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Preliminary studies for the creation of a functional archive of constructional solutions

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1. Research background

The mechanical design process requires, as the fundamental aim, to identify the technical solutions for the functions that the product must perform as specified by the market. This process requires the ability to conceive the solution by means of the elaboration of the information available. Hence the principal role of a designer is to make decisions on the basis of scientific criteria and technical experience.

Decisions are governed by multiple measures of merit and involve the treatment of multileveled information. The information required to arrive at a decision comes from different sources, disciplines and they may not be easily available.

One of the most important questions about the design process regards the definition of tools able to support the search and the management of the information. These tools must be able to support the expectations of the designer in terms of knowledge, examples and methods.

In this environment, an important problem for the designer is, for example, how to identify and choose the technical principles among the ones that perform the functions. While the choice depends on the requirements of the specific designed product, the identification is a process that could be expanded in diverse directions, without limitations.

The identification process, in fact, could be useful to inspire the creativity of the designer, providing a wide spectrum of technical principles. Many examples are directly obtained from both the experience and the know-how of the designer, but many others could be derived from different sources.

The development of a procedure to face this stage together with its implementation in a computer tool is an interesting effort to support the designer work.

At the beginning of the 1990 a first attempt to develop a catalogue of constructional solutions was made at the Mechanical Department of Politecnico di Milano (Galli & Rovida, 1993; Biggioggero, Galli, & Rovida, 1995): a set of principle functions and related components were collected from technical books and papers. The set of solutions of the mechanical functions were ordered based on a common systematic approach and registered in a bidimensional CAD system, capable of performing queries regarding functions and solutions (Figure 1).

Due to the Information Technology limit of that period, after the initial gathering and structuring of the catalogue, the development and deployment of the catalogue itself has been interrupted.

The studies described in this paper are part of wider research which is currently being conducted at the Politecnico di Milano. Figure 2 (Rovida, Viganò, De Crescenzo, & Raco, 2005) shows the general procedure under study, from the required function to the adopted product solution chosen to satisfy it. Two principal steps are highlighted on the flow diagram, created in compliance with the Concept Maps representation criteria (Trochim, 1989). The two main steps are:

1) the identification of the technical principles able to perform the function required (Figure 3);
2) the choice of the final solution for the product (Figure 4).

This scheme shows, in a very general way, the procedure that links a requested function to its constructional solutions, regardless of the exact nature of the tools employed to allow such link.

The first step of the proposed procedure, as in Figure 3, regards the identification of the technical principles. This step could be performed by the subdivision of the principles in two categories:

- the first one based on known solutions
- the second one based on innovative solutions

In this classification, the known solutions can derive both from the "state of the art" of the current industrial artefacts and from the historical industrial heritage.

The result of the above proposed procedure is an archive of known technical solutions that fulfil the given function. This archive could be useful to extract ideas that could be critically analyzed for the determination of innovative solutions.

2. Research objectives.

At present, the first phases of the procedure shown in Figure 2 are taken into examination. Ongoing research has started with the following primary objectives:

1) Creating a general procedure able to provide all the principles enabling to achieve a given function.
2) Creating an interactive catalogue of the main functions and their principles.

Notably, this paper illustrates the preliminary studies conducted in order to organize the catalogue so as to achieve both the primary objectives and the following secondary objectives, which have later emerged:

1) Organizing the interactive catalogue. Therefore, by entering a function, a few progressive steps may be made through subsequent choices, resulting in a group of possible solutions among which the designer may choose the most suitable or from which he may draw inspiration to conceive new solutions.
2) Trying both to use a defined, easy-to-learn vocabulary and to organize the catalogue so that it may be used intuitively. This would minimize misunderstandings.
3) Possibility of both constantly updating the material included in the catalogue and of sharing it within an "open" computer environment.

In view of the above-mentioned objectives, we have decided to create this interactive catalogue by means of a database. This has immediately seemed a better choice than using a "static" structure. In fact, the interactive catalogue has a number of advantages, notably concerning information management operations. Furthermore, it may be constantly updated by different users.

