INTERNATIONAL DESIGN CONFERENCE - DESIGN 2004
Dubrovnik, May 18 - 21, 2004.

POTENTIAL OF KNOWLEDGE TWISTING

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Keywords: synthesis, knowledge twisting, function, structure, part

1. Introduction

Many approaches found in literature tackle the question of how to generate alternative solutions to various design problems by varying physical laws, material, form, dimensions and geometrical position [e.g., Jung, Koller, Rodenacker]. Rodenacker's approach seems to be useful also when searching for new functions based on same physical phenomenon (see also definition of *Physics P*). Since there is a correlation between the number of generated alternative solutions and their quality, it is reasonable to search for additional methods for generating alternative solutions.

In order to shed some more light on product synthesis, a broader term, "framework of synthesis" was proposed by [Hansen&Žavbi]. The framework links the stepwise determination of the products's characteristics during the design process to different ways of carrying out functional reasoning; it consists of mental objects and operations between them. They are described as follows [Hansen&Žavbi]:

- Pr (Problem): A design problem, which is based on a perception of a need;
- F (Function): Function, i.e. a thought, idea or intention to design something, or a more crystallized statement about the action behaviour of the product to be designed. *Function F* is not just a functional aspect of a product, but the main function, which makes the product purposeful and gives it *raison d'être*. F may be expressed verbally as an effect: "create heat" and may be related to an object: "make arm move";
- D (Design): Design, which is specified as a model of part(s) to be produced and assembled;
- S (Structure): Structure, i.e. a model of organ structure, which carries the functionality F. The structure is more or less concrete and detailed [Hansen&Andreasen] and specified by its organ relations and organ characteristics;
- P (Physics): The view upon a design or structure, which explains physical effect of realizing functions. Physical phenomena are represented by models, theories or laws that are described by parameters and their functional (from mathematical point of view) relations. A physical effect is either expected, Pe, to realize the required function, or it is a predicted physical behaviour, Ps, of a structure or design.

Between the above mental objects, three types of mental operations related to synthesis were proposed:

- Carrying out a synthesis step, e.g. Pr→F or F→S or S→D;
- Creating a view upon the structure or design, e.g. S→P or D→P;
- Making an abstraction (e.g. of a design into its structure); e.g. D→S or S→F or F→Pr.

The set of identified objects and operations leads to the framework of synthesis shown in Figure 1. The framework can also be seen as a map, which shows how and where to go from the start, e.g. from a required function, to the final position, e.g. product structure and form.

An activity, which can be identified in the framework of synthesis and is hidden in *the Physics P→Function F* relation, is called "knowledge twisting" as proposed by [Andreasen]. Knowledge twisting is a kind of manipulation of *Physics P* (as a mental object) in order to achieve new *Function(s) F*.

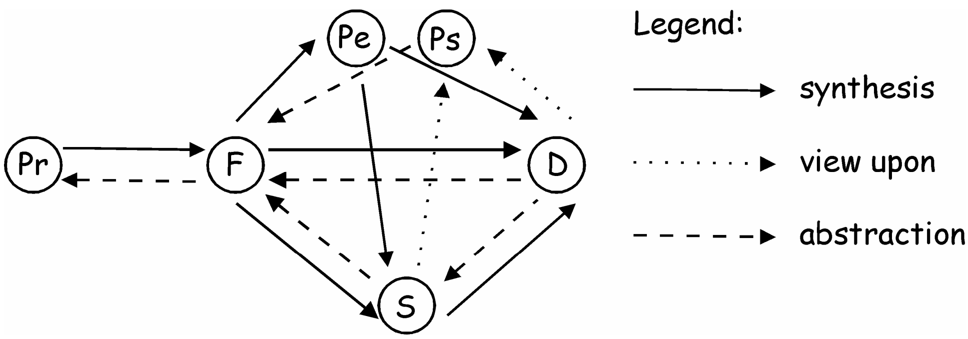

Figure 1. Framework

The objective of this paper is twofold:

- to broaden the idea of knowledge twisting. Namely, two similar relations can be identified in the framework of synthesis: *Structure S→Function F and Design D→Function F*;
- to present, clarify and address some of the open research questions regarding knowledge twisting.

