PROPOSAL ABOUT THE USE OF DATA BASE IN ENGINEERING DESIGN

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ABSTRACT
Design can be defined as the human activity aimed to conceive and develop the "best" constructive solution, capable to perform a given function. In this paper we will present the conception of a data base capable to archive constructive solutions related to a given function. The aim of this DB is to be the starting point of the design process and a useful tool for the designer. The structure of this data-base has been conceived starting from the schema of the design process, in order to store a functional model derived from several functional representations available in the technical literature.

Keywords: Design Method, Functional Modeling, Knowledge storage.

1 INTRODUCTION

Design can be defined as the human activity aimed to conceive and develop the "best" constructive solution, capable to perform a given function. One of the starting points of a designer is the "state of the art", i.e. the known solutions that perform the given function. The designer can use a known solution as is, or modify and upgrade it to obtain better performance, always respecting the objectives of the specific design problem. Therefore, it is important for a designer to have the possibility to access as many known solutions as possible. Only after having examined all the already existing and suitable solutions, he/she can decide if it is necessary to develop innovative solutions and the aspects that should be involved in the innovation process.

Briefly, a data base can be defined as a tool to store and retrieve knowledge. In the considered field and context, a data base can then be used to archive the constructive solutions particularly related to a given function; hence such a data-base could be the starting point of the design process and a useful tool for the designer. Since it is intended to be used in the early stages of the design process, this data-base will contain only general information about the solution: a figure representing the solution and a short description of its structure and behavior are the minimal data that have to be stored in each record.

In the following sections, the first steps of the realization of a data-base of this kind are presented and discussed. First a design process logical schema is presented: this schema is the starting point for the data-base definition. Then, several definitions and formalizations of the concept of "function" are summarized and critically evaluated and, finally, a function representation schema is derived and adopted to define the data-base structure. A practical example completes the paper.

The role of this kind of data base for teachers, students and historians is briefly highlighted.

2 DESIGN PROCESS SCHEMA

On the basis of some of the main logical schemas available in literature [1] [2] [3] [4] [5], the simplified schema of the design process depicted in Figure 1 has been assumed as a reference. Roughly, the design process has been subdivided in two main steps. These steps have been represented as consecutive, even if they can be interconnected in several ways, with many possibilities to create iterative and parallel loops.

In the first step, initially designers look for and critically evaluate the existing solutions capable to deliver the required results, in order to determine if any of the retrieved solutions (or any of their sub-system) can be still useful.

In the second step, designers conceive and embody new solutions on the basis of known solutions (analyzed in the first step), as well as of innovative principles or, more likely, of a combination of them.

The sources of known solutions more commonly used in the first step are:

1. *Historical solutions*, that are available in archives, museums, libraries;
2. *State of the art* that can be derived examining catalogues of industries and, in general, the scientific and technical literature.

The first step goal is the selection of the “best” known solution: a designer has then to retrieve as many information as possible about these solutions, so that he/she can evaluate how each solution “behaves” in each phase of the life-cycle of the product being designed.

Besides this main goal, this first step has an important positive side-effect: the analysis of the past solutions helps the designers to familiarize with the specific design problem, highlighting the typical problems and their more common solutions.

The main problem of this first step consists in the great amount of resources and time required to retrieve and evaluate a significant number of known technical solutions. A data-base storing known solutions can greatly help designers in this first step (i.e. the known (historical and modern) solutions collection and evaluation). In this way, in fact, known solutions retrieval and analysis tasks are made only once, and their results will be available for all the designers that have to face similar problems. Past solutions search and analysis will anyway require much time and a lot of resources, even if some tools (like text mining software) can greatly help in accomplishing these tasks.

The designer usually continues the process, designing innovative solutions, following several design methods, like:

1. *Traditional methods*, based on physical phenomena, geometry, kinematics, dynamics, and so on;
2. *TRIZ*, based on its well know tools, characteristic of this theory;
3. *Biomimetic*, based on the idea to use nature as a source of ideas for innovative solutions;
4. *Critical analysis of the historical heritage*, based on the critical elaboration and evolution of some historical solutions, to find innovative solutions.

During this second step, several design concepts are usually available; hence it is necessary to evaluate them and to select the “best in class”. Since the product is still under development, no previous experience is available, therefore its evaluation process is usually realized by means of (mathematical or iconic) models and/or (virtual or physical) prototypes of the product.