Once this choice made, before creating the database and starting to enter the data, we have had to deal with the following issues:

- Choosing which fields to be inserted in the database
- Organizing the database fields in a defined hierarchy also reflecting the pathway from the abstract to the concrete, thus leading from a function to its constructional solution
- Defining the database fields univocally and, whenever possible, establishing a fixed vocabulary enabling to minimize misunderstandings

3. Concretization level and complexity level

To a certain extent, the procedure assessed in our research, through all its steps, may be identified with the design process itself and it follows the pathway from the abstract to the concrete through progressive levels of concretization. In general, we may say (Biggioggero & Rovida, 2005) that *"design consists in defining the constructional solution allowing to achieve a given function, according to specific needs"*.

During our research, we have analyzed different methodical design procedures. Despite the very different approaches found in literature, these procedures always show a common point of view on the whole design process, such as a series of successive steps (and of any iterations) leading from an abstract initial objective to a finished product.

According to one of these approaches (Hubka, 1982; Hubka, Andreasen, Eder, & Hills, 1988), as the degree of concretization increases, a technical system may be represented in subsequent steps by different representations, or structures:

1) Functional structure
2) Concept
3) Layout

Such structures result from the union of different elements and their links. Such constitutive elements are:

1) Functions
2) Function-carriers
3) Constructional elements

We have opted for these last concepts and their relative definitions for the database in study. Thus, it will be possible to arrange the items which will be entered in the database according to their increasing degree of concretization. In particular, as for these phases of preliminary study, we have decided to study more in depth the link and the steps leading from the function to function-carriers. Thus, we have postponed to future studies a thorough analysis of the relations between function-carriers and constructional elements.

Technical systems may be classified not only according to the degree of concretization they are described with, but also according to their level of complexity. In particular, according to the same author again (Hubka, 1982), four different levels of complexity may be identified:

I. Component, part: "Base systems, produced with no assembly operations"
II. Group, mechanism, subassembly: "Simple systems, which may accomplish some more elevated/complex functions"
III. Machine, equipment, device: "System made of subassemblies and parts, which, on the whole, achieve a function"

IV. Plant, equipment, complex machines: “Complex systems achieving a certain number of functions which are composed of machines, groups and parts and generate a spatial and functional unit”

The complete method of methodical design proposed by the author (Hubka, 1982) is based on the hypothesis that technical systems of the III or IV level should be designed. If properly assembled, Level I and II systems form the most complex systems.

To be straightforward, in these preliminary phases we have only considered technical systems of the I and II level. The treatment of more complex systems and any database adjustments will be dealt with later in our research.

In Table 1, the subjects which have been considered in this preliminary study are put into evidence, in terms of both their complexity and concretization level.

4. Definition of functions and flows

As mentioned above, all the methods of either methodical or systematic design are characterized by a series of steps, which, in turn, are grouped into phases.

In particular, we have focused on how different authors deal with the “conceptual design” phase, which is perhaps, to a certain extent, the most sensitive and important of the whole design process.

In view of the intrinsic functional nature of the database in study, we have focused on the different elements of the functional analysis, which is one of the operations recurring in the various approaches to conceptual design.

In general, a technical system may be represented in an abstract way through the so-called “black-box” model (Koller, 1985; Pahl & Beitz, 1984). Figure 5 shows a general schematization of this model.

Regardless of what happens within the “black-box”, a technical system may be characterized by indicating:

- *flows* input into the “box” and any flows output
- the *function* which is achieved within the “box” and which exerts an action on the flow

In a “verb-object” formulation in which “function-flow” are indicated respectively, it is possible to describe in a functional way any technical system without formulating any hypothesis on how it is.

This kind of abstraction fits our purpose of linking a given function to a certain number of solutions enabling to achieve such function, regardless of the constructional details concretely distinguishing them from each other.

In the different approaches which have been considered, we have noticed that one of the most significant differences consists in the “vocabulary” employed to define functions and flows. The syntax which is employed is often different, however, most importantly, there is no common, acknowledged vocabulary. The same function or flow may be called with different “names” by different authors. Sometimes, the functions and flows described in a given approach may even be completely absent in another one.

As it may be inferred, this last issue is the one mostly concerning our work. In fact, since the database will be used and updated by different people, functions and flows need to be expressed through a single, clear, complete vocabulary, with no possibility of misunderstanding.

In order to solve this problem, we have decided to use the vocabulary and the definitions provided by the so-called Functional Basis (Hirtz, Stone, McAdams, Szykman, & Wood, 2001).

