INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED15
27-30 JULY 2015, POLITECNICO DI MILANO, ITALY

DESIGN FOR EMBODIMENT THROUGH SMART ARCHIVES

Rosa, Francesco; Viganò, Roberto; Rovida, Edoardo
Politecnico di Milano, Italy

Abstract

The design of a new product begins with functional analysis, and then continues with conceptual solution. Only in final and somehow separate stages, the designer has to embody and then to design in detail any part of the product. Even if the great majority of the recent developments in design methods and tools are devoted to the first two and more abstract steps of the product development process, as shown above, the last two steps are the among the more common activities of a design office, and are also the more time and resource consuming steps. These considerations apply not only to the design of a new product, but also to the very common re-design activity, where the past experience plays an important role in "suggesting" how to avoid "trouble". In order to overcome these limitations, the structure of an archive is presented, discussed and applied to a practical case study. This catalogue is the result of a tailoring process of an amalgamation of the Systematic Design catalogues with the aim of easing and anticipating the issues typically relegated to embodiment and detail design, in order to recognize as soon as possible practically unfeasible concepts.

Keywords: Design engineering, Design methods, Embodiment design, Design practice, Design methodology

Contact:
Dr.-Ing. Francesco Rosa
Politecnico di Milano
Dipartimento di Meccanica
Italy
francesco.rosa@polimi.it

Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 20th International Conference on Engineering Design (ICED15), Vol. nn: Title of Volume, Milan, Italy, 27.-30.07.2015

1 INTRODUCTION

To design a product-to-be optimized, Systematic Design relies on generating and examining the broadest range of solutions in a systematic and methodical way (Phal, 2007). This strategy has been defined as "breadth-first top-down, which means first finding the largest possible number of abstract solutions (breadth-first) and then more concrete ones (top-down)" (Motte, 2011), passing through several levels of detail depending on the adopted product model.

In recent years, this approach has been criticized by several researchers (Cardillo, 2011) (Langeveld, 2011), who pointed out that time and resources consumed during "trial and error" iterations has to be reduced to face the competitiveness challenge required by current globalized market. The commonly proposed improvement consists of moving some of the embodiment tasks to the conceptual design phase. Dr. Nevala enforced the conclusion that embodiment and detail design should be more integrated with other design steps in his thesis (Nevala 2005), by concluding, on the basis of a "thorough empirical investigation of a large scale industrial innovation process", that "The problems aroused only when the need for abstracting the descriptions of design engineering procedures was identified in the 1950s. When abstracting things or thoughts the true content elements fade away. They are replaced by schemes. […] The gap between high-level abstractions of design engineering procedures and real-life thinking can perhaps be filled by a bottom-top approach through research directed to the real contents of thinking." Dr. Nevala's avowal of the importance of the more concrete stages of the design process was also endorsed by Eder (Eder 2008) in the interpretation of the comments he made to Dr. Nevala doctoral Thesis. In particular, Eder stated that "according to Pahl (Pahl 2007) *der Teufel steckt im Detail* (the devil hides in the detail) not only in design engineering, but in all constructive and creative activity. Detail can ruin a good concept, but cannot rescue a poor concept. Conceptualizing, embodying and detailing are all necessary for producing optimal results in design engineering."

It is also worth noting that these considerations apply, even to a greater extent, to the redesign and the improvement of existing products, two of the usually predominant activities of the engineering and design divisions. In these tasks, in fact, both the embodiment and the detail stage turn out to be the fundamental steps, since the solution to practical problems consists in new embodiments and/or revisions of the detail design of the involved components.

A possible strategy to overcome all these shortcomings consists in software tools capable of anticipating some of the issues typically faced only in the embodiment stage. These tools may improve design process in two ways. First, they can ease discarding practically infeasible solutions even in the early stage of the process; secondly, these tools can shorten the design process of the more promising solutions by automatically addressing designers toward more appropriate solutions.

All these considerations put in evidence the needing of software tools capable to store, manage and retrieve the deep and detailed knowledge embedded in practical technical solutions as well as the related practical background; the first step in the deployment of these tools, hence consists in analysing broad sources of technical knowledge. The organization of the knowledge available in the industrial world to anticipate and/or support the embodiment and/or detail design phase is therefore the focus of the investigations presented in this paper.