In the next sections, fundamental criteria of realization, first results and possible applications of the above mentioned data base are presented.

3 FUNCTION DEFINITION

Since in the proposed design process schema the starting point is a “Given function” (the function for which the designer has to develop a solution), the above introduced data-base will be organized on a functional basis. A function representation schema has then to be developed.

3.1 A brief state of the art

Even if the field of research about functional analysis and modeling born several decades ago, the debate on some basic concepts is still open: the semantics of function, for example, seem to be still far from a universally accepted formulation.

In this section we will summarize the approaches on the basis of which we have conceived and developed the model presented in the next sections and adopted to store the data.

In our opinion, function representation models can be grouped into three main categories:

1. verb- noun pairs;
2. input-output flow transformations, where the flows can be energy, materials, or signals (information carriers);
3. transformation between input-output situations and states.

Rodenacker [1] defined a function as the transformation between input and output flows of material, energy and information. He suggested also that, in the design process, the designer has to sub-divide the product main function into sub-functions, up to the level where “simple” physical principles can perform the corresponding sub-functions. Although Rodenacker’s definition is quite widely accepted in the design research field, it has some limitations. The following list summarizes the issues raised by Umeda et al. [9]:

- no clear definition for the “function” itself is supplied;
- not all the functions involve transformation between input and output;
- the procedure to subdivide function into sub-functions may be subjective.

- Rodenacker's approach implies that the product is the resultant of the entire sub-structure correspondent to sub- functions: in many product domains this does not happen.

