems involved. The key to understanding what is actually afforded in any given situation is this: it is the structure of the two systems (internally and externally) that determines what affordances exist, and their respective quality.

In the case of an artifact designed to be used by people, such as a consumer product, the designers are concerned at the highest level with the affordances between the artifact and user. At a lower level, the designers are concerned with the affordances that exist between the artifact's subsystems (i.e., parts). The basic idea of affordance based design is that the affordances of the artifact must be determined with respect to the artifact's users, and that the structure of the artifact is specified such that certain intended (positive) affordances exist while at the same time eliminating, minimizing, or mitigating certain negative affordances of the artifact. Whether a particular affordance is beneficial or harmful is taken with reference to the human user.

Notice that we are restricting ourselves to only certain affordances in the design process. That a drill, or a chair, or a any of a multitude of common artifacts can all be used to break a glass window, and thus afford "window-break-ability" is probably too general to be of interest to designers unless these items are being specifically designed for people living in glass houses. Yet consider the fact that a chair can also be used as a stepping stool and thus pose a risk of falling, or that a drill might be used in a wet environment and thus pose a risk of shock; these scenarios should be of interest to designers, and it is not unreasonable to expect designers to foresee these kinds of negative affordances in the design process, before accidents occur in practice, people are injured, and companies are sued. What is needed is proper methodological support and practical tools—design methods, prototyping technology, ethnography, domain specific knowledge, etc.

That an affordance can be anything simply means that anything can be designed. If it were not so, the concept of affordance could not be used to design any artifact. In other words, using the concept of affordance, designers maintain complete design freedom. Just as using the concept of color does not limit the limitless choice of colors, but rather describes them (as in the color wheel shown in Figure 1), the concept of affordance does not limit either the structures that designers can design, or the consequent behavior of those structures (as in the affordances in the generic affordance structure template in Figure 2). And just as there are an infinite number of colors, so too are there an infinite number of affordances.

Figure 1. Range of colors shown in this cyan-magenta-yellow (CMY) color wheel

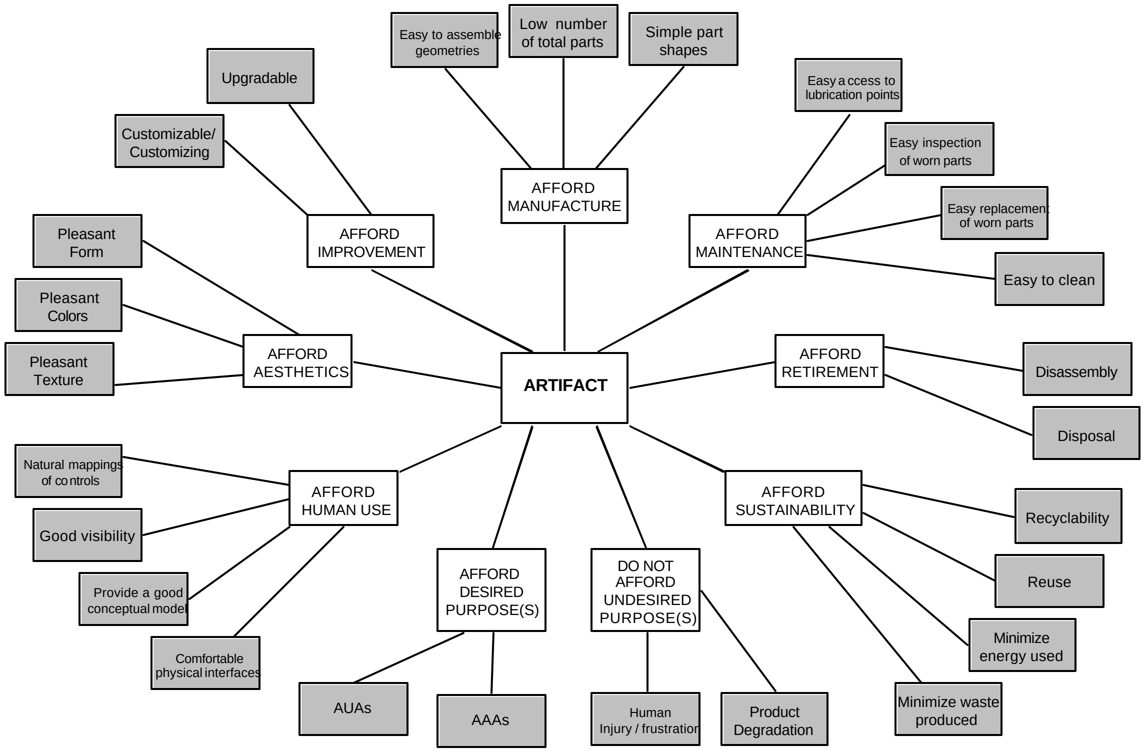

Figure 2. Range of affordances shown in the generic affordance structure template [32]

This breadth does not inhibit the usefulness of either the concept of color or the concept of affordance. The designer must exercise control over this breadth, by determining which affordances (and which colors) are of interest. Central to this activity is the ability of designers to identify affordances. To wit, in the next section we offer four strategies for identifying affordances.