Many scholars have faced this issue in the past, and several computer programs capable to store, manage and retrieve product documentation are commercially available. Product Data Management systems are maybe the more common practical implementations. Anyhow, these tools usually operate on functional basis (i.e. allowing searching for the constructive solutions that perform a given function) or on commercial basis (i.e. allowing searching for part code, generic name, supplier …). A search focused only the functional aspects may not allow finding out solutions categorized under a different main function. This is particularly true for very practical solutions, i.e. when a "simple" redesign of a sub-assembly may solve practical problems encountered during product utilization. Similarly, a search from a "commercial" point of view cannot lead to identify proper solutions. Practically, the organization of these systems is usually not meant to help designers in finding practical appropriate solutions, and commonly they do not contain all the necessary information, in particular the advantages and the disadvantages of a specific solution.

2 ARCHIVES IN DESIGN: A BRIEF STATE OF THE ART

Archives of technical solutions have been investigated since the first systematic design studies. For example, in the ‘80s, Beitz (Beitz,1981) proposed some ideas about archives of geometric structures, while Pahl (Pahl, 1982) and Koller (Koller, 1984) presented some simple collections of technical structures and solutions, besides some considerations about systematic design. In the following decades, with the evolution of design methods and of informatics tools, the necessity of archives of technical solutions to support designers becomes increasingly evident (Hubka, 1988) (Ullman, 2009). Systematic design and the related archives have been also coded in VDI German guidelines (VDI-Richtlinie, 1993), (VDI-Richtlinie, 1997), (VDI-Richtlinie, 1982), (VDI-Richtlinie, 2004).

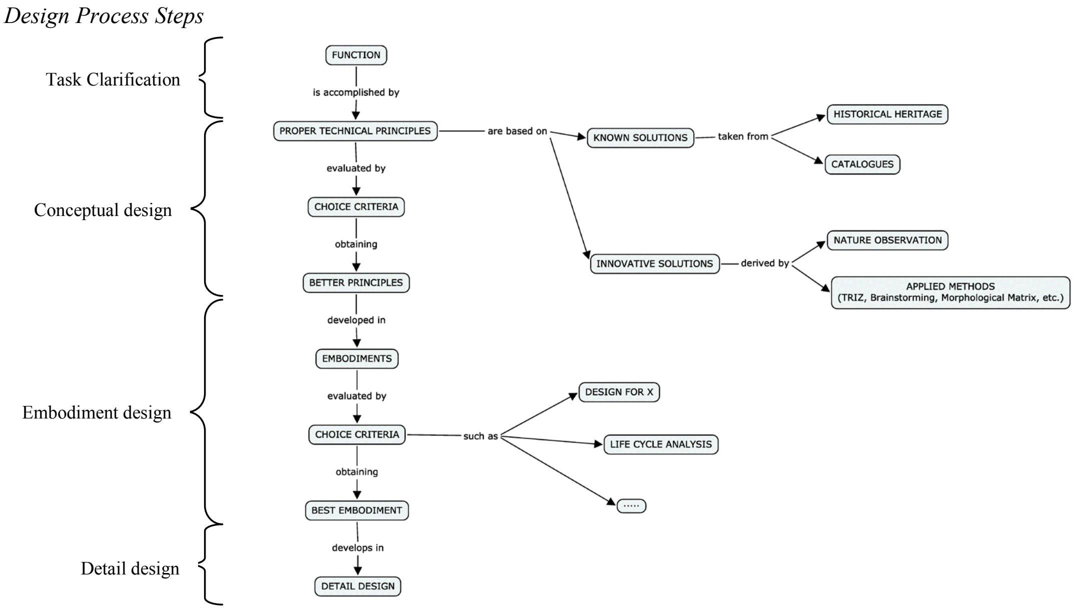

Figure 1. General schema of a design activity

3 APPROACH OVERVIEW

In order to better understand how the tool under development can be integrated within the usual design activities, let consider the general schema depicted in Figure 1. The design of a new product begins with its functional analysis, i.e. the identification of its main function as well as of all the required sub-functions. On the basis of these first analyses, the designer conceives a conceptual solution, i.e. a conceptual and abstract schema mainly based on a sequence of physical phenomena the scope of which is the main function. Finally, the designer has to embody and then to design in detail any part of the product.

Even if the great majority of the recent developments in design methods and tools are devoted to the first two and more abstract steps of the product development process, as shown above, the last two steps are the among the more common activities of a design office, and are also the more time and resource consuming steps. As previously discussed, designers have seldom to create completely new practical solutions; more often, they can get proficient and effective inspirations from past solutions, adapting and evolving them to solve new problems. These considerations apply not only to the design of a new product, but also to the very common re-design activity, where the past experience plays an important role in “suggesting” how to avoid “trouble”. It is furthermore worth noting that the search for adapt solutions may not be limited by functional considerations or within a specific industrial sector. A problem that is completely new in an industrial sector may have been faced and solved in other fields. On the other hand, “elementary” functions are commonly present in the embodiment of many function of higher level; hence limiting the search for the solution to a given functional family of products may automatically and involuntarily exclude a wide range of valid solutions. It clearly emerges from these considerations that a data-base of existing solutions is fundamental to retrieve the more adapt, promising and inspiring solutions.