It is believed that elaboration of the additional two activities will stimulate a synthesis of techniques for straightforward manipulation of Structure S/Design D in order to achieve new Functions F. This is because such manipulations provide additional ways for generating alternative solutions.
The structure of the article is as follows: the section on knowledge twisting presents three relations (activities) that are characteristic of the search for alternative solutions. Each activity is presented with an example in order to shed some more light on the idea. Open research questions, which require further discussions and research, are stated throughout the subsections. The applicability of the idea of knowledge twisting and a need for creating implementation techniques are emphasised in the conclusion.

2. Knowledge twisting

The basic idea of knowledge twisting is expanded; it is defined as a kind of manipulation of *Physics P/Structure S/ Design D* (as mental objects) in order to achieve new *Function(s) F*.

2.1 Physics P→Function F relation

In case of the manipulation hidden within the *Physics P→Function F* relation, the same physical phenomenon is used to fulfill various functions. The phenomenon of linear thermal expansion: $\Delta l = f(l_0, \alpha, \Delta T)$, which was originally used to fulfill the function e.g. "measure temperature", will be used as an example (Figure 2 and Table 1) [Žavbi]. The physical phenomenon can also be used to fulfill the function e.g. "check material type".

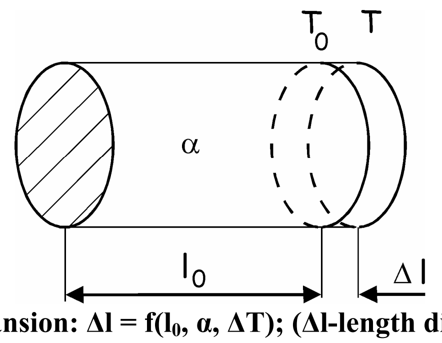

Figure 2. Linear thermal expansion: $\Delta l = f(l_0, \alpha, \Delta T)$; ($\Delta l$-length difference, l_0-original length, α-linear thermal expansion coefficient, ΔT-temperature difference)

Table 1. Variation of physical law's (linear thermal expansion) independent/dependent parameters

Independent parameter	Dependent parameter (response)	Constant	Function
ΔT-stimulus	Δl	l_0, α	e.g. “measure temperature”
α	Δl	l_0, ΔT-stimulus	e.g. “check material type”
l_0	Δl	α, ΔT-stimulus	e.g. “check original length”
α	ΔT-stimulus	l_0, Δl	not possible
Etc.	etc.	etc.	

When the coefficient of linear thermal expansion is identified as an independent parameter, this means that a change in the coefficient (i.e. a change in the type of material) affects the difference in length. This combination can be used for fulfilling a function, e.g. “check material type,” when using ΔT as a stimulus. The combination of ΔT (i.e. stimulus) and Δl (i.e. response) can be used for fulfilling a function, e.g. “measure temperature.” In both cases, the law governing the behaviour is that of linear thermal expansion. When it is stated that a temperature difference cannot be a response to a change in the coefficient of linear thermal expansion, this means that the temperature difference cannot be affected by it.

Physical phenomena are described by parameters (independent, dependent and constants) and their functional (mathematics) relations. The manipulation represented by the *Physics P→Function F* relation is achieved by varying the equation's independent/dependent parameters (i.e. variation assigns (in)dependency to some parameters, while others are kept constant). It is believed *that Physics P→Function F* is “one-to-many” relation. The use and one of the impacts of this kind of manipulation was presented in [Žavbi]. The use of variation of (in)dependency for various ways of fulfilling one function (i.e., measurement of viscosity) with a single physical phenomenon (i.e. capillarity) is described in [Rodenacker]. Applicability of physical phenomena parameters for fulfilment of different functions was also recognized by e.g. Jung [Jung].

In order to execute variations, it is not necessary to know the operators in an equation; knowledge of the parameters and their status (i.e. (in)dependency and constants) will suffice. In this way, equations with which physical phenomena are modelled can be systematically analysed.

2.1.1 Open questions regarding knowledge twisting

Several questions can be asked and addressing them will require further research. One of open questions refers to loss of information when equation operators are ignored. Some researchers believe that the use of physical relations without operators is too simplified. The author believes that operators are not necessary for the conceptual design (i.e., synthesis) of technical systems. This is because quite often the exact relations (i.e., operators) between the parameters are not even known and still need to be established by performing an experiment on the designed technical system (i.e., prototype). The analysis and optimisation of a technical system’s characteristics undoubtedly also require knowledge of the operators in equations used for modelling physical phenomena.

