A PRODUCT DESIGN PRINCIPLE

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Design Principle, Functional Reliability, Uncertainty Elimination, User Must-Actions

1   Introduction

General principles are a principal outcome of scientific endeavour. While most sciences, with understanding as the main aim, seek to develop factual principles only, design, with changing reality as objective, seeks principles [1, 2, 3, 4] of both "factual and ethical" [5] nature.

Design principles are recurring patterns of various degree of generality that are distilled out of observation and experience in design. They may result from product-based experience, process-based experience, or both. This paper will present a research method for analysis of products in order to develop product-based principles of an ethical nature, and present a principle developed using this framework.

2   Research Method

A principle of an ethical nature presumes a certain value, good or bad, and suggests a way of attaining or avoiding this value in a product. The research method has three loosely adhered, and not necessarily linear, steps:

- *Clarify the value to be (un-)desired and formulate tentative principle*
Often this gets clarified while analysing the products. Some principles may be direct translations of higher level values: "minimise the number of parts" as a product-oriented translation of "reduce cost".

- *Analyse the product groups in terms of the above value and consolidate the principle*
It may be helpful to choose the products for analysis such that these contain a number of groups, each disparate from the other in terms of the function addressed and technology employed. This would allow analysis, within each group of products, in terms of the relationship between their structural difference and the difference in their value. This would allow an evaluation of the principle's generality by having checked for its existence across the product groups.

- *Ideitify the patterns of products where the principle can be applied and validate principle*
The extent to which such patterns can be formed provides contextual information about the principle so formulated. If there are product groups to which a principle does not conform, this may be an indication of its scope, or that further investigation and revisions are required.

3   Results

Here, the results contain two outcomes: the principle itself, and evaluation of the validity and scope of the principle.

Three groups of products are analysed, in terms of their operational steps, termed here as user actions, in order to clarify the value affected. These are: doors and door closing mechanisms, toilet flushing mechanisms and electric cookers. It will be demonstrated, in the rest of this section, that the evolution of products in each of these groups indicate the existence of a principle, *eliminate uncertainty using* **must-actions** *as inputs,* resulting in increased reliability in the products in achieving their intended function.

3.1   Formulate tentative principle

During this stage, we form a tentative principle by analysing one of the above three product groups, such that the principle, if used in their product development process, could have guided the evolution of these products in the way they have evolved. The group of products analysed are doors, *with* and *without* door closing mechanisms.

Door closing mechanisms use energy stored during the door opening operations for automatic closing of doors. We use an analysis of the motivations of the user in order to identify the niche for such a system. We start with the relationships between functions of a door without a door closing mechanism, and decide from these the user-actions required. The main function is the passage of materials, energy or signal through the door. If the door is initially closed, it must be opened in order to pass through. As the door is open while one passes through it, it must be closed after the passage has occurred, if that is the desirable, usual state of the door. The main actions required in using a door, therefore, could be written as:

open door -> pass through door -> close door -> open door -> pass through door ...

Now we do a motivational analysis of the user for each of these actions. The user would surely open the door, as this must be done if (s)he must pass through it. The user would of course pass through the door, or allow passing of materials or energy or signal, as this is the main purpose. However, closing the door remains uncertain. The user may or may not close the door depending on whether there is strong motivation or not.

When we contrast the functions of a door *without* door closing mechanisms with that of one *with* a door closing mechanism, we notice that their functions are the same. However, for the latter product, door closing is ensured. The uncertainty about leaving the door open is eliminated by using an obligatory action of the user (henceforth termed a *must-action*): that of opening the door for passing through. We could form a tentative principle from this analysis: *eliminate uncertainty using* **must-actions** *as inputs,* resulting in increased reliability of products in achieving their intended function. If the intention is to have doors that must remain closed at all times except when used for passage of things, doors with closing mechanisms, which could have been a result of using such a principle, are more functionally reliable than those without closing mechanisms.

Another example of such mechanisms are automatic doors which open by sensing the presence of users at the door, and close by sensing their absence, both *must-actions* of users.

3.2   Consolidate the principle

Two product groups are analysed: toilet flushing mechanisms, and electric cookers.

A. Toilet Flushing Mechanisms

As before, we start by identifying the functions of a toilet, the desired actions of a user in achieving these functions, and the motivations a user has in doing these. This is in order to see whether the product evolution could largely be explained in terms of the tentative principle formulated in the last step.

The function of these mechanisms are to enable the user to clean toilets after use. So the desirable actions for the user are as follows:

be present at the toilet -> use toilet -> clean toilet -> go away -> be present to the toilet...

As the primary purpose for users is to use the toilet, and as in order to use the toilet they have to be present there. Users have strong motivations for the first two actions, and therefore these will always be achieved. However users may not have a strong motivation for cleaning the toilet after use, especially if they are unlikely to use it again. Therefore, a toilet with flushing mechanisms the use of which depends on the discretion of the user, has uncertainty of its use, and such toilets cannot be guaranteed to be clean each time they are used. The principle suggests that this uncertainty be eliminated by using user *must-actions*. What are the user *must-actions* here? These are: 'being present at the toilet', 'using the toilet', 'not being present at the toilet', and transitions between them. Any of these could be used for designing toilet flushing mechanisms which ensure flushing after use. Many automated toilet flushing mechanisms sense the change from presence to absence of users at the toilet in order to activate the flushing mechanisms, leading to products with enhanced functional reliability.