3 STRATEGIES FOR IDENTIFYING AFFORDANCES

3.1 Predetermination

Using the high-level affordance based design process shown in Figure 3, the first task for the designer is to determine the artifact-user affordances that the artifact should have and not have. To wit, because of the polarity of affordances, the designers should identify both positive affordances and negative affordances. And because of the complementarity of affordances, 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 discussed previously by the authors for creating affordance structures [32], 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. As described in previous work, [32] the generic affordance structure template (shown in Figure 2) should also be consulted in the process to insure that common affordances are not omitted.

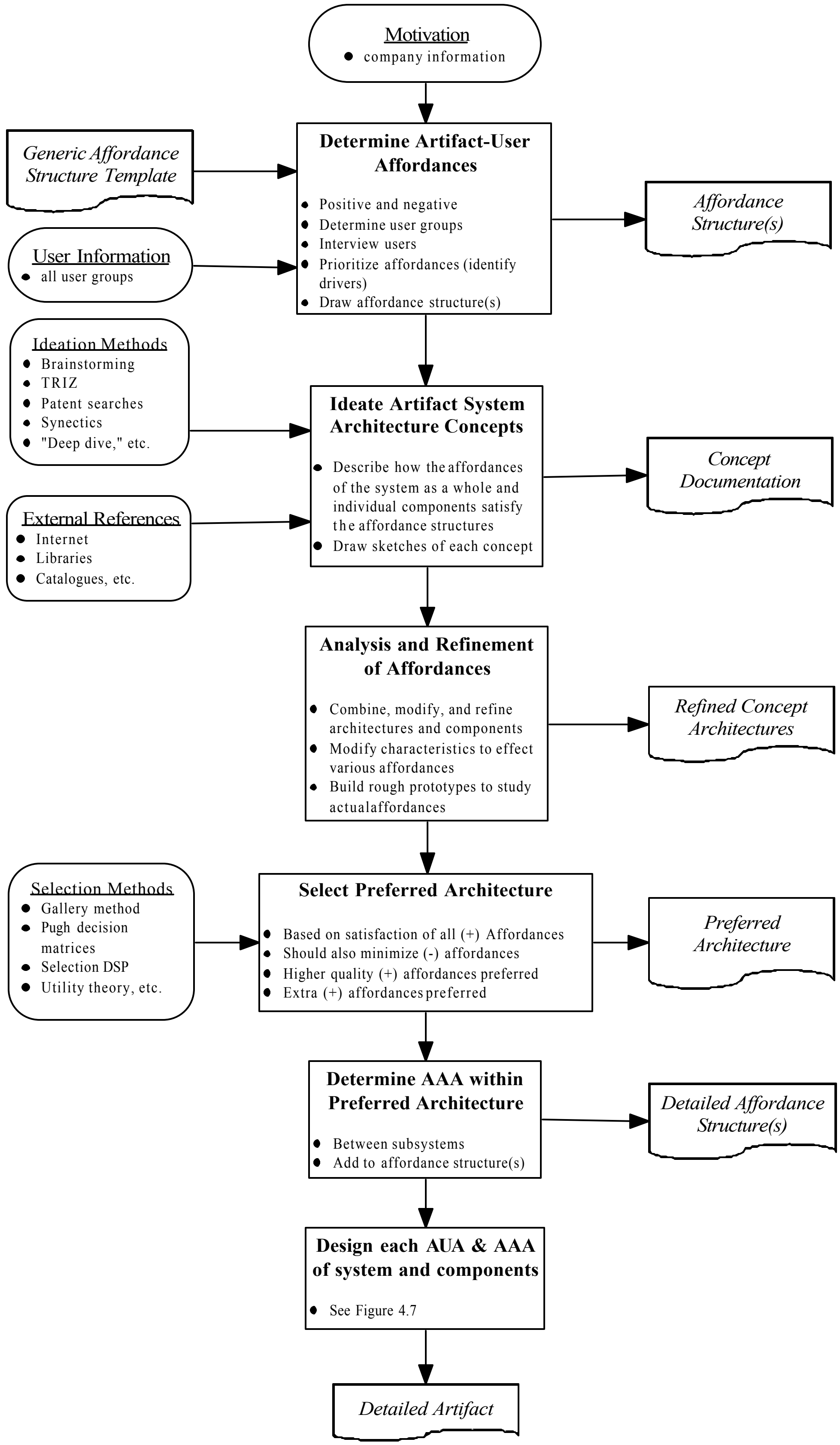

Figure 3. Overview of the affordance based design process

3.2 Direct Experimentation

In J. J. Gibson's original formulation, the affordances of the environment are perceived directly by animals in that environment from visual information ("the optical array" in Gibson's terminology) [1]. In a series of psychological experiments, E. J. Gibson has shown that this model describes well the sort of learning that human infants do while exploring their environment (e.g., discovering the affordances of new play objects) [12]. Likewise, Murphy [29] has shown that artificial systems can ascertain affordances of their external environment, with favorable results as compared with a more traditional model-based artificial intelligence system.

Direct experimentation requires that an artifact already exist to be experimented upon, such as artifacts that already exist in the environments of users. While designers are in the process of determining what a new artifact will be, physical prototypes are the chief tool available for direct experimentation. Obviously, the higher the fidelity of the prototype, the more in-depth and accurate an analysis of the affordances can be. Prototypes range from virtual prototypes on paper or computer screen to crude physical prototypes (say of wood or paper) to rapid prototypes (say of plastic or metal) to full-scale mockups.

As the physical reality of a prototype contains more information than a comparative description of it, for affordance based design the authors advocate prototyping early in the design process in order to facilitate the identification and modification of affordances beginning in the conceptual design stage [32, 34, 35]. This advice seems to resonate with practice in industry design firms such as IDEO [40] which also advocate performing early prototyping.

In particular, IDEO's recommendations for prototyping are as follows:

- "Sketch ideas and make things, and you're likely to encourage accidental discoveries."
