An Investigation of Function Based Design Considering Affordances in Conceptual Design of Mechanical Movement

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Abstract. Using the concept of affordances could lead the designer to consider the user's possible actions during design activities, which is increasingly important in many design cases. This paper proposes a model that attempts to incorporate the concept of affordances to function based design in conceptual design of mechanical movement. The role of affordances in the initial design process considers the user's possible actions to the solution in the environment. A simple example of door latch design is demonstrated to see how affordances can support in the divergent and convergent design activities.

Keywords: function based design, affordances, mechanical movement, conceptual design, engineering design process.

1 Introduction

The use of functions and functional decomposition has been used widely for designing artifacts, particularly in the area of mechanical and product design [1, 2, 3]. The function of a product is what the product is expected to perform [3]. Function-based design is the generic term that researchers or practitioners, in this realm, emphasizes form ever follow function. The 'shape-giving' of a product is derived after a series activities related to functions such as developing function structures [1].

Function is identified from the design problem. The definition of function has been defined differently. One common definition is to represent function as an isolated input-output transformation within a "black box" where function structure is to be developed and mapped or transformed into form by a series of approaches. However no generally agreed definition of function has emerged so far.

Activities, following this type of design, show potential use in innovative design and in the situations where design problems are ill-defined or partially recognized [4]. However, functional requirements distilled to represent user requirements might often

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ignore user's potential reactions after the solution is embodied. To complement this device-centric perspective, the concept of affordances is considered here. The term, affordances, originally derived from Gibson [5], has been popular within design community. This is particularly true, in the user centric design community, mostly through the introduction from the book "The Psychology of Everyday Things [16]. One challenge of function-based design is that potential positive functions and negative functions might not be identified during the design process. This is addressed in Brown & Blessing [7]. They mentioned the role of affordances in the design process is significant to complement function based design. Therefore, this paper proposes a refined model with an attempt to incorporate the concept of affordances into a function-based-design model in the initial design process. An illustrative example is given to show how the concept of affordances is used in this model.

1.1 The Concept of Affordances

Gibson [5] defined affordance as "the affordance of the environment are what it offers the animal, what it provides or furnishes, either for good or ill. … It implies the complementarity of the animal and the environment" According to Gibson, the examples of the environment include terrestrial surfaces, other animals, air, water, and solids. One example is such as, "air affords breathing". The concept of affordances is discussed in a complementarity of the two things, such as "A" and "B". The complementarity includes a range of perspectives, such as design for X, recognition, etc. Examples, explained in everyday objects design from Norman [6], are "a chair affords for sitting" and "Glass is for seeing through". The two things here in everyday objects are "the user" and "the object". The complementarity focuses on usability of the object. For the concept of affordances applied in artificial intelligence, one example is such as "how to design robots that recognize affordances in their environments [8]". The two things in robot design are "the robot" and "the environment" (may include many objects). The perspective of complementarity emphasizes recognition-related capability. The object, in some design community, is treated as artifact, such as Maier & Fadel [9]. Some good discussions of different definitions on affordances can be seen in You & Chen [10], Torenvliet (2003), and McGrenere & Ho [12].

2 The Design Model

The design model proposed in this paper is shown in Figure 1, where solution alternatives are consolidated from abstract textual representation toward a concept sketch to fulfill a few qualitative functional requirements following the multiple divergent and convergent steps. This is a refined model from the one shown in Liu, et al [13]. This refined model has the following characteristics.

Separate Divergence and Convergence. Two major types of design activities are: divergence and convergence. In the divergent step, a wide range of possible alternatives are generated. These alternatives meet one or some of the requirements, and can be refined and embodied later. In the convergent step, solution alternatives need to be screened, scored, and refined at the earliest possible moment; otherwise the