In an ideal world, the wider this data-base is, the major probability to retrieve a “good” solution exists, and hence the goal would become the creation of a data base containing the experience of all the existing companies, which represents the technical “state of the art”. Nevertheless, this is obviously infeasible. More realistic is an archive based on the knowledge of a single company or of groups of companies. The experience of the company can be organized on a functional basis as a catalogue that contains all the solutions adopted by the company in the past. Besides its function, the record of each solution will contain the description of its behaviour and links to the drawings describing its structure, as well as a quantitative evaluation of such behaviour and structure with respect to a series of relevant characteristic. The tool will therefore suggest a selection of relevant solutions on the basis of the comparison between the sought solution and characteristics and the ones stored in the catalogue representative of the experience of the industry.

Examining Systematic Design Theories and related VDI standards (VDI-Richtlinie, 1993), (VDI-Richtlinie, 1997), (VDI-Richtlinie, 1982) (VDI-Richtlinie, 2004), it seems possible to draw the conclusion that the last and more concrete stages are the more difficult not only to systematize and integrate with other design steps, but also to address and help. In fact, they mainly rely on a knowledge that largely coincides with the experience of the designers and/or of the team. Detail design, in fact, is one of the stages where designers’ personal experience and judgment plays a fundamental role in driving the identification of the constructive solution that better fulfils the design requirements.

The explored way to partially overcome these difficulties consists in conceiving a “smart archive” capable to store and to make easily accessible the practical knowledge needed to design in detail the practical solutions, even in the first steps of the design process. Such an archive have to ease designers' task of designing and/or selecting the constructive solutions that are more adapt for specific requirements, in order to improve the efficiency as well as the efficacy of the whole design process.

Let now examine archive structure in more detail.

First, in order to ease its integration with the usual design procedures, instead of defining new types of catalogues, the archive under study will be based on the catalogues defined in the Systematic Design Theories, on which the above introduced design approach (Figure 1) is also based. According to VDI Standards and to Roth (Roth, 2000a), (Roth, 2000b), three distinct categories of catalogues exist:

- *Object* catalogues contain “objects” information fundamental to design, like physical phenomena, geometrical and material properties, technological data, standardized components, well known kinematic schema and mechanisms ...;
- *Operation* catalogues contain rules, sequences of steps and procedures used to design, define functional structures (i.e. define function and sub-function of a product), variants as well as procedures to select the better solution, or to evaluate part strength;
- *Solution* catalogues contain solutions organized on a functional basis. The stored solutions may even be simply represented by means of flow charts.

Operation Catalogues contains knowledge from textbooks, handbooks and scientific papers and can cover the great part of a designer needing from this point of view. Abstract concepts Objects Catalogues can be obtained from the same sources of the Operation Catalogues, while the practical elements of Object Catalogues are nowadays retrievable from on-line and/or digital catalogues of standardized parts (screw, gear wheel ...) and/or products (roller bearing, pump ...).

The major difficulties occur compiling *Solution Catalogues*. Even if Solutions Catalogues are explicitly defined and generally described, their detailed description is actually missing in the VDI standards, as well in the related literature. Anyhow, on the basis of their definition, it appears evident that these solutions can range from a simple gasket to a whole portion (sub-assembly) of a machine. The issue of storing simple and standardized solutions may be somehow faced and solved. On the other hand, a "brute-force" approach is obviously infeasible for the more complex sub-assemblies. It is therefore necessary to define a strategy to identify which solutions and which related piece of knowledge it is worth storing in Solution Catalogues. Anyhow, this task can be faced if the investigation field is limited to the applications that a specific designer really needs. In other words, this catalogue does not have to be considered as a part of a universal engineering design process, but as a support to the designers that need to find practical solutions to actual problems in his/her peculiar context. The practical infeasibility of such a universal catalogues begun to become evident in the mid of the 1970s, when Gerhard Pahl and Klaus Ehrienspiel realized that the rigid engineering design approaches (proposed by Roth, Koller, Hubka and Rodenacker's in the 1950s) did not spread among engineers (Delahousse, 2009).