Another question arose while studying example of an “oil wedge” (to study this particular example was Andreasen’s proposal to the author [Andreasen]), which was used by Rodenacker [Rodenacker] to clarify the derivation of new applications – new functions (e.g., mixing, making a foil, Figure 3) based on the oil wedge and its complementary physical phenomenon: Are the physical phenomena

governing for example “mixing” and “making of foil” (i.e. new *Functions F*) really the same as in the case of “generating force & enabling rotation” (i.e. original *Function F* of an oil wedge)?
Physical phenomena are certainly different. During mixing, for example, substances may be involved that differ e.g. in their aggregate states, temperatures, densities, viscosities and acidity. Therefore, a wedge contains several substances with different properties; this is not taken into account in the original physical law describing the conditions in the oil wedge. The law also does not describe the influences of the stated parameter, e.g. on the degree of mixture homogeneity. Similar can be said of parameters and their interactions in case of the function “making of foil”.

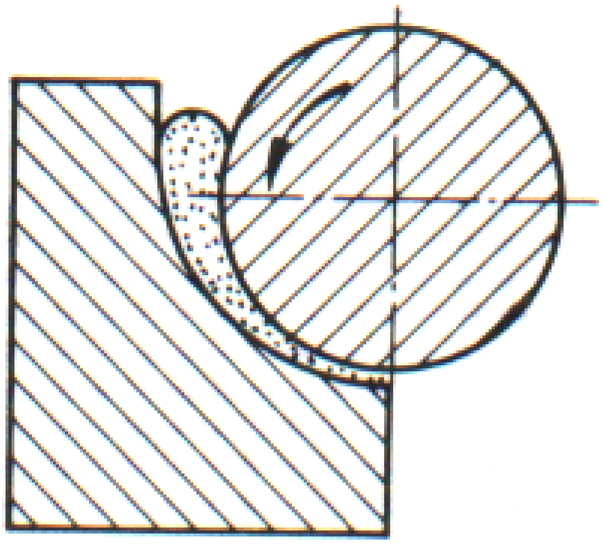

Figure 3. Oil wedge (i.e., Structure S) [Rodenacker]

It is thus clear that variation of an equation's independent/dependent parameters cannot be used to search for new functions if these are fulfilled via other physical laws (not original ones); therefore, the relation *Physics P→Function F* does not describe Rodenacker’s case (i.e., application of oil wedge for “mixing”).
The case of oil wedge use is therefore probably a result of one of the two activities identified in the framework of synthesis: *Structure S→Function F* and *Design D→Function F*. It is anticipated that an expanded idea of knowledge twisting enables the search for new functions, which are based on the same structure of wirk elements (i.e., *Structure S;* see Jensen’s definition of a wirk element in the next section) or parts (i.e., *Design D*), but different, altered or supplemented physical phenomena.

2.2 Structure S→Function F relation

It was explained in the introduction that *Structure S* refers to the model of organ structure, which carries functionality F. The structure is specified by its organ relations and organ characteristics. According to Jensen [Jensen], an organ is a structure of wirk elements capable of completely implementing a function and a wirk element is a structural design element at the lowest level of resolution in the organ domain. Terms such as e.g. organ, part, wirk element, organ domain and structure of wirk elements are described in detail in the domain theory that offers three synthesis-oriented views (transformation, organ and part view) of the mechanical artefact being designed [e.g. Hansen&Andreasen, Jensen]. The concept of wirk elements is a frequently discussed topic e.g. also in [Ersoy, Hubka&Eder, Koller, Rodenacker], naturally with differences in details.
Here is another example of presentation of the activity *Structure S→Function F* (Figure 4). For simplicity, *Structure S* will be used, which has only one wirk element. *Structure S* possesses specific material properties and geometry (i.e., shape and dimension) characteristics. The original *Structure S* fulfils the function “conduct electric current” (i.e. *Function F*).