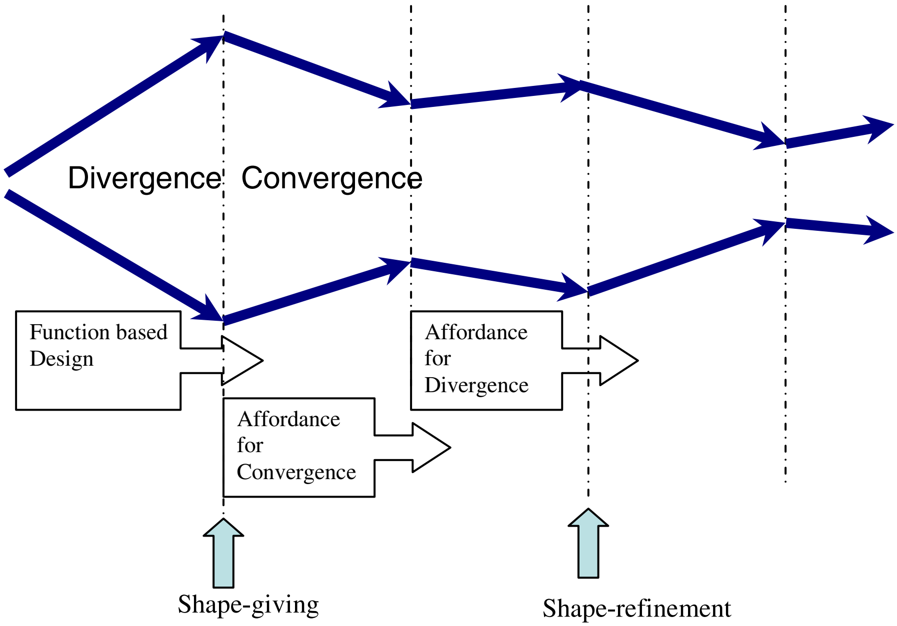


Fig. 1. The design model with the multiple divergent and convergent steps

number of proposals to consider will continue to grow. The purpose of separate divergence and convergence is to explicitly each step in a disciplined manner for easy management.

Iteration. The design activities are seen as an iteration of divergent and convergent activities. This could reduce the challenge that design is under such a situation where the designer may not be fully understood design problem, solution alternatives, user's needs or the environment that the solution will be used. To resolve this, a constant review of these is helpful.

Multiple Abstraction Levels of Concepts. It is important to generate a broad range of concepts (e.g., hundreds of concepts) so that better or optimal concepts will not be overlooked. The challenge is that a sudden expansion of solution number can be overwhelmed. An alternative way is to gradually increase the solution number by means of multiple abstraction levels of concepts. Concepts are represented from abstract toward detailed when more design parameters (e.g., energy, materials, orientations, direction, or others) are considered.

Reduced Number of Alternatives. The final selected concept is derived from different steps of synthesis, mixed with a series of narrowing down process, in which the total search space is noticeable reduced as the solutions become more and more concrete.

Tactics for Divergence. Tactics for generating solutions include decomposition, transformation, classification of search space, morphological matrix, etc. Decomposition subdivides function into its respective sub-functions and further so as to develop a hierarchical tree. Transformation links the function into possible perceived sketches, i.e., alternative concepts, through investigation of archives, consulting with experts, searching existing products, conducting creative methods, etc. Classification of search space provides a systematic way to explore the potential concepts in a specific domain. Within a certain morphological matrix that the sub-functions are listed in a column of a matrix, and the alternative concepts for each function are placed in adjacent rows. The total number of theoretically possible combinations is equal to the product of the number of concepts for each sub-function. More detailed explanation of the relevant tactics are shown in Cross (2000), Ullman (2002), Ulrich and Eppinger (2003).

Tactics for Convergence. Tactics for generating solutions include screening and scoring. Given a list of design criteria (e.g., functionality and manufacturability), one concept is selected as the datum concept or reference concept. For each criterion each concept is marked whether the selected concept is better, worse, or about the same as the datum. A broad range of concept is quickly screened for further score. Importance weights are given for each criterion. Each selected concept is rated as unsatisfactory, moderate, or good using an ordinal scale such as 0, 1, 2, 3, or 4. Concepts are reviewed with a quantitative perspective. Consensus or common understanding of the important design issues can also be reached. Again, the detailed explanation of the relevant tactics are shown in Cross (2000), etc.

2.1 Affordances of the Model

This model currently considers only functionality, the use of affordances to support divergent and convergent activities are discussed below.

Affordances for Convergence. In the form-giving activity, the solution alternatives are derived from one or few requirements. The rest of the requirements need to be considered. Solution alternatives are selected, otherwise, require refinement to the extent that they afford for these requirements. This activity is done through the user' manipulation (i.e., possible actions). Some solution alternatives are refined and thus afford the requirements. The others are deleted from further refinement and embodiment.

Affordances for Divergence. Once form is given, the designer can explore two types of functions with the concept of affordance. The first type is to explore additional needed functions. The possible manipulation of the physical object could lead to uncover functions that were not thought beforehand. This kind of discovery can add additional use to the design. For example, a pair of scissors affords for cutting. However, though user's physical interaction or thinking to figure out, the possible use of the scissors can be shown in Figure 2.

The second type is to explore undesired functions or side effect from the perspective of "what could go wrong". This could be useful when considering design for error or design for safety. Let's take the scissors example again, afford for punching which leads to the possibility of hurting the user or others.