The Functional Basis (Stone & Wood, 1999; Hirtz, Stone, McAdams, Szykman, & Wood, 2001) has summarized previous classifications and has created a more complete and considerable set of functions and flows compared with the past, eliminating any redundancies and making up for any shortcomings of previous vocabularies.

Table 2 shows a part of the Functional Basis vocabulary. The complete vocabulary and relative definitions are available on-line (Hirtz et al., 2001).

5. Definition of the principles

Studying methodical design procedures, the authors found that, a further element, defined generally as "principle", may be useful to define a new level of the procedure that links a function to a constructional element. Each function can be in fact realized by the means of different principles, on which the different function-carriers are based.

Technical systems of the III and IV degree in charge of accomplishing a complex technical process are characterized by a *technological principle*, whereas simple systems of the I and II degree are characterized by a *principle of action* (Hubka, 1982).

We have opted for the generic term *principle.* It is implicit that, in the case of simple systems, it will correspond to the concept of principle of action. Instead, with complex systems, which will be dealt with later in research, it will correspond to the concept of technological principle.

In this case, our purpose was to create through principles a sort of "filter" for the function-carriers: once entered a function-flow pair, a list of principles will be received. For each principle, any function-carriers based on the principle achieving that given function will be indicated. Once selected a principle, the relative function-carriers will be listed.

An extremely helpful resource including much information on principles and physical effects is represented by a catalogue of principles found in the literature (Koller, 1985). This catalogue includes a number of physical effects, divided according to achieved functions and transformed into flows. The information includes graphic schemes of the physical effect, the formula ruling the effect, notes explaining the effect and applicative examples.

We have decided to classify principles (whether they result from Koller's physical effects, or from other sources) by using the same criteria employed in a table of classification (Pahl & Beitz, 1984) including a few illustrative physical effects divided according to the physical field they may be referred to.

Furthermore, the list of the principles will be drawn simultaneously with data entry in the database. In fact, unlike what has been made for functions and flows, there will be neither a pre-established vocabulary, nor a fixed number of possible choices to be made. This will enable to enter principles which have not been taken into consideration from the beginning, enabling to enlarge the list whenever needed.

Figure 6 shows the procedure of data input in the database, evidencing the inclusion of a new principle into the list.

6. The database structure

In conclusion, a summary of collected elements has been made, resulting in the preliminary database structure. In Table 3, the main database fields are listed.

Figure 7, instead, shows a tree diagram illustrating the simplified hierarchy of the information contained in the database, with a few choice steps evidenced.

In Figure 8 it is possible to see an example of the hierarchy defined by the authors, from Function to Constructional Element. The example regards the function "Transmit torque" and shows some items inserted in the database, related to the Principle, Function Carrier and Constructional Elements that absolve the stated function.

7. Conclusions and future developments

The overall objective of this research is the definition of all the elements needed to define a structure for an interactive catalogue of principles and constructional elements, realised by the mean of a database. The database is structured in such a way that it is possible to perform queries based on the required function.

The authors have focused the research inside the methodical design theory. After have analysed the different methodical design approaches, the authors have defined the elements for the definition of the catalogue structure. In details, it has been possible to:

1) Define the hierarchy of the catalogue using the abstraction levels of technical systems introduced by Hubka.
2) Insert in the catalogue structure the important level of the principles, between the level of functions and function carriers.
3) To adopt, in the case of the definition of functions and flows, a common solid vocabulary, constituted by a limited number of well defined terms.

At the moment, the database is focused on mechanical engineering design. In the future, the database will be improved, regarding its implementation, in order to reduce the redundancy in the data structure. Then it will start to be populated. A new interface will be implemented in order to have the database fully available over the internet, in a way that will permit public access and updating.

