Proposal of a database to support the embodiment design phase

F. Rosa [(a)], E., Rovida [(a)], R., Viganò [(a)]

[(a)] Politecnico di Milano – Dipartimento di Meccanica, Italy

Article Information

Keywords:
Creativity,
Redesign,
Knowledge based engineering.

Corresponding author:
Roberto Viganò
Tel.: +390223998217
Fax.: +390223998202
e-mail: roberto.vigano@polimi.it
Address: via La Masa, 1

I-20156, Milano (ITALY)

Abstract

Identifying the technical solutions for each function performed by the product under development is one of the fundamental targets of the design process. This activity involves the treatment of multileveled information, collected from several sources and disciplines, and the selection of the technical solutions is based both on scientific criteria and on technical experience. Finally, the solutions more adapt to answer the product requirements are usually selected on the base of measures of merit and by designer experience.
In this context, a particular role is played by the tools able to support the designer during the search and the management of this information. These tools have to satisfy the expectations of the designer in terms of knowledge, examples and methods. An important problem consists in identifying and choosing the technical principles capable to perform the required functions among all the adapt ones. While the choice among different technical principles depends on the requirements of the specific product under design, their identification is a process that can be expanded in several directions, without limitations. Thus, the development of a procedure to support the identification stage is an interesting aspect of the research activities devoted to assist the designer work.
The authors think that this flexibility can also be used during the subsequent phase devoted to the embodiment of the selected solution. In fact, the data collected in the database can be useful to improve the known how of the designer regards specific aspects of the technique. So, it is possible to use the technical solutions present in the database as examples from which to extract ideas to improve the solution under development.

1 Introduction

Identifying the technical solutions for each function performed by the product under development is one of the fundamental targets of the design process. This activity involves the treatment of multileveled information, collected from several sources and disciplines, and the selection of the technical solutions is based both on scientific criteria and on technical experience. Finally, the solutions more adapt to answer the product requirements are usually selected on the base of measures of merit and by designer experience.

In this context, a particular role is played by the tools able to support the designer during the search and the management of this information. These tools have to satisfy the expectations of the designer in terms of knowledge, examples and methods. An important problem consists in identifying and choosing the technical principles capable to perform the required functions among all the adapt ones. While the choice among different technical principles depends on the requirements of the specific product under design, their identification is a process that can be expanded in diverse directions, without limitations. Thus, the development of a procedure to support the identification stage is an interesting aspect of the research activities devoted to assist the designer work.

The use of archives of solutions is considered fundamental to support the designer during the identification and selection phase. So many tools in this way were developed in the time, but a significant improvement was obtained when the archives of the technical solutions have been implemented into informatics databases. The informatics implementation permits a higher flexibility in the treatment of the information, because it collects the data in a more structured mode than the traditional archives and allows accessing them by means of different key words and queries.

The authors think that this flexibility can also be used during the subsequent phase devoted to the embodiment of the selected solution. In fact, the data collected in the database can be useful to improve the known how of the designer regards specific aspects of the technique. So, it is possible use the technical solutions present in the database as examples from which to extract ideas to improve the solution under development.

2 Background

Archives of technical solutions able to perform a given function have been investigated since the first studies about the methodic design. For example, Beitz [2] proposed some ideas about archives of geometric structures, while Pahl [10] and Koller [8] presented some simple collections of technical structures and solutions, besides some considerations about methodic design. In the time the necessity of archives of technical solutions to support the designers becomes increasingly clear [7] [11] [15] [16].

An example of archive of technical solution was developed during the '90 years at the *Mechanical Department* of the *Politecnico di Milano* [3] [5]. This first archive contained a set of principles and functions and the related technical solutions, collected from technical books and commercial catalogues. The set of technical solutions were organized on the basis of the "typical" systematic approach and their representations have been implemented in a bi-dimensional CAD system. Finally, a specific application has been developed to retrieve the solutions corresponding to a given function from the archive.