In this narrower perspective, the Solution Catalogues do not need to contain any possible solution that may fulfil a given function, but only the practical solutions that are applicable in a given industrial field. More light can be shed on this perspective starting from the following passage of VDI 2221 about the step *Search for solution principle* in the third stage of the Systematic Design approach: "The aim is generally to utilize well-tried and commercially available solutions, particularly for the realization of auxiliary functions. Individual steps associated with this stage are not applicable for such solutions. In the case of our present example, commercial solutions which are available include electric motors, bearings, gaskets and control elements".

It is therefore possible to extend the field of applicability of this procedure and, at the same time, the source of examples to build the Solutions Catalogues. In the Embodiment and Detail Design stages, the Solution Catalogue main contribution seems to consist in retrieving standardized components. Actually, their usability can be broadly expanded. Companies, in fact, usually design and manufacture families of the same product that can differ in terms of performances, automation, accessories... Usually, in developing all these variants, the design division create several solutions for each sub-function, each conceived to satisfy one or more specific requirements (cost reduction, usability, robustness, lightness...). Each of these solutions can therefore be stored in a Solution Catalogue, besides basic and standardized components. The sources of solutions can be further expanded by including the solutions not specifically developed to accomplish the given function, as suggested by K.-H. Roth (Roth, 2000b), who suggested to include also solutions from other industrial sectors can be used to populate the Solution Catalogue, provided that these solutions are based, at least, on the same effect or procedure. It is also worth noting that VDI standards suggest beginning retrieving data from Solution Catalogues before the stage in which "the concept [...] is structured into the assemblies and parts which determine the embodiment". This implies that the search for adequate solutions has to be based on product general requirements; hence, the catalogues under development shall contain also preliminary evaluations of each solution according to a pre-determined list of general requirements. Besides typical requirements, since the catalogue under development may be also used to re-design a portion of an existing machine, connections requirements have also to be described.

On the basis of these considerations and of the discussion in (Rosa, 2015), at a glance, this "smart archive" has, at least, to contain the following information:

- The accomplished **functions**/tasks. This classification can be standardized by means of a standard functional basis. Even if function definition and representation are still evolving (Fantoni, 2009) (Carrara, 2011), since our investigations are focused on the embodiment step, the "classical" function representation compatible with the "traditional" Hirtz's (Hirtz, 2002) will be adopted.
- **General characteristics** that almost all the solution may satisfy (cost reduction, robustness, lightness...), that is the characteristics shared by many of the solutions. This list may therefore be compiled "once and for all", maybe not in a universal sense, but it can be shared by all the solutions stored in a specific company, since it can be assumed that the relevant general aspects in a peculiar industrial sector do not change rapidly and continuously.
- **Peculiar characteristics** that a peculiar family of solutions satisfies. This list may not be compiled "once and for all", since it should put in evidence the peculiarities of the solution, for example the possibility of mounting it in a particular way, or of sealing it and to avoid periodic re-lubrication…
- **Generalities, notes, tricks and tips derived from previous experiences**. This field is obviously not universal, since it should contain any peculiarity that occurred not only during the design process, but also during the operating life of the sub-assembly. PLM systems can greatly help in managing this information.
- **Parts list, connections and drawings**. This information are the more likely to be automatically retrieved, since PDM systems should already know pieces of it and tools for the automated analysis of CAD assemblies are under development (Viganò, 2012).

It is finally worth underlying that this archive can include more information than the Catalogues proposed by Roth and the data management systems usually implemented in PDM and CIP systems. In particular, users can store in this archive the practical reasons why a solution has been adopted, its advantages and disadvantages as well as its practical pre-requisites (see examples) and mounting peculiarities.

4 PRACTICAL APPLICATION

In order to better and practically illustrate the “smart archive” conceptually developed in the previous Section, let consider the solutions to the problem “how to mount a bevel pinion” as a case study.