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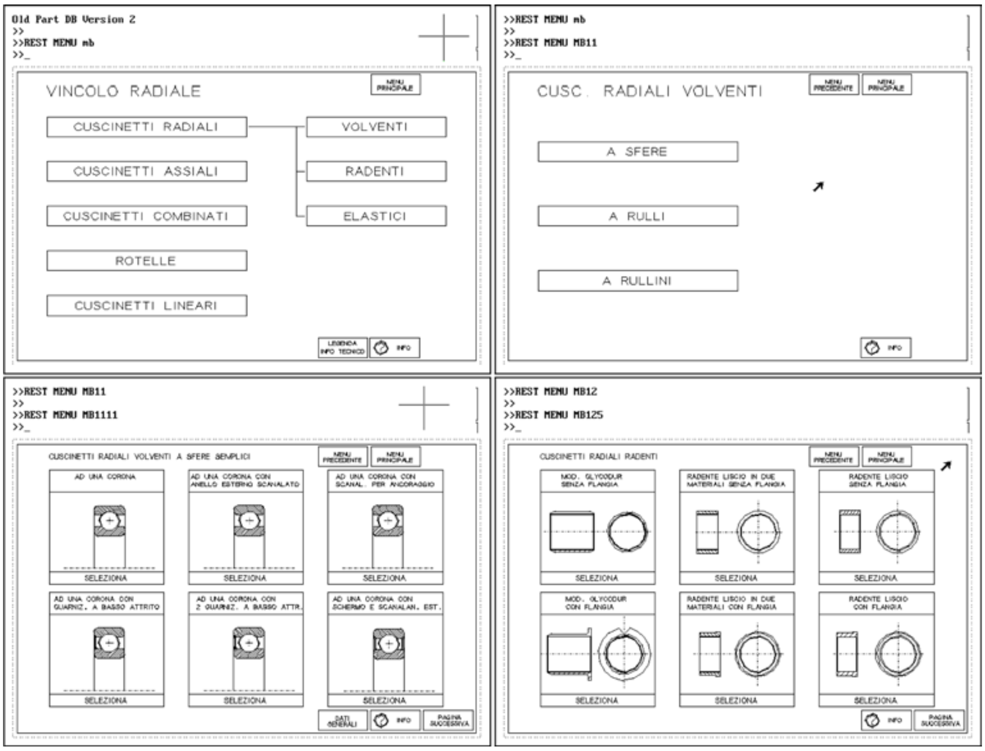

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Figure 1: Screens capture of the implemented procedure for the definition of design solutions based on specific function. The case regards the "*support of the rotation movement*".

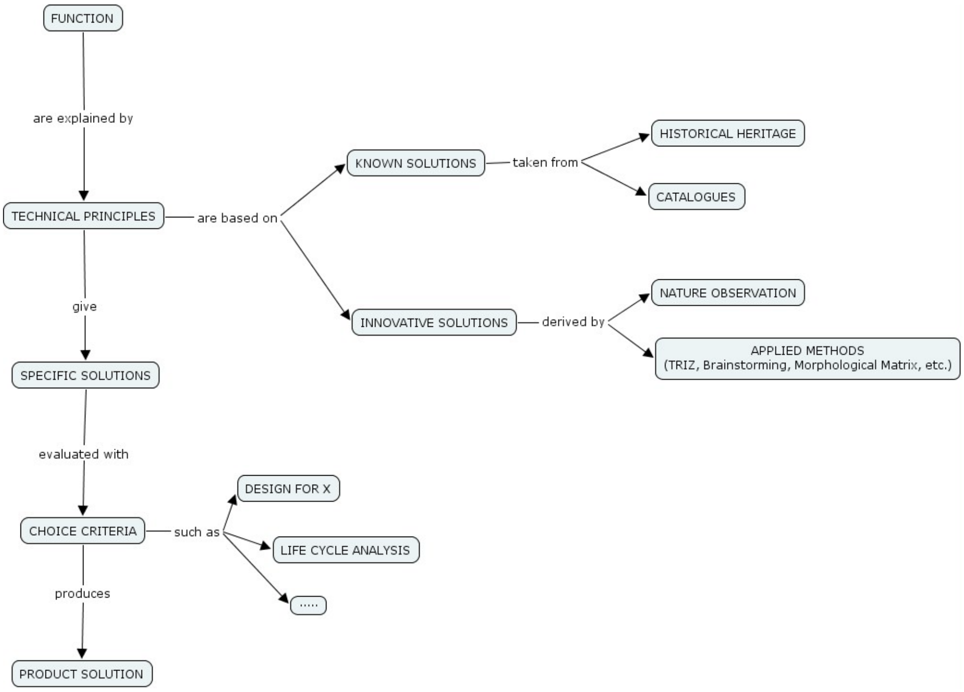

Figure 2: The general procedure under study.