These first studies have been continued and extended in more recent years, expanding the field of usage of the archives in the design context [17]. Figure 1 shows the general procedure currently adopted to describe the design activities, from the definition of the required function to the selection of constructive solution consistent with all the design requirements. The flow diagram shows the principal aspects of the procedure, in a very general way, regardless of the exact nature of the design tools employed to develop all the activities. In particular, the activity consisting in "identifying the technical principles to perform the function required" is directly related to the use of the archives. This activity has been subdivided in two categories: the first one is based on known solutions, and the second one on innovative solutions. The known solutions are derived both from the "state of the art" of the current industrial artefacts and from the historical industrial heritage. Innovative solutions may be researched by means of the use of techniques of analysis and observation of the nature as well as by means of the application of systematic methods (TRIZ, brainstorming, etc.).

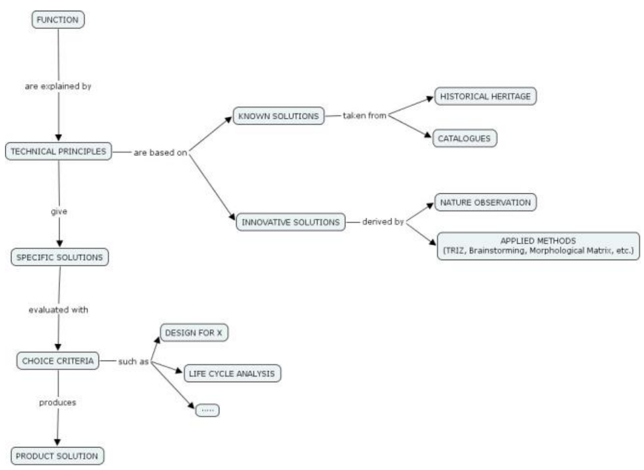

Fig. 1 Logical schema of the general procedure.

3 The database

The starting point of the above mentioned database is a catalogue of functions, built according to functional basis derived by the results of several previous studies [6] [8] [9] [11]. Each function is linked to the constructive solutions able to perform the function itself. The database is therefore constituted as represented in Figure 2.

As shown in this figure, after the choice of the function in the catalogue (F_i), it is possible to extract the list of families of products (i.e. constructive solutions) (P_{ij}) capable to perform the chosen function. Successively, within the above introduced family, it is possible to select a specific product (P_{ijk}) and see, in an Excel sheet, the different constructive solutions of the product, together with some information about drawing, manufacturer, country, year, structure and behaviour (Figure 3). The information is completed with links to the sources.

4 The role of the data-base in subsequent design phases

As a result of the approach described in the previous sections, the designer usually obtains a technical solution for each specific function.

The description of these solutions is usually quite general. In fact, the information stored in the data-base have to be adaptable to a wide variety of practical situations, hence storing a highly detailed solution is practically not feasible and may be also counterproductive. Several details can make less easy the identification of the fundamental functioning principle of the technical solution itself (especially if the designer is not familiar with it) and of its main properties and aspects; as a consequence a designer may experience severe difficulties in properly embodying the chosen solution within its practical problem, or even decide to discard it.

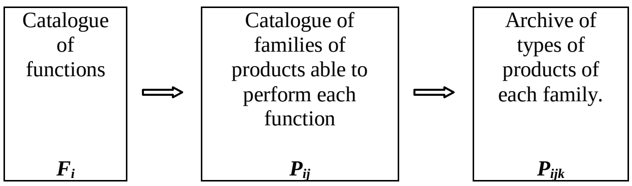

Fig. 2 General schema of the functional database.

During these stages of the product development, besides the accomplishment of the primary function, the selection of a particular solution is also driven by some fundamental goals, i.e. the optimization of some aspects that are very important for the product itself. For example, in a product designed for the aeronautical field, lightness is a primary requirement. The satisfaction of this requirement drives therefore the design choices, compatibly with the other requirements, as part strength. In other words, the aspects considered to select the "best" solution are also the driver of the entire design process. The satisfaction of these requirements is pursued not only in the first stages of the design, but also in all the subsequent steps, up to the final embodiment of the chosen solutions.