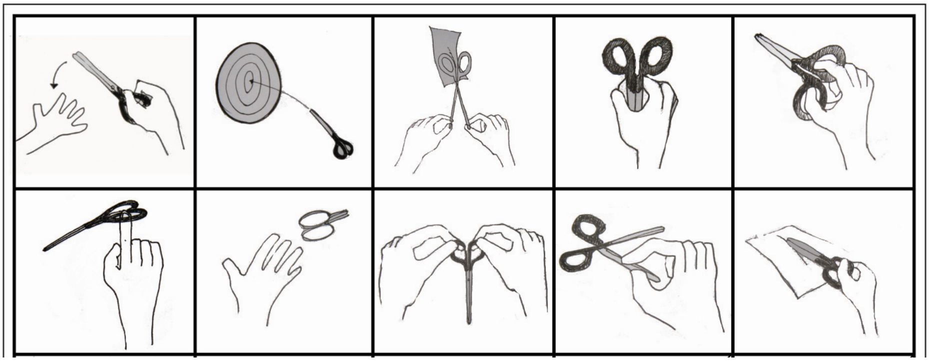


Fig. 2. Examples of the affordances of a pair of scissors

3 The Simplified Illustrative Example

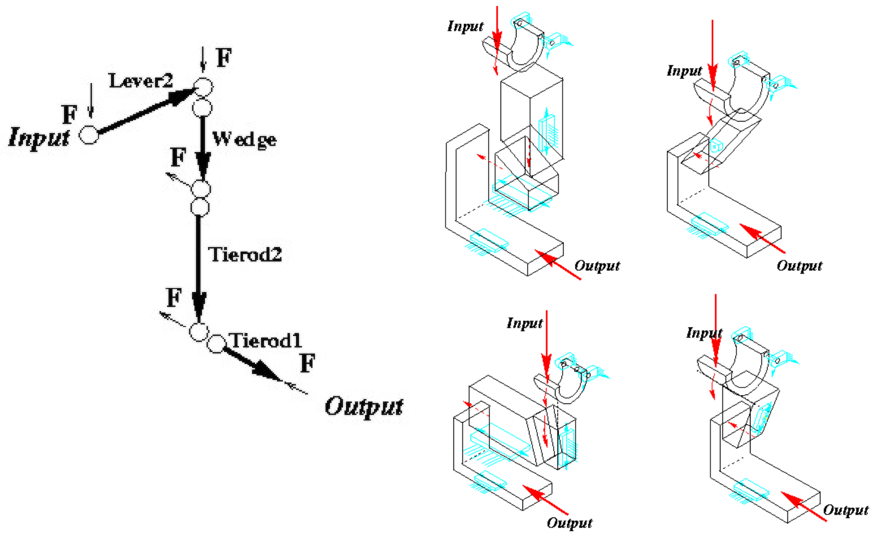
In our model, possible embodiments generated (Figure 3(c)) from one (combined) spatial configuration (Figure 1(b)) are generated. The abstraction level of possible embodiments here is seemed as generic physical embodiments. Solutions are generated through the levels of text, spatial and thus embodiment. A detailed description of how solutions are generated and represented is shown in Liu et al [13].

To use the concept of affordance, the model is considered with three factors, i.e., user, solution, and environment. User is the individual who will eventually use the designed device. Solution is derived as the designer come up with a set of solution alternatives though various abstraction levels of representation. These are considered to be the preliminary form of a final designed device. This designed device exists in the world. Environment refers to the rest of the world that matters to the users. Four types of relations can be discussed with the concept of affordances. These types are user-solution, user-solution-environment, user-environment, solution-user, and environment-solution-user. The definitions of these are shown in Table 1.

Table 1. The types of relations considering the concept affordances

Types of relations	Definition
User-Solution	User's possible actions upon the solution
User-Solution-Environment	User's possible actions upon the solution under the condition of considering the environment
Solution-User	The affordances of the solution that could afford for the user.
Environment-Solution-User	The affordances of the solution under the condition of the environment that could afford for.

Therefore, a refined description considering affordances will add the perspectives of the user and the environment as shown in Table 2. One example with the type of "Solution-User" is shown in Table 3. This table describes the designer first follow function-based design to come up with the solution. This solution should have the affordances as shown in the first line of the table. However, the designer with the perspective of "what could go wrong" could help to examine the statements described in the second. Ideally, the refined solution is made to ensure positive affordance is maximized and negative affordance is minimized. One example is shown in Table 4.