4.1 Generalities

Besides holding pinion in the correct position and reacting meshing forces, as in any other type of gears, bevel gear sets need also to be adjusted to each other so that they run smoothly and keep the correct amount of tooth clearance (backlash) in any operating conditions. For cylindrical gears, the best orientation requires only to pay attention to centre distance and to shaft alignment. This is not true for bevel gears, the mounting arrangement of which usually allows for a wider variation of positions. Each of these degrees of freedom has to be accurately adjusted, since all types of bevel gears have an optimum position for best performance. Manufacturers determine this optimal position by means of tests on each gear set. The gearbox and assembly designer have therefore the responsibility for allowing reaching this optimal positioning in the gearbox by means of shims and/or adjustable axial constraints. Furthermore, and obviously, the possibility of these adjustments has to be granted by allowing and, possibly, easing gear set mounting and assembling (Wasilewski, 1994). According to AGMA 2005-D03 (2005), as well as to Wasilewski (1994) and many others, bevel gear sets mountings can be grouped in two distinct main categories: straddle and overhung. The straddle mounting of a bevel gearbox is preferred since it greatly reduces misalignments and relative displacements between gear and pinion due to meshing loads. If a straddle arrangement is not practically feasible for both members, the member that have to bear the higher radial load should be straddle mounted. The usual reason for adopting this solution usually consists in gear box space limitations. Generally, bevel gear mountings should have an adequate rigidity. Only overhung mounting examples are hereafter considered.

4.2 Actual case studies

In the next three subsections, three practical examples of bevel pinions overhung mounted are presented and briefly illustrated. The selection of these examples from (FAG, 2012) simulates the knowledge elicitation procedure, required to collect all the knowledge related to a practical solution developed in the past by the company. It is also important to note that these solutions has been taken from three different industrial fields, in order to make even more evident one of the ideas on which the presented approach rely: often, the practical solutions are not limited to a specific field, but are shared among in a wide range of sectors.

4.2.1 Example No. 1 - Figure 2: Bevel gear – spur gear transmission (FAG, 2012)

Spacer A between the cups adjusts the tapered cone bearing pair to achieve an adequate axial clearance prior to mounting. The floating bearing (cylindrical roller bearing) has a tight fit on the shaft and a slide fit in the housing. Axial pinion adjustment is achieved by grinding the spacers B and C to suit able width. For axial adjustment and adjustment of the axial clearance of the gear the spacers D and E are ground to suitable width.

4.2.2 Example No. 2 - Figure 3: Final drive of a passenger car (FIAT 1500) (FAG, 2012)

The pinion is accurately positioned with respect to the crown wheel by means of shims inserted between housing shoulder and bearing cup. The cones are circumferentially loaded, but only the cone of the larger bearing can be press-fitted. The cone of the smaller bearing is slide-fitted because the bearings are adjusted through this ring. Crown wheel and differential are mounted on the same shaft. Both bearing and gear mesh adjustment are achieved by means of shims. To allow the pinion to be adjusted to a certain torque and to avoid expensive fitting work (for instance machining of a solid spacer), a thin walled preformed sleeve is provided between the bearing cones. The sleeve is somewhat longer than the maximum distance between the two bearing cones. Depending on the width tolerance values of the bearings there will be some elastic deformation of the sleeve (a few microns at most).

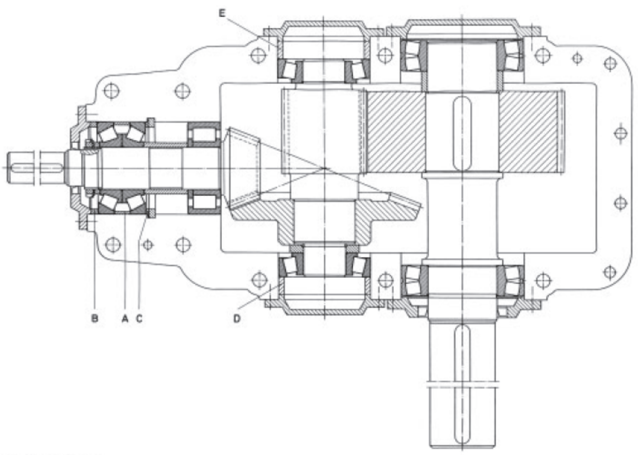

Figure 2. Bevel gear – spur gear transmission (FAG, 2012)

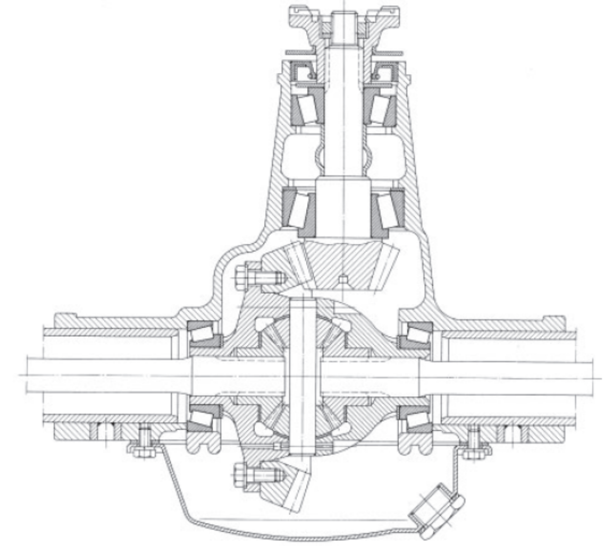

Figure 3. Final drive of a passenger car (FIAT 1500) (FAG, 2012)