4.1 Optimization of the single technical solution

During the embodiment phase, the solution is usually developed in order to obtain the maximum performances in terms of the aspects that have to drive the selection of the solution itself.

For example, if a solution has been chosen because its ranking in a peculiar aspect is higher, the designer will try to further improve this specific aspect in each sub-system. Very often, designers adopt typical solutions to reach this goal; for example, if the requirement is "lightness", the typical lines of actions consist in choosing lighter materials, and in lightening the parts by removing as much material as possible. Strength requirement usually is the main constraint to lightness. Lighter materials are usually also less resistant, and, obviously, it is possible to remove only the material that is not directly involved to support the loads applied on the parts. Nevertheless, other characteristics may have a big influence; for example, particular environmental conditions may prevent from adopting some light materials.

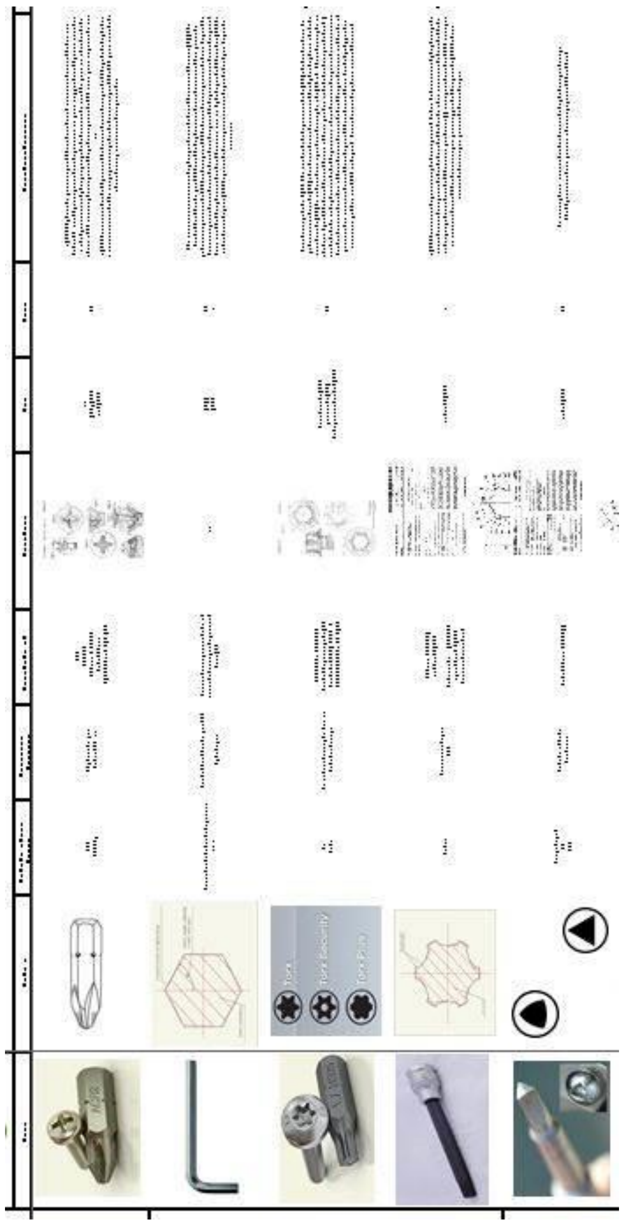

Fig. 3 Partial example of the information stored in the database.

The part under study may have to operate in a high temperature environment, hence fiber reinforced materials may not be suitable, or it may come in contact with particular substances that can corrode the lighter materials.

More in general, after having chosen a solution on the basis of one or more particular aspects, the designer usually needs to optimize the adopted solution with respect to these aspects. The strategies to pursue this optimization are usually based on general applied methods and approaches, widely known such as topological optimization to lighten structures. Nevertheless, a more general perspective view of the available solutions can help the designer in this phase.