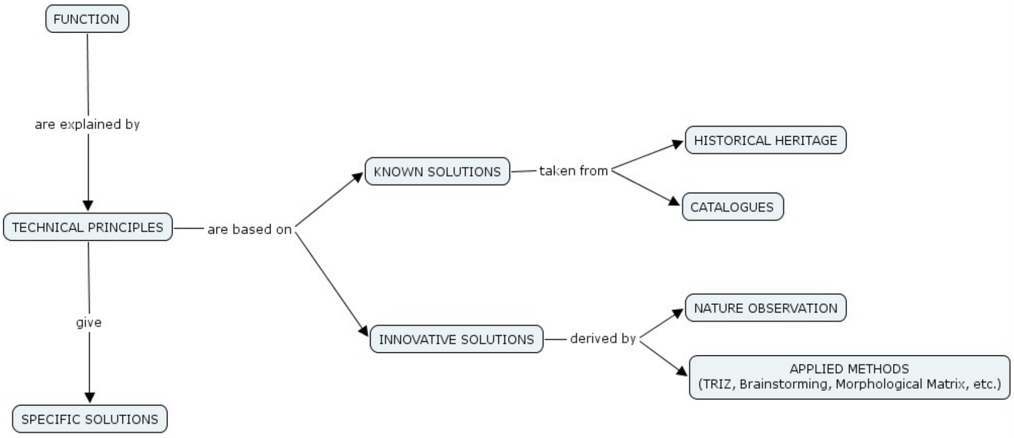

Figure 3: Identification of the technical principles.

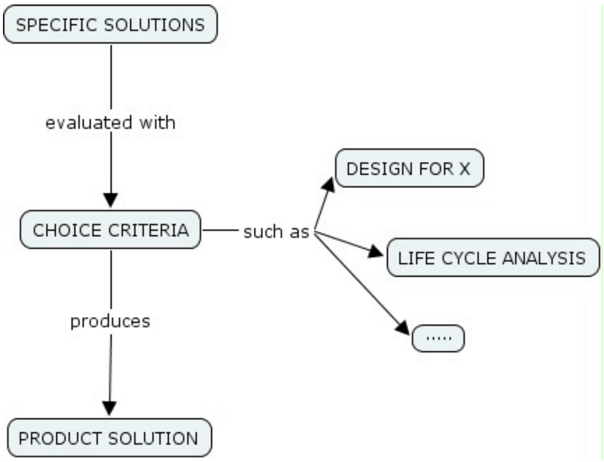

Figure 4: Choice of the final solution.

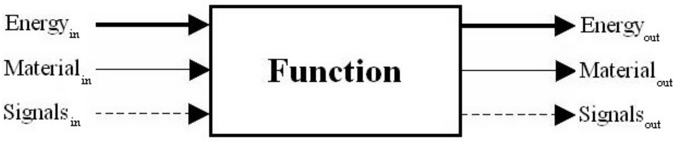

Figure 5: "Black-box" model of a generic technical system.

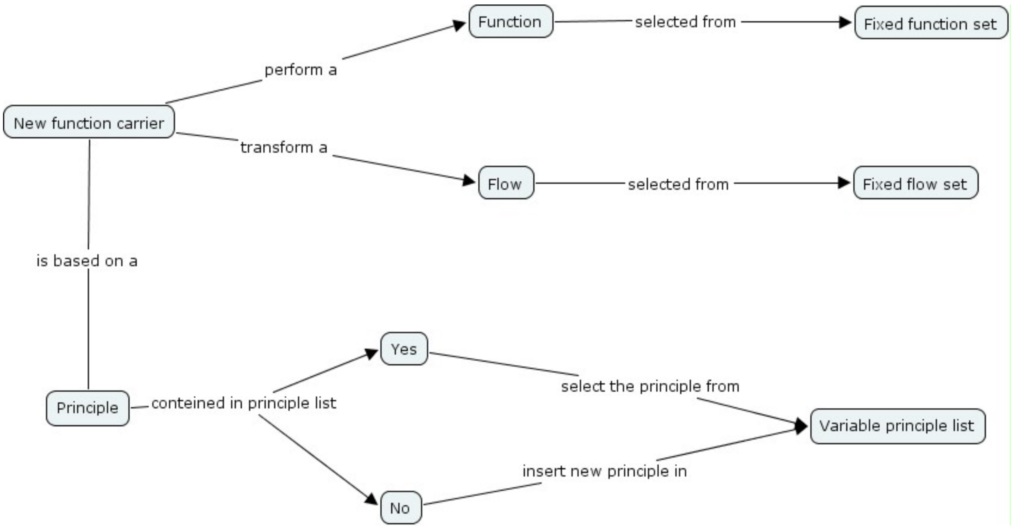

Figure 6: Scheme of the process of new data input in the database, evidencing any entry of a new principle.