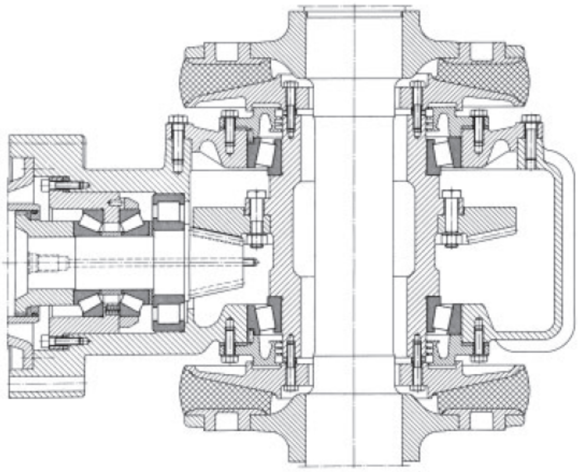

Figure 4. Bevel gear transmission for city trains (FAG, 2012)

4.2.3 Example No. 3 - Figure 4: Bevel gear transmission for city trains (FAG, 2012)

With a so-called two-axled longitudinal drive in under-ground and metropolitan vehicles, the traction motor (usually direct current motor) is arranged in the bogie in the direction of travel. A bevel gear transmission is flanged onto both sides of the motor's face. The drive unit firmly attached to the bogie frame is elastically supported by the wheel sets. The drive power is transmitted from the pinion shaft to the hollow ring gear shaft and then via rubber couplings to the driving wheel shaft. This drive design leads to good running behaviour and moderate stressing for the traction motor, transmission and track super structure.

Pinion shaft. A single row cylindrical roller bearing is mounted as a floating bearing at the pinion end. It accommodates the high radial loads. The machined cage of the bearing is guided at the outer ring. Two tapered roller bearings are used as locating bearings. They are mounted in pairs in O arrangement. The bearing at the motor end accommodates the radial loads as well as the axial loads from the gearing; the other tapered roller bearing only accommodates the axial loads arising during a change in direction of rotation. A minimum bearing load is a requirement in order to avoid harmful sliding motion (slippage) and premature wear. The cups of the tapered roller bearings are therefore preloaded with springs.

Ring gear shaft. There is a tapered roller bearing at each side of the ring gear. Both bearings are adjusted in X arrangement.

4.3 Case studies analysis

Besides the descriptions of the details of each practical solution, it is worth noting that these three solutions have been conceived on the basis of three different mounting strategies.

In Solution No. 1, the gearbox case is opened on a plane containing all the axes of the gears, hence each shaft with all the rotating components can be laid down into an half seat. Furthermore, bearings, spacers, sleeve and locking nuts can be easily mounted on the bevel pinion shaft, adjusting its axial position before closing the system with spacer B and cover. Similar considerations apply to bevel gear mounting. On the other hand, if the gearbox case cannot be separated along the gear axes plane, one of the other two solutions can be adopted. Solution No. 2 is adapt for situations were pinion seat is in one piece, but can be accessed by both sides: smaller bearing, seals and cover are inserted from the upper side, while before mounting gear and differential, bigger bearing and pinion are inserted from lower side. Finally, Solution No. 3 is adopted if components can be introduced from one side only (lower one): first pinion with cylindrical roller bearing is introduced till bearing external ring is in contact with the shoulder on the case; then sub-assembly with the other bearings can be introduced and fixed to the case by means of screws.

It is also worth noting that in all this cases but the first, the bearing immediately behind the pinion is “bigger”, since it has to accommodate an higher radial load (because of the shorter arm), regarding less the fact it has or not to accommodate an axial load (see also AGMA recommendations). This consideration has a strong influence on the design and on the previously summarized mounting procedures.

4.4 Archive construction

After having elicited the relevant knowledge embedded in the selected case studies, it is possible to compile the previously identified records. Table 1 shows the result of this operation. The knowledge retrieved and discussed in the previous sections is summarized and somehow condensed in the fields of this table. It is worth noting that only the more peculiar data about each solution have been directly stored in the records, while links have been used to link the more general information that apply also to the specific case, in order to avoid replicating the same data. In this example, one of the possible practical utilisations of this kind of archive emerges in the “Peculiar characteristics” section, which allows a direct comparison among existing solutions, helping designers to the more promising solutions, taking into account their limits and requirements, even form a very practical point of view, like the constraints due to the mounting procedures.