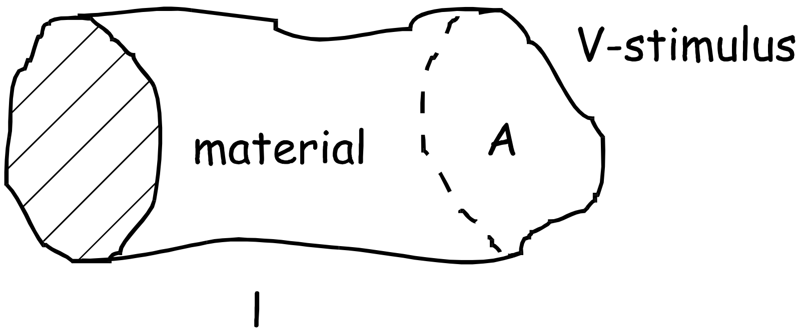

Figure 4. ***Structure S*** **with its characteristics (i.e. material, cross section area A, length l, voltage V as a stimulus)**

Alternatively, this same structure can be used to transfer e.g. the torque (Figure 5), force or heat (i.e. new *Functions F*).

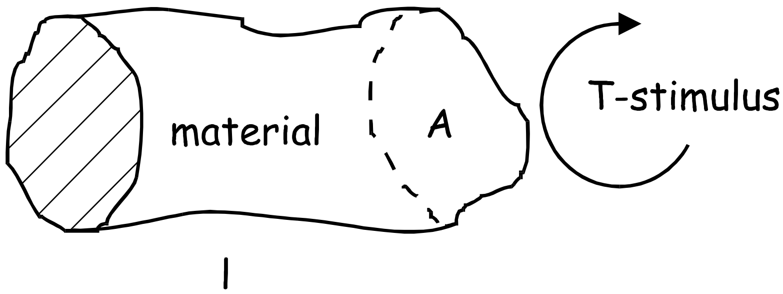

Figure 5. The ***Structure S*****, but with a new stimulus (i.e. torque T)**

These new functions are based on the same *Structure S* as the function "conduct electric current" (i.e. *Function F*), but they are fulfilled by different physical phenomena that are triggered by a new stimulus (i.e. torsional moment T). In order to perform the manipulation, the physical phenomenon need not be known. The relation *Structure S→Function F* is also believed to be "one-to-many" relation.

2.3 Design D→Function F relation

This relation refers to the use of *Design D* to fulfill *Function F*, which differs from that stated in the original design problem. The activity *Design D→Function F* can best be presented with two practical examples (Figures 6, 7 and 8).

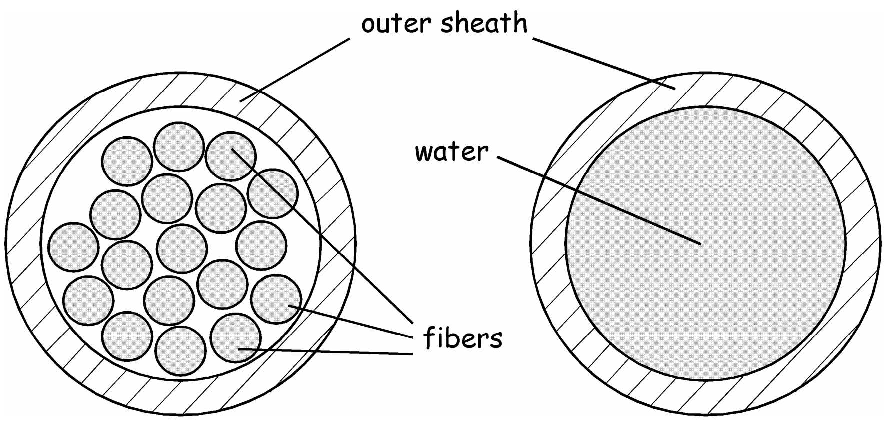

Figure 6. Use of underwater telecommunication cable's outer sheath (i.e. Design D) for transport of water from mainland to an island (i.e. Function F)

Originally, the outer sheath of an underwater cable (i.e. *Design D*) serves as protection for optical fibres and copper conductors (i.e. original *Function F*). Alternatively, the outer sheath can also be used for the transport of water from mainland to an island (i.e. new *Function F*), for example.
A reinforced concrete pipe (i.e. *Design D*), which is originally intended for drainage (i.e. *Function F*), can also be used to support a base plate (i.e., new *Function F*).