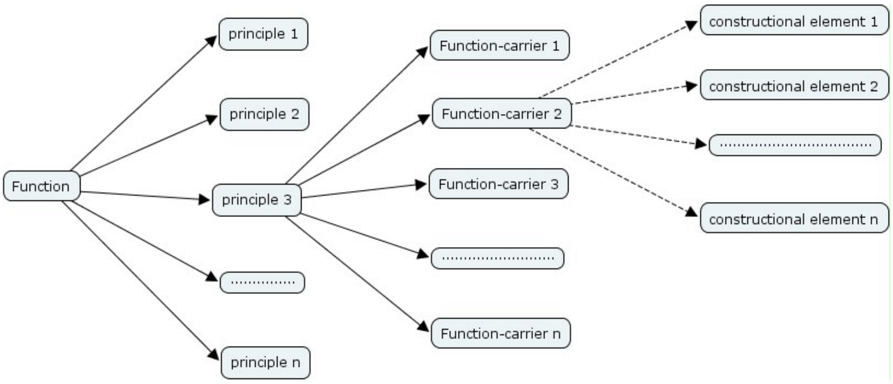

Figure 7: Simplified database hierarchy.

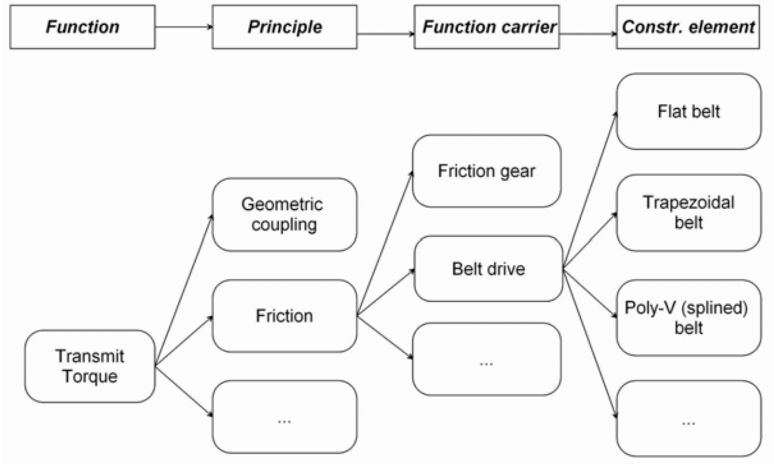

Figure 8: Example of hierarchical choices.

Table 1: Cases examined in the preliminary studies, in relation with the complexity level of the technical systems and the level of concretization they may be represented with

Complexity Concretization	I	II	III	IV
Functions	Yes	Yes	╳	╳
Function-Carriers	Yes	Yes	╳	╳
Constructional Elements	╳	╳	╳	╳

Table 2: Summary of the Functional Basis

Flow Set	
Class (Primary)	***Secondary***
Material	Human
	Gas
	Liquid
	Solid
	Plasma
	Mixture
Signal	Status
	Control
Energy	Human
	Acoustic
	Biological
	Chemical
	Electrical
	Electromagnetic
	Hydraulic
	Magnetic
	Mechanical
	Pneumatic
	Radioactive / Nuclear
	Thermal

Function Set	
Class (Primary)	***Secondary***
Branch	Separate
	Distribute
Channel	Import
	Export
	Transfer
	Guide
Connect	Couple
	Mix
Control Magnitude	Actuate
	Regulate
	Change
	Stop
Convert	Convert
Provision	Store
	Supply
Signal	Sense
	Indicate
	Process
Support	Stabilize
	Secure
	Position

Table 3: Summary of the fields chosen for the database

Database Fields	
Function-Carrier	Name
	Complexity Rate
Principle	Physical Field
	Name
Function	Class (Primary)
	Secondary
	Tertiary
Flow	Class (Primary)
	Secondary
	Tertiary