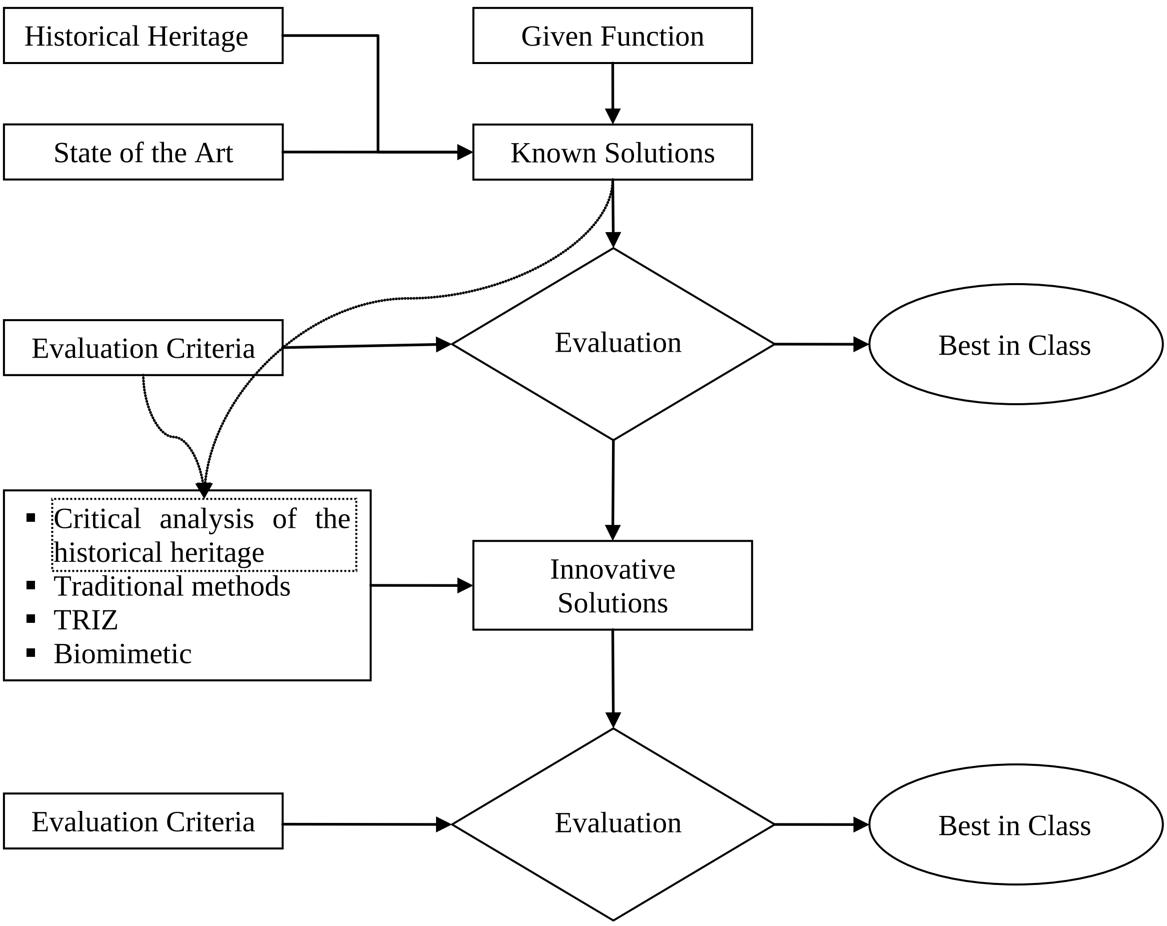


Figure 1. Assumed schema of the design process.

Umeda et al. [9] proposed the FBS (Function-Behavior-State) diagram to model a system with its functional descriptions. They defined a function as "a description of behavior abstracted by the human through recognition of the behavior in order to utilize it", and "call the state and the structure altogether state", since the main difference between them consists only in their duration: structure "exists for a rather long time", while a state "changes in a rather short time". The main shortcoming commonly ascribed to the FBS model consists in the lack of the possibility to explicitly model product geometry and kinematics that are essential concepts in the design of many products.

Goel and Stroulia [10] proposed a functional model called Structure-Behavior-Function (SBF) model. While the FBS model is mainly focused on input and output state/structure of a device, the SBF models put emphasis on the representation of the internal causal processes of the product (the consequence of which are device output states).

System interaction with the working environment is another important aspect in many systems, but few functional modeling approaches model this interaction. Deng et al., for example, at the end of the state of the art review, stated that "all the above introduced models lack an explicit representation of the product's working environment […]. This aspect of design information includes not only the environment, but also the relationships and the interactions between the environment and the desired product". The model proposed by Deng et al. [7] relies hence on the abstraction of four aspects of functional design: function, behavior, structure and working environment. Prabhakar and Goel [8] developed another approach capable to model also the working environment; they extended the SBF approach by introducing the "Environmentally-bound Structure–Behavior–Function (or ESBF) model, to represent and organize knowledge of the functioning of a device, including the role of its environmental interactions”, by considering the environment “as a ‘device’ which supports the device model, so that the integrated device model achieves its function”.

3.2 Proposed function representation schema

On the basis of the results of the previously summarized studies and of many others (like [11], [12], [13]), we have developed a function representation based on the verb and noun schema [2], assuming that it is capable to completely describe a function, at least in the early stages of the design process. A detailed discussion of this function definition can be found in [17].
In our opinion, such a definition (i.e. “verb” & “noun”) is sometime too general: for example, a great variety of solutions is available to accomplish the function “reduce speed”, but their applicability greatly depends on what we want to slow down (a car, a plane, a fluid in a pipe…). A predicate has been then added in order to better specify the function characteristics.
The presence of this predicate can also be seen as a tool to include the functional environment (as well as any other system that deeply interacts with the product being designed) in function definition itself, without requiring a deep analysis of this environment.
Anyhow, we think that these additional information are non-mandatory to describe a generic function. Practically, in order to guarantee to the designers as more freedom as possible and make this approach more flexible, we think it is important to allow designers to search also for all the solutions capable to accomplish the function described by a <Verb> <Noun> pair only, independently from the environment.
The following function representation schema has then been derived:

<VERB> <NOUN> <PREDICATE>

where the Predicate is composed by two elements:

<PREDICATE> = <PREPOSITION> + <NOUN>

and its main aim is to represent the functional environment, as to say where the solution has to accomplish the action described by the <Verb> + <Noun> part of the construct.
To better illustrate this, let consider a public transportation system as an example. The more general and abstract representation of the main function can be formulated as <move> <solid>. A designer (who usually operates in that field) would automatically add (maybe implicitly) the <on> <solid> specification, since he/she has already in mind the more common solutions, as to say ground vehicles (trains, subways, buses …). In this way, several other possible solutions are discarder a priori. This limitation can be overcome following the above introduced procedure, in which a designer searching for a solution becomes at least aware of other possible solutions.
Figure 2 shows a sample catalogue of functions by means of the following fields:

1. List of verbs
2. Object of the verb
3. The environment where the verb action takes place
4. Other specific characteristics like involved physical phenomena, …

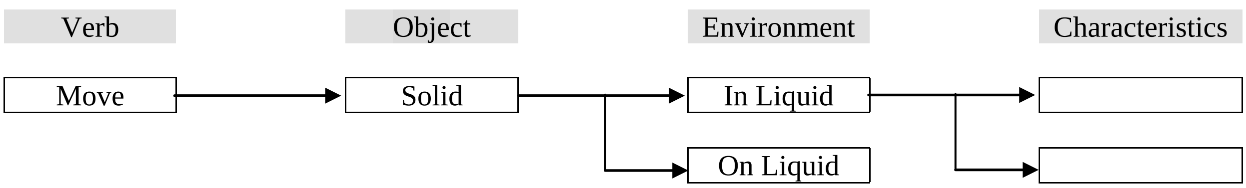


Figure 2. Function catalogue.

4 SOLUTIONS REPRESENTATION

The next step is the definition of a schema to represent all the retrieved solutions.

The starting point of the proposed data-base is a menu with a list of function stored by means of the above introduced syntax (Figure 2). Each of this function has then been linked to all the corresponding solutions. Besides picture, structure and behavior, several other fields have been added. In particular, two additional fields have been introduced to store input and output flows of each solution. Each of these two fields has been subdivided in three sub-fields, according to their classical subdivision in material, energy and signal.

Picture	Name	Date	Author	Historical Comments	Structure	Behavior	Keywords	Input flows			Output flows		
								E	M	S	E	M	S

Figure 3. Constructive solutions catalogue.

The structure of the archive of solutions is depicted in Figure 3: the solutions are collected with Picture, Name, Date, Author (and/or manufacturer), some Historical Comments, Description of Structure (how the solution is realized and configured), description of Behavior (how the solutions performs the function), some key-words and Input and Output flows (Energy, Material and Signal).

Since the goal is to help designers during the earliest stages of the design process, when they are looking for a "generic abstractions" among technical and biological systems, solution description has to be as simple as possible. This is one of the main reasons why we think it is better not to include a detailed description of the considered systems, but only a brief summary of their structure and functioning.