It is also worth noting that simple unlabelled text boxes have been adopted instead of strict and high-level data structure. Two are the main reasons behind this decision: this archive has to have a very limited impact on the usual design procedures, and its compilation has to be quick and to require few resources. More prosaically, in author’s opinion, the less time and effort is required to the designer, the higher is the probability that designers will systematically compile it with care, and that the management of the design office will accept it. In other words, in a consolidated design process the introduction of new and complex systems aimed at solving the issues highlighted in the Introduction may have the same fate of the strict design procedures proposed in the 1950s. Using this simple data structure instead of highly abstracted models coded in complex data structure and based on deep interview, designers and users can more easily fill in their personal experience and knowledge. The drawback of this data structure is that the search within this kind of archive has to rely on a free-text search.

Table 1. Data base records of the case studies

		Sol. No. 1	Sol. No. 2	Sol. No. 3
Function (Hirtz, 2002)		Transmit Torque	Transmit Torque	Transmit Torque
		Stabilize Solid	Stabilize Solid	Stabilize Solid
General characteristics				
Peculiar characteristics	Mounting type	Overhung	Overhung	Overhung
	Mounting directions	Axial from inside Axial from outside Radial	Axial from inside Axial from outside	Axial from outside
	Mounting hints	ANSI/AGMA 2005 Wasilewski, 1994 PDM Product documents	ANSI/AGMA 2005 Wasilewski, 1994 PDM Product documents	ANSI/AGMA 2005 Wasilewski, 1994 PDM Product documents
	Mounting requirements	Gearbox case opened on a plane containing all the axes of the gears	Pinion seat is in one piece, but can be accessed by both sides	Pinion seat is in one piece, and can be accessed by one side only
	Assembly problem solved	Limited space on one side of the pinion	Limited space on one side of the pinion	Limited space on one side of the pinion
	Axial Positioning	Achieved by grinding spacers	Achieved by means of shims. To adjust pinion to a certain torque, a thin walled preformed sleeve is mounted between bearing cones	Achieved by means of shims inserted between the cartridge holding the pinion and the housing
	Stiffness	High	High	High
Notes	Generalities	Section 4.2	Section 4.2	Section 4.2
	Peculiarities	Section 4.2.1	Section 4.2.2	Section 4.2.3
Part list, Drawings	PDM	Figure 2	• Figure 3	Figure 4

5 DISCUSSION

This paper presents and discuss the so-called "smart archives". This archive relies on the Systematic Design theories, methods and tools and have been specifically conceived to ease designers' activities in the final steps of the design process, i.e. embodiment and detail design. At a glance, they can be briefly described as a tailored amalgamation of *Solution* and *Operation* catalogues described by Roth, widened to contain pieces of knowledge usually needed in Embodiment and Detail Design. Practically these deep roots in Systematic Design ease its introduction within existing common design practice.

In Embodiment and Detail Design steps, in fact, designers usually search for adequate practical solution to embody the conceptual solutions previously conceived, mainly relying on their personal experience; the range of solutions is therefore somehow limited and strongly influenced by their psychological inertia. A search based also on practical aspects and requirements may individuate alternative solutions, as well as some hints to designers who have to re-design a sub-assembly of a generic machine, providing uncommon practical solutions that overcome or even avoid the problem that led to the re-design needing. By means of this archive, an improvement of the efficiency of the Systematic Design approach can be also expected: not only the number of trial and error cycles is likely to be reduced, but also some practical data can be anticipated in the earlier design stages, easing the early individuation of the practically infeasible conceptual solutions.

6 CONCLUSIONS AND FUTURE DEVELOPMENTS

In this paper the basic structure of a "smart archive" have been presented and discussed and finally applied to a practical case study. This archive relies on the Systematic Design theories and has been specifically conceived to ease designers' activities in the final steps of the design process, i.e. embodiment and detail design. Next steps consist in a more precise definition of the information archival system, as well as of the search engine to retrieve the relevant data, in order to realize an experimental validation of the whole procedure. Another possible evolution of this archive may consist in the introduction of a text-mining tool capable to automatically extract and structure the knowledge embedded in the free text entered by users, a strategy proposed in other research fields with similar problems (Vandevenne, 2015). Such a tool may operate in background and be completely transparent for the user, whose data-entry activity has to be as easy and natural as possible.