- "It's easy to reject a dry report or a flat drawing. But models often surprise, making it easier to change your mind and accept new ideas. Or make hard choices, such as forgoing costly and complex features."
- "We believe in that great old saying, a picture is worth a thousand words. Only at IDEO, we've found that a good prototype is worth a thousand pictures."
- "We pitch presentations in stages, show the rough sketch, the cheap foam model, and use them to right the course before it's too late."
- "Just as writers block happens when writers stop writing, so, too, does innovation grind to a halt when prototypes stop being built. When the muse fails you don't mope at your desk. Make something."
- "When all else fails, prototype till you're silly."
- "Never go to a meeting without a prototype." [40:102-114]

Figure 4. Prototypes of the Microsoft mouse designed by IDEO [40]: 101

As the above quotes illustrate (along with the over fifty prototypes shown in Figure 4), physical prototypes contain more information, and more psychological creative fodder, than textual or graphical representations alone. As Herbert Simon himself quipped, “The world is its own best model” [cf., 41-42]. A physical prototype allows affordances to be experimented with directly. New positive affordances can be realized and taken advantage of. Negative affordances can also be identified, and designed against.

An important consideration when doing direct experimentation with prototypes is that the affordance will vary according to particular users. The affordances identified by a designer may not be the same affordances that would be identified by an end user, service technician, manufacturing worker, or any other person or group that would later use the actual artifact. Therefore we recommend that prototypes be evaluated by users representative of the various groups that will later use the artifact, not just be the actual designers.

3.3 Indirect Experimentation

When a physical prototype cannot be built, whether by nature of the artifact being designed, or due to time, cost, or other constraints, the designer is still responsible for identifying and refining the affordances of the artifact under design. Particularly during the very early stages of design, before a concept architecture has been found, or during the ideation process itself, the designer’s greatest tools are his or her own mind and experience. We call this indirect experimentation.

According to studies performed by E.J. Gibson and others [cf., 13], exploration of the environment (both natural and artificial) results in the learning of the affordances of the environment. As more affordances are learned, more complex behavior is possible, and the apparent abilities of the explorer increase. Once learned, affordances are remembered, such that when similar physical objects are encountered again, the affordances are directly apparent.