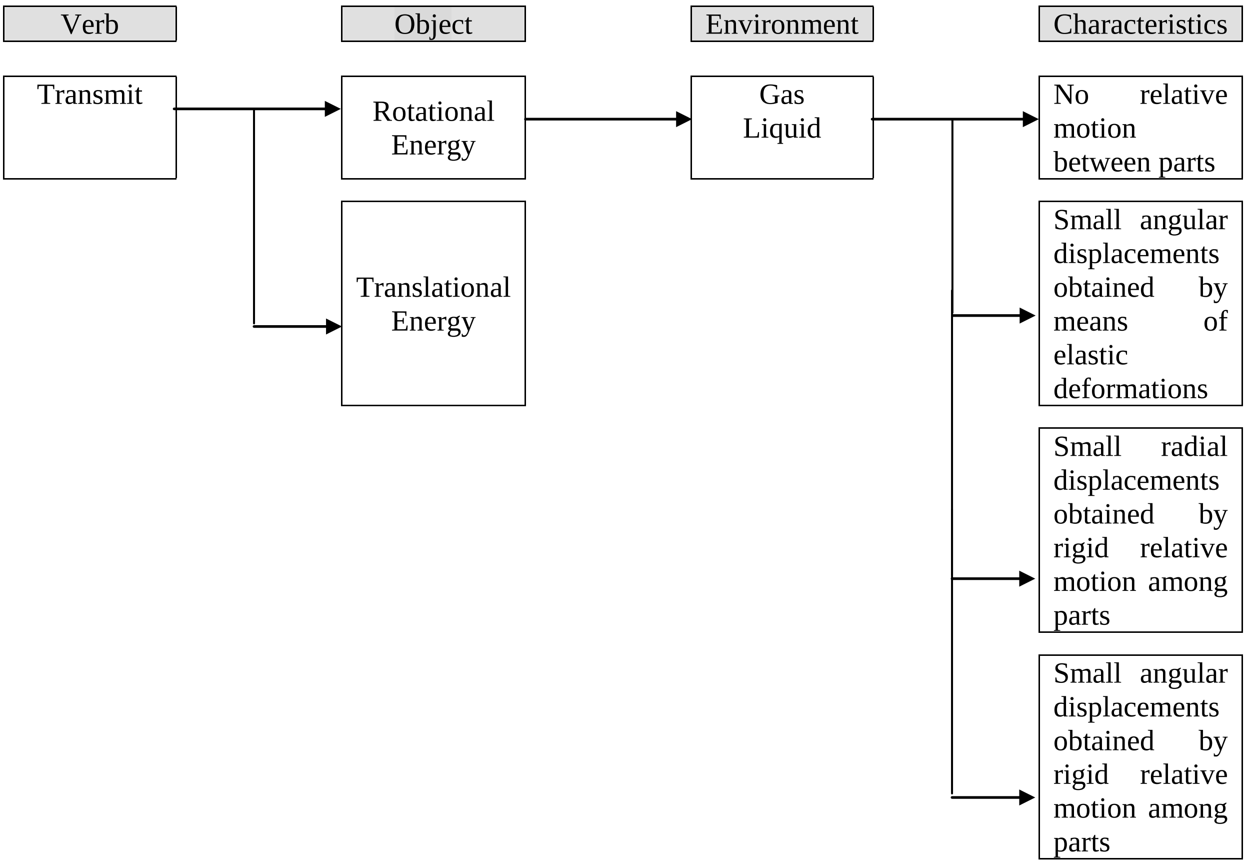


Figure 4. Sample function representation in the function catalogue.

5 PRACTICAL EXAMPLE

The function <Transmit> <Rotational Energy> is used as an example.
According to the above introduced function representation schema, an environment can be specified.
Three main environments have been considered up to now: solid, liquid and gas. Obviously, this definition can be greatly improved and enriched by considering also some characteristics (temperature …) of the environment itself. In the following, gas and (non-corrosive) liquid environments will be considered.
Figure 5 shows some of the retrieved solutions querying the data-base for this function.
The columns containing input and output flows of the solutions of Figure 5 have been omitted, since in these solutions the only flow is rotational energy (power losses due to relative sliding between couplings parts are assumed to be negligible).
Other solutions may have other flows; a hydraulic clutch, for example, has also an input flow of hydraulic energy, and an output flow of thermal energy (power losses are not negligible).

6 ROLE OF THE DATABASE

We believe that he above mentioned data base can be useful for many categories of users (see also [18]).

6.1 Technicians, engineers and designers

Some historical solutions that have not been completely developed in the past (for example, because of a lack of adequate materials or manufacturing technologies) could be re-utilized today as the starting point to conceive and develop innovative solutions.
In other words, the critical analysis of the historical data-base can become the core of a heuristic design method. As an example, the *abstraction* method is hereafter proposed [15].
The logical schema of this procedure to embed the historical heritage in the design process has been derived from the TRIZ general schema. One of the fundamental points of the TRIZ method is to generalize the given problem, instead of searching only for a specific solution for it. The TRIZ method suggests to first search for a solution of a generalization of the given problem, and then to particularize this more general solution in the specific given field.
In our opinion, the historical solution data-base can help designers to better understand the problem they are facing (abstraction step), since it where them a more general and complete overview of a specific design problem, highlighting its typical problems. By means of such a data-base, for example, the designers can easily retrieve all the “tricks” typically used to solve the problem. This information help him/her, on one side, to identify which solutions are actually innovative and which have already been fully exploited, and, on the other side, to find out the actual core of the problem, that is the sub-system where most of the “tricks” are applied. A catalogue of historical failure events [14] can be somehow considered an extreme member of this kind of data-base: it can greatly help to prevent disasters, but it can not help to design a new product (and, after all, it is not intended to do this).

6.2 Other users [16]

- Standardization organizations: some historical drawings could be source of modern drawing standards.
- Teachers and students: in the teaching activity, particularly in engineering design field, the possibility to choose a solution in a given archive, could be a good basis for the innovation
- Historians: the data-base can make easier the research of historical technical solutions. For example, such a data-base can permit to search all the machines with given technical characteristics, realized in a specific year, or by a given industry, or in a given country.

7 CONCLUDING REMARKS

In the present paper, the fundamental principles of a data base capable to store past constructive solutions are presented and illustrated. We believe that the above mentioned data base could be a useful for designers, teachers and students, as well as for historians. The described data base could be a basis to explore and evaluate the existing solutions, as a first step, in the design process, before studying other possible and innovative solutions.