REFERENCES

ANSI/AGMA 2005-D03, Design Manual for Bevel Gears, 2003, ISBN: 1-55589-818-1

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

Cardillo, A., Cascini, G., Frillici, F., Rotini, F., (2011), Computer-aided embodiment design through the hybridization of mono-objective optimizations for efficient innovation process. Computers in Industry, 62(4):384-397

Carrara, M., Borgo S., Garbacz, P., Vermaas, P., (2011) A Formalization of Functions as Operations on Flows. Journal of Computing and Information Science in Engineering 11: 031007 (DOI:10.1115/1.3615523).

Delahousse, B., Meganck, M.:Engineering inContext. Authors and Academica, Aarhus, Denmark (2009). ISBN 978-87-7675-700-7

Eder,W., E., Cognitive and systematic design. MM Science Journal, June 2008, 9–12

FAG, (2012), The Design of Rolling Bearing Mountings - Design Examples covering Machines, Vehicles and Equipment, Publ. No. WL 00 200/6 EA, June, Kraus, Germany

Fantoni, G., Apreda, R., Bonaccorsi, A., (2009), A theory of the constituent elements of functions, International Conference on Engineering Design - Stanford University, ICED 2009, ISBN: 9781904670063

Koller, R. (1984), Entwicklung einer Systematik fuer Verbindung – ein Beitrag zur Konstruktionsmetodik. Konstruktion, 36.

Langeveld, L., (2011), Product Design with Embodiment Design as a New Perspective, Industrial Design - New Frontiers, Prof. Denis Coelho (Ed.), ISBN: 978-953-307-622-5, InTech

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, February 2002

Hubka, V., Eder, E., (1988), "Theory of technical systems." Springer.

Nevala, K.: Content-based Design Engineering Thinking - In the Search for Approach. Doctoral thesis, University of Jyväskalä, Finland, Jyväskalä: University Printing House (2005)

Pahl, G., Beitz, W., Feldhusen, J., Grote, K. H., (2007). "Engineering design – A systematic approach." Third Edition, Springer, Cambridge and Berlin

Prasad, Biren, (1996), Concurrent engineering fundamentals. 1: Integrated product and process organization, Upper Saddle River: Prentice Hall, ISBN:01-314-7463-4

Prasad, Biren, (1997), Concurrent engineering fundamentals. 2: Integrated product development, Upper Saddle River: Prentice Hall, ISBN:01-339-6946-0

Suh, N., (1990), "Principles of design." Oxford Series on Advanced Manufacturing.

Motte, D., Bjärnemo, R., Yannou, B., (2011), "On the interaction between the engineering design and the development process models — part I: elaborations on the generally accepted process models", Research into Design — Supporting Sustainable Product Development. Edited by Amaresh Chakrabarti, Published by Research Publishing, ISBN: 978-981-08-7721-7

Rosa, F., Viganò, R., Rovida, E., Embodiment for requirements, International Journal on Interactive Design and Manufacturing, Submitted.

Roth, K., Konstruieren mit Konstruktionskatalogen. Band I - Konstruktionslehre. Springer, Berlin, 2000.

Roth, K., Konstruieren mit Konstruktionskatalogen. Band II - Konstruktionskataloge. Springer, Berlin, 2000.

Ullman, D., (2009), "The mechanical design process." Mc-Graw Hill.Pahl, G., (1982), "Foerderung der Kreativitaet in Grundlagenfach Maschinenelemente durch methodisches Konstruieren." Konstruktion, 34.

Vandevenne, D., Verhaegen, P. A., Dewulf, S., & Duflou, J. R. (2015). A scalable approach for ideation in biologically inspired design. Artificial Intelligence for Engineering Design, Analysis and Manufacturing, 29(01), 19-31. doi: 10.1017/S0890060414000122

VDI-Richtlinie, VDI 2221. Produkte, Methodik zum Entwickeln und Konstruieren technischer Systeme und Produkt, 1993.

VDI-Richtlinie, VDI 2222 Blatt 1. Konstruktionsmethodik - Methodisches Entwickeln von Lösungsprinzipien, 1997.

VDI-Richtlinie, VDI 2222 Blatt 2. Konstruktionsmethodik; Erstellung und Anwendung von Konstruktionskatalogen, 1982.

VDI-Richtlinie, VDI 2223. Methodisches Entwerfen technischer Produkte, 2004.

Wasilewski, R. F., How to install bevel gears for peak performance - Power Transmission Design, Gear Technology, March, 1994