(a) One spatial configuration of the topological solution Lever Wedge Tierod Tierod

(b) Four possible physical embodiments of (a)

Fig. 3. The possible physical embodiments of the solution

Table 2. Description of a door latch example with functional reasoning considering affordances

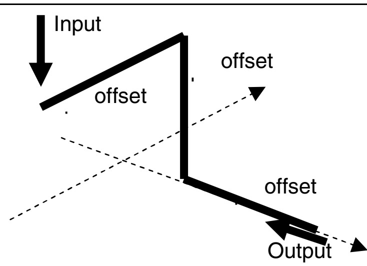
Functional Based Design Considering Affordances		Representation
Simplified Design problem	The design problem, among other things, has the input pointing downward and require a leftward output	

Table 2. (*continued*)

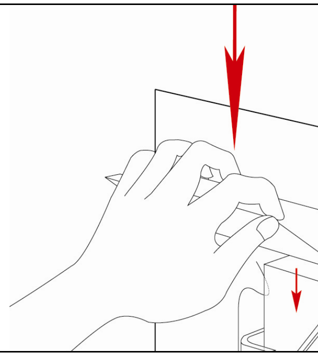
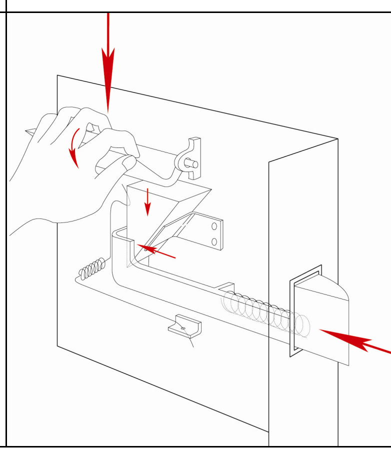
User	The user has the goal of opening the door with the intention that his/her hand raise at an appropriate angle at a certain distance to the door.	
Environment	The environment that matters is the door frame.	The door affords for installing with the device.

Table 3. Description of a door latch example with affordance in the convergent step

Designer's Perspective	Uncertainty statements described with the concept of affordance
Solution-User (what should go right)	• The handle affords for pushing towards the door and pulling toward the user. • The handle affords for releasing of user's hand. • The handle affords for reversing to the original position. • The locking bar affords for returning to the original position.
Solution-User (what could go wrong)	• The door affords for blocking the user's hand. • The handle affords for over-returning to the original position. • The locking bar affords for over-returning over the original positions.

Table 4. Description of the solution considering user-solution-environment

Designer's Perspective	Desired behavior	Representation
User-solution-environment	To fulfill the user's initial plan, the user will carry out several steps. First step is to push downward the latch with proper angle and unlock the door bar, hold the latch and pull toward the user. Second, is to move and rotate the door. Thirdly, the user pushes the door back to the original state. Finally, the door latch is released and the door lock moving back to the original position.	

4 Discussion and Assessment

The potential use of the concept of affordance is to ensure that the user's needs are fully grasped by the designer. Affordances could help to deal with the challenge under the situation where the designer may not be fully understood design problem, solution alternatives, user's goal intention or the environment surrounded. To ensure the designer's solution is what the user desires and thus will fit in the specific environment, we believe it is necessary for a constant review using the concept of affordances.

Having generated potential physical embodiment, the designer analyzes current generic embodiment with the user's intention and possible actions in the specific environment. The affordances of a design solution result in searching possible actions of the user as to the solution. Whether the user will conduct a certain action (e.g., the user push downward to the handle) to the solution is a matter of possibility.

The possibility can be low or high, depending on the user, the solution or the environment. The action with higher possibility has a higher change of happening. The result of conducting a certain action can be good or ill with various impact levels. Each possible action can be assessed, weighted, and prioritized. Possible actions link to the matter of 'what might go wrong' and 'what could provide more' are listed for review. The quantity of the possibility to a certain action and the impact of a certain action is useful for the designer to focus on those with high possibility and high impact. Refinement of the solution should ensure positive affordance is maximized and negative affordance is minimized, if it is possible. Preventive actions to mitigate or avoid can be considered before the completion of designing.

A recently approach, affordance based design, emphasizes to analyze concepts with respect to desired & undesired affordance early in the design process [9]. Their work contributes to a relation theory of design and the identification of six properties of affordance. Comparing with their work, this paper attempts to use the concept of affordance, to complement the functional reasoning design, rather than developing a new design approach.

5 Conclusion and Future Work

This paper has proposed a model in conceptual design of mechanical movement. This model attempts to incorporate the concept of affordances as a complement to function based design. A simple example of door latch design was demonstrated to see how affordances can support in the divergent and convergent design activities. The role of affordances in the initial design process of function based design plays a substantial role with the addition of considering the user's possible action in the environment. Using the concept of affordances could lead the designer to consider the user's possible actions, which is important in many design cases.

Future work includes exploring more design examples to evaluate and consolidate the model. Also, it is necessary to identify positive and negative functions through steps for the concept of affordance. These steps include guidance or methods for designers to explore the potential functions in a reasonable and prioritized manner. We believe the focus on complementarity as well as the relations of user, solutions and environment might need to identify first so as to explore potential functions in a directed manner.

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