B. Electric Hobs

Electric hobs are meant to enable heating of food, placed on them in containers. So the function is to heat the container and thereby its content. This will require switching on and off, so as to heat only when required. Containers need to be placed on the hob in order to be heated, and need to be removed from the hob in order for their contents to be used. The actions required, therefore, are as follows:

turn on -> put container -> heat container -> remove container -> turn off -> turn on...

Now we do a motivational analysis of each of the actions above. As heating the container is the main function, doing that by the user is ensured. So are the placement of the container to the hob and switching on the heat, as without either the container cannot be heated up. However, both the other two actions are at the discretion of the user. The user has relatively strong motivation for removing the container, as its contents must be used. However, switching off the cooker is not a must for the user, although this can have various consequences, from unnecessary energy loss to safety problems. The above principle suggests that user *must-actions* are necessary for eliminating uncertainty. One Japanese cooker design does just that. It generates heat only when it is both switched on and a container is on the hob. Therefore the transition from a container *not placed* on the hob to a container *placed* on the hob, is used (along with switching on the hob) to start generating heat, and its opposite used

for turning it off. The system is inherently more robust than those from which it originates, in terms of how well it satisfies the same functionality.

3.3   Validate the principle

Within a group of products having largely the same function, there are two types whose work would not be covered by this principle. One of these are products having largely the same function, but uses substantially different set of actions in order to achieve of the purpose. For instance, a revolving door, which is always open (for people to pass through it) as well as closed (direct passage of things is not allowed), does not change the state of the door to 'not closed' when it is 'open', and therefore cannot be arrived at from action-sets such as the examples in the first step which assume that being 'open' necessarily means 'not closed'.

The other type has an action structure with possible alternative states that can be reached by the product via different sets of actions. However, it contains inherent ambiguity as to which of these alternative states should be attained at a given situation. Therefore, *must-actions* cannot be used to choose between these alternative states without conscious user interference. For instance, there are doors with both door closing mechanisms and mechanisms for keeping doors open. The assumption is that most of the time the door needs to be kept closed after passage of materials etc, although sometimes it needs to remain open, such as in the summer afternoons in a cold country, where at all other times the door is kept closed in order to retain heat. In these cases, a *must-action*, or a combination of *must-actions* cannot be used as it is unclear as to when the door must attain which state.

4   The Issue of Validation of a Principle

Validation of a principle is a tricky issue. Previous proponents of principles [1, 2, 3] for engineering design do not discuss this issue. Principles are often presented without specifying their scope of application, often with a single or a few examples of how they are applied. However, it is essential to have an idea of how confident one can be about using a principle, and under what situations.

Three criteria are used for the validation of a principle. They all clarify, from separate but related aspects, the generality of the principle. These are as follows.

- *Applicability:* The wider the range of products to which a principle can be applied, the more general it is. In the present example principle, we have applied the principle to three different classes of products. However, a question remains as to how many classes of products must a principle be tested against before this would have a datum validation.

- *Exceptions:* The smaller the number of the products within each class to which a principle cannot be applied, the more general it is. For instance, in the case of the doors and door closing mechanisms class of products, the principle proposed in this paper does not seem to be applicable to (i) doors with both door holders and door-closers, and (ii) revolving doors. Again, question remains as to how to measure its validity and apportion a datum validity so that a user has some confidence for using it.

- *Predictability:* A principle, when applied, should enable conception of product ideas (i) for some other existing products not used in formulating the principle, or (ii) for which no

product exists, although the idea could be developed into products with enhanced value propounded in the principle. For instance, although the principle of elimination of uncertainty was formulated with hinged and sliding doors in mind, it was later found that, if applied to continuous curtains, this principle could lead to the design of split curtains, which, unlike continuous curtains, eliminate uncertainty about closing them after use by storing energy during the user *must-action* of 'opening' them.

5   Conclusions and Further Work

The importance of formulation and validation of principles for design is discussed. A research method for the development of product-based principles of an ethical nature for design is proposed, and it is illustrated through the development of a product design principle using three different classes of products. The principle suggests that uncertainty in realising product function should be eliminated by using the *must-actions* of the user. For instance, the function of *keeping doors closed always except for movement across* will be violated if a user did not close a door, without closing mechanisms, after use. A *must action* of the user (e.g., opening the closed door) may, however, be used as signal or energy required for closing the door, leading to designs more robust in achieving the function than otherwise. It is argued therefore that a conscious use of this principle should lead to functionally reliable products.

Use of such a principle should allow alternative must-action combinations to be considered for optimisation of a given product concept or existing product, as well as consideration of alternative use of these actions (as energy or signal, for instance). Each may be embodied using possible alternative physical principles. For instance, in the case of a door design, the possible actions, to be used for door closing while not in use for passage of materials, energy or signals, are: 'open' only, 'pass through' only, or a combination of these two. Each of these could be used as either energy or signal for the subsequent door-closing operation. For instance, the energy spent in opening the door is stored for closing it subsequently in *spring-and-damper* door-closers, while this is used as a signal for a separate supply of energy to be used in door closing operation, as in automatic doors. For each such use of a specific action combination, such as using the 'open' action for providing energy for subsequent closing of the door, different alternative principles could be used for its implementation, such as using a *spring-and-damper*, or a *screw joint* for lifting the door. This means that the use of the principle should encourage creation and exploration of a wider range of possible product modifications, increasing the chances for an overall product improvement.

The principle is most applicable for optimisation of existing designs or concepts, where its functionality and user actions remains largely un-altered. Designs best suited are those without ambiguity between the exact situations when each of their possible and desirable alternative states should be achieved.

Further work involves using the same framework for development of other principles as well as evolution of the framework for better development of principles.

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