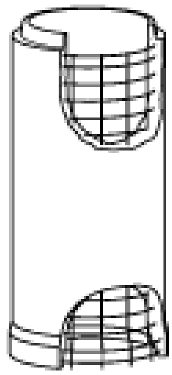

Figure 7. Concrete pipe

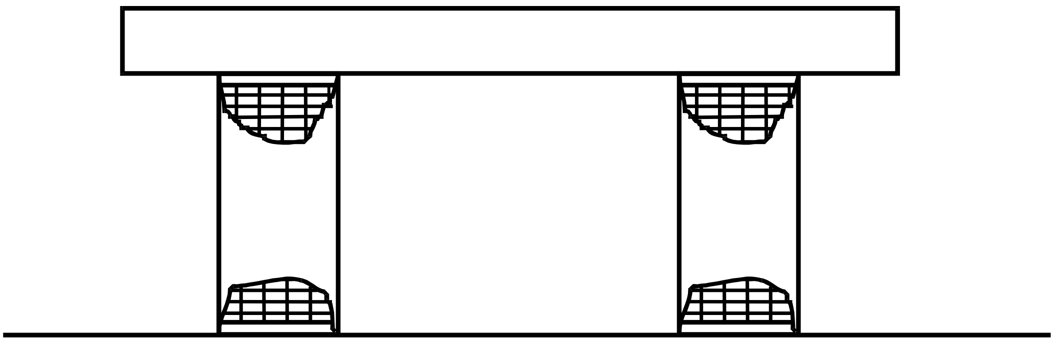

Figure 8. Use of a reinforced concrete pipe to support a base plate

In this example of knowledge twisting, new functions are based on the same part or assembly of parts. It is believed that the *Design D→Function F* relation is "one-to-many" relation. The new function is fulfilled by a different physical phenomenon, but this need not be known to perform the manipulation. In order to check for applicability, the physical phenomenon has to be known or an experiment needs to be performed. Currently it seems that this manipulation is the most suitable when searching for new *Functions F* of simple *Designs D*.

At present, there are no methods developed for the manipulations presented with the relations *Structure S→Function F* and *Design D→Function F* that would enable their simple performance (as in the case of *Physics P→Function F*) and consequentially fulfillment of new functions. From among existing methods, brainstorming and lateral thinking are worth the try, for example.

It was found for both relations that new functions are based on the same *Structures S/Designs D*, but are fulfilled by different physical phenomena. One wonders if these two activities could serve as a particular way of finding new applications (i.e. new *Function(s) F*) for which physical laws are unknown/difficult to describe and are as such inaccessible to physical reasoning (functional reasoning based on the engineering designer's knowledge about physical laws is known as physical reasoning). In order to perform the manipulations, it is not necessary to know physical phenomena.

Two other interesting questions arise in relation to this: What came first: A design/experiment or a physical phenomenon [Andreasen], and may they be discussed separately?

3. Conclusions

Considering one of the objectives of product design, which is to generate as many alternative solutions as possible in order to be able to select those which are truly the best, it also makes sense to look for additional methods that will enable the generation of alternative solutions. It is believed that knowledge twisting supports this objective.

In addition to activities represented by the relation *Physics P→Function F*, the expanded idea of knowledge twisting also comprises activities represented by the relations *Structure S→Function F* and *Design D→Function F*; all of these three relations are identified within the framework of synthesis.

Currently, brainstorming may be used, for example, as an aid in implementation of the activities *Structure S→Function F* and *Design D→Function F*, but in the future, attempts will be made to find ways for a more straightforward implementation, as is the case with the activity *Physics P→Function F*.

Which category does Rodenacker's case (Figure 3; oil wedge: *Structure S*) belong to? Since *Structure S* is explicitly involved, which can be used for example for "mixing" and "making of foil" (i.e. new *Functions F*), this case is classified as activity *Structure S→Function F*. It appears that in practice this activity is the least widely used, primarily because concepts such as wirk elements are very abstract. In spite of a quite extensive discussion of wirk elements in professional literature, no methods have been developed as yet for a comprehensive synthesis of technical systems that would be based on their use. There have been more examples of the other two activities, primarily of *Design D→Function F*, probably because this one takes place at a more concrete level (e.g., alternative applications of reinforced concrete pipe).

Irrespective of the open questions and lack of a straightforward method, the author believes that knowledge twisting is a set of activities that contributes to the search for alternative ways for fulfilling various functions. It is also believed that awareness of the existence of alternative concepts for generating solutions will contribute to the search for straightforward methods for their implementation.

Acknowledgment

The work described here is supported by The Ministry of Education, Science and Sport of the Republic of Slovenia (Contract No. 0782-019 P2 0256).

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