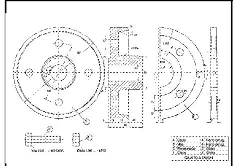
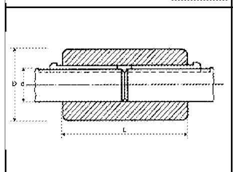
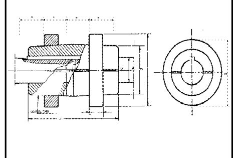
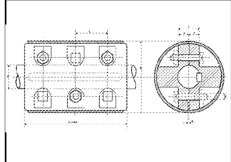
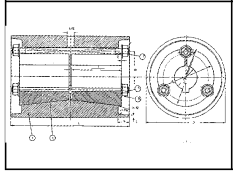
Drawing	Name	Inventor	Year	Country	Historical notes	Description	Operation
Rigid couplings		Rigid couplings are mechanical components, usually made of cast iron with a relatively simple design, aimed at connecting the ends of two rotating shafts (coaxial and perfectly aligned) in order to transmit a torque from a shaft to the other.					
	Flanged coupling					The coupling between each disk and its shaft is made using a key or by mean of a forced coupling, generally H7r6. The number of bolts (generally 4 to 8) is defined upon the size of the disks.	The force transmission between the two disks is achieved by mean of the friction between the two contacting surfaces, kept togheter by a series of bolts.
	Sleeve coupling					This kind of coupling is based on a cast iron cylinder, coaxial with both shafts and fit to them using a key, slightly oblique. Hammering the head of the key it is possible to force the coupling thus trasmitting torque by mean of the friction between the cylinder and the shafts. The coupling is generally protected by a steel laminate.	Torque is transmitted from the primary shaft to the cylinder and then to the secondary shaft.
	Ring sleeve coupling		First half XIX century		It is very difficult to indentify the inventor and the first usage of this type of coupling, due to its very simple behaviour. The first wide-scale usage of them took place in the first half of the XIX century, during the first industrial revolution, when the necessity to connect the various shafts of complex machines brought to their adoption	In this case the sleeve is composed by two semi-cylindrical shells with conical external surfaces with a slope of 1:40 to 1:25. The shells are clamped on the two shafts to be connected by two steel rings (plus, in general, fitting keys). The internal surfaces of the rings are conical with the same slope of the outer surfaces of the shells.	Torque is transmitted from the primary shaft to the cylinder and then to the secondary shaft.
	Shell coupling					The coupling consists of two shells, usually made of cast iron, which are tightened on the shaft by bolts, adding keys for high torques. The cylindrical shells are hollow to host the heads of bolts and nuts. The joint is protected by a steel laminate.	Torque is transmitted from the primary shaft to the cylinder and then to the secondary shaft.
	Sellers coupling					The Sellers coupling summarizes the advantages of the rigid joints previously reported. It consists of a cast iron sleeve having a bi-conical inner surface with a slope of about 12°. Inside the sleeve there are two cast iron cones (compasses), cut along an axial plane and fit onto the shafts by mean of keys.	The torque is transmitted from the shaft to the compass, from this to the sleeve, then to the second compass and finally to the second shaft, by mean of the friction between the contacting surfaces, enhanced by the tightening of bolts.

Figure 5. Solution archive example. Some columns have been omitted.

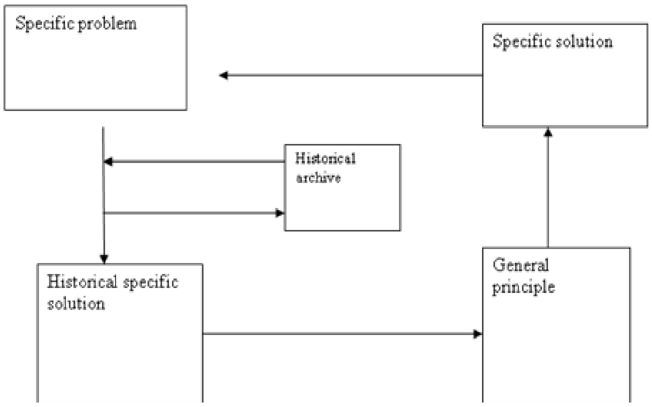


Figure 6. Abstraction method schema.

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