These general considerations suggest an alternative use of the above introduced database of constructive solutions:

1. Find and examine all the solutions that better behave according to the set of aspect of interest;
2. Extract and generalize the methods commonly adopted to improve these particular set of aspects;
3. Exploit these methods (if possible) to even improve the performances of the selected solution.

In order to ease this work and to avoid repeating several times the same analyses, a future development of our research may consist in the creation of specific fields, containing a description of the "reasons" why a particular aspect is better achieved in a particular solution.

Practically, this phase requires a different perspective in enquiring the data-base. Instead of searching for all the solutions that can perform a given function, the data-base has to be queried for all the solutions that better satisfy a particular aspect, irrespectively from the function they accomplish. From such a wide research, the designer can retrieve a huge amount of solutions that can also be very far from the problem under study. It can therefore be very difficult to extract the appropriate and adapt information. A possible solution may consist in filtering this search, for example, by limiting it indicating only one of the components of the definition of the function. For example, if a designer is searching for a solution to "move a solid", and the lightness is one of the fundamental aspects, the search may be limited to all the constructive solutions that "move" something and have a high ranking in the lightness aspect, so that the extracted principle may be more easily applicable to the concrete design problem.

4.2 Detail Design of the single technical solution

Besides searching for solutions that best fulfil the requirements of a specific "aspect", the use of the data-base can be generalized in another way.

The constructive solution defined following the methodical design approach may require particular parts and/or sub-assemblies.

As an example, let suppose that the adopted solution need an elastic elements (a spring, for example). The designer has then to properly constraint it to the other parts so that the forces are correctly transferred, and the desired relative motion is permitted. The designer can face these problems by following again the complete procedure, that is searching for a proper function (<Transfer> <force>, for example) and evaluating each of them. At this level of the design process, such a search may lead to identify a very wide spectrum of solutions, relying on very different principles, the great part of which will probably not be adapt to the very specific situation.

A search for all the constructive solutions that use a particular part (the spring) may be a possible alternative to overcome this problem and to ease the retrieval of adapt solutions. Analysing these solutions, the designer can more easily find out the more common practical solution to constraint a spring to other parts that satisfy the design requirements (Figure 4).

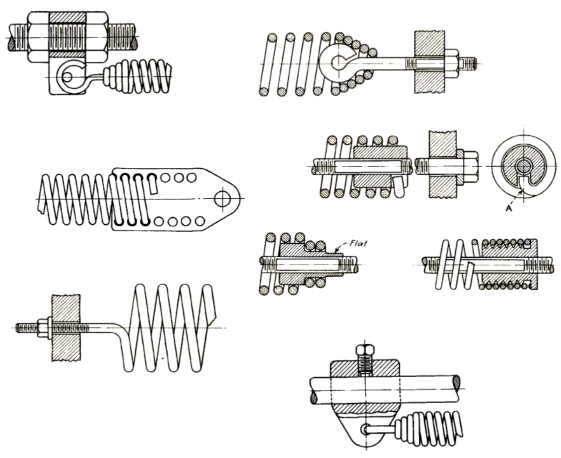

Fig. 4 Logical schema of the general procedure.

Let now suppose that, looking for a way to transmit the torque from the shaft to the hub, a designer find the parallel-key solution. In the corresponding record, the designer will find the description of the parallel key principle, of all its practical variants, and the information that the parallel key does not axially constraint the hub. The selection of the specific variant, as well as the way to axially constraint the hub (Seeger-ring, nut, etc.) will be not only based on the requirements of the specific product, but also on several practical aspects (e.g. parts accessibility). In other words, a set of concrete and practical examples may be more useful than a general investigation for a designer that is investigating such a particular situation.

Practically, these considerations lead to another way of querying the data-base of historical, contemporary and innovative constructive solutions; besides searching for specific functions and aspects, it may be also useful to query the data-base searching for one or more specific parts within the structure field of the above introduced data-base.

5 Conclusions

The authors think that the above introduced data base can help the designer not only in the first stages of the design process, but also in the subsequent steps, and it is therefore an interesting tool from many point of view.