Based on a lifetime of knowledge and experience, designers can similarly recognize the affordances of concepts before they are prototyped. This can occur very naturally during ideation, before ideas are even sketched, when concepts and geometries are fluidly manipulated in the mind.
This is a fertile research area, more so for psychologists than for engineers, although the implications for design engineering are certainly important. One result that is known is the tendency for designers to fixate on the first reasonable concept they conceive. This phenomenon of design fixation is well documented [43]. Other researchers in creativity methods have emphasized the need to consciously break-down mental barriers [cf., 44].
Albert Einstein famously used the "thought experiment" technique in his pioneering work on the physics of space and time, asking himself hypothetical questions about the rates of clocks, trains, and light [45].
Essentially the designer can perform a similar "thought experiment" [cf., 46] by asking himself or herself "what are the affordances of this concept?" The designer can reasonably be expected to answer that thought question based upon the designer's past real experience with affordances that pertain to the concept. However, the designer cannot be expected to ascertain new affordances, at least until they have the opportunity actually to interact with the concept, say in the form of a prototype during direct experimentation.

3.4 Automated Identification

Using modern technology, we can go one step beyond relying solely on human experience. Expert knowledge about the affordances of existing artifacts can be captured in a database and integrated into a computer assisted design environment. Geometries can then be pattern matched against the database to identify automatically the affordances, both positive and negative, of new geometries. A schematic of such a system is shown in Figure 5. The development and implementation of such a system is the subject of on-going research, and does not yet exist to aid designers in identifying affordances.
The most serious limitation of such a system is the inability to recognize affordances not documented in the database. Such as a system could therefore assist a human designer in identifying common affordances (such as sharp edges that afford cutting) but the designer would still be responsible for identifying new affordances, using either direct or indirect experimentation.
Another limitation of such an automated system is that it could only report on affordances with respect to specific user groups. A sharp edge, for example, can be defined strictly in terms of geometry. But the affordance of cut-ability depends on the sharpness of the artifact as well as the vulnerability of the human user, which could be different for children than for adults (for example leading to duller children's knives, forks, and other utensils.) However, once the characteristics of various user groups are input in the database, the system would have the capability to identify affordances pertaining to user groups to which the designer himself or herself does not actually belong. This could potentially lead to better designs for user groups such as children and the elderly.

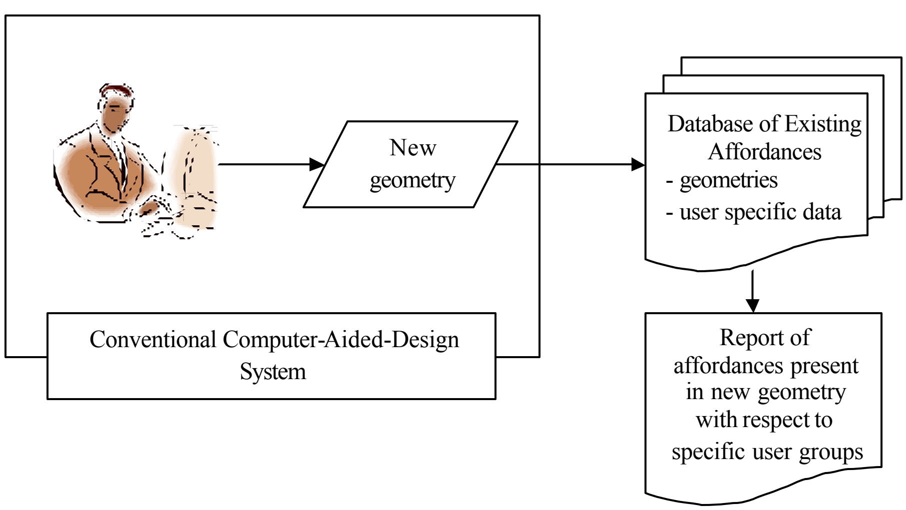

Figure 5. Schematic of affordance identifying database system [47]

4. SUMMARY REMARKS

In this paper we have discussed four methods for identifying affordances. The presentation of these methods has been fairly straight-forward in an effort to illustrate that identifying affordances is in fact not all that difficult. If the ecological approach to perceptual psychology is indeed correct, identifying affordances is an automatic process. Affordances are perceived directly, even by infants. Designers should likewise be able to identify and manipulate affordances easily, although this hypothesis has not yet been tested. Predetermining design requirements, doing thought experiments, experimenting with prototypes, and using computer assisted design systems are all common tools to modern design engineering. In this paper we have argued that all these familiar methods can be adopted to work with the special properties of affordances.

7. ACKNOWLEDGEMENTS

We would like to thank Professor Joshua Summers of Clemson's Automation in Design (AID) lab, Professor Bernie Bettig of West Virginia Technological University, and Adriano Galvao for their helpful comments and discussion of this work.

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