The critical observation of know solutions can be a source of new ideas, by modifying or improving such solutions (using, for example, new materials and/or new production technologies).

Besides helping the designer in the practical embodiment phase, the survey about the state of the art of constructive solutions can be a useful tool in many other fields. The data base can be interesting from the point of view of Standardizing Institutions: the data base is a collection not only of constructive solutions, but also of drafting methods: the critical considerations of technical representation could suggest new proposal of drawing standards.

The data base, finally, as a collection of historical solutions can be an interesting tool for historians that look for a survey of historical solutions, in order to study the technical evolution of past economical systems.

The authors are continuing the implementation of the above mentioned data-base. Some parts of the data base are on the website of the Dean of Italian Engineering Faculties [18].

This is only, of course, one of the first steps towards the conception of a complete design procedure. Besides the use of known and upgraded solutions, the authors are working on the integration of other tools, like heuristic methods, such as TRIZ or Biomimetic (Biomimicry).

References

[1] AA.VV. (2012). *List of screw drives - Wikipedia, the free encyclopedia*. Tratto il giorno 12 28, 2012 da Wikipedia: http://en.wikipedia.org/wiki/List_of_screw_drives

[2] Beitz, W. (1981). Grundlagen methodischen Vorgehens beim Konstruieren. *International Conference on Engineering Design ICED 81.* Rome (Italy).

[3] Biggioggero, G. F., Galli, P., & Rovida, E. (1995). Methodisches Konstruieren: ein Anwendungssoftware. *Workshop ALPINA 95 .* Rigi Kaltbad (CH).

[4] Dahmus, J. B.-Z. (2001). Modular product architecture. *Design Studies, 22*(5), 409-424.

[5] Galli, P., & Rovida, E. (1994). Vorchlag eines Softwares feur das methodisches Konstruieren. *Workshop ALPINA 94 .* Rigi Kaltbad (CH).

[6] Hirtz, J., Stone, R. B., McAdams, D. A., Szykman, S., & Wood, K. L. (2002). *A Functional Basis for Engineering Design: Reconciling and Evolving Previous Efforts.* NIST Technical Note 1447 .

[7] Hubka, V., & Eder, E. (1988). *Theory of technical systems.* Springer .

[8] Koller, R. (1984). Entwicklung einer Systematik fuer Verbindung – ein Beitrag zur Konstruktions metodik. *Konstruktion, 36*.

[9] Kroes, P. (2010). Formalization of Technical Functions: Why is that so difficult? *TMCE 2010 .* Ancona (Italy).

[10] Pahl, G. (1982). Foerderung der Kreativitaet in Grundlagenfach Maschinenelemente durch methodisches Konstruieren. *Konstruktion, 34*.

[11] Pahl, G., & Beitz, W. (2007). *Engineering design.* The Design Council. Springer.

[12] Rosa, F., Rovida, E., & Viganò, R. (2010). Design in nature and engineering: Knowledge transfer through a data-base of biological solutions. *TMCE 2010.* Ancona (Italy).

[13] Rosa, F., Rovida, E., & Viganò, R. (2011). Proposal about the use of data base in engineering design. *ICED 11.* Copenhagen (Denmark).

[14] Stone, R. B., Wood, K. L., & Crawford, R. H. (2000). A heuristic method for identifying modules for product architectures. *Design studies, 21*(1), 5-31.

[15] Suh, N. (1990). *Principles of design.* Oxford Series on Advanced Manufacturing.

[16] Ullman, D. (2009). *The mechanical design process.* Mc-Graw Hill.

[17] Viganò, R., Rovida, E., De Crescenzo, A., & Raco, D. (2006). Preliminary studies for the creation of a functional archive of constructional solutions. *Wonderground - Prooceding book.* Lisboa (Portugal): Design Research Society.

[18] AA. VV., Conferenza Presidi Ingegneria - Mediateca sulla storia dell'ingegneria, http://www.confpresing.it/, last accessed 02 April 2013.