Structuring knowledge use in Inventive Design

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Abstract. Computer Aided Innovation (CAI) has emerged for a few years as a scientific field offering a framework for contributions aiming at providing assistance to designers and industries in the problematic brought by innovation's organization. In the context of R&D activities' management when in Inventive Design context, it is nowadays acknowledged that a significant attention needs to be given to problem formulation of a studied system associated to a specific domain. It is also commonly agreed that the use of domain knowledge and in particular their synthesis, is essential to the understanding and the elicitation of problems in a given field of industrial actors/competitors. Through this article, we are aiming at communicating on the results of a research activity led within an industrial context, where it was required to build an appropriate use of domain knowledge to ease the comprehension of key domain problems and assist decision making for R&D deciders.

1 Introduction

1.1 Opposition between an « optimizing » mode and an « inventive » mode of design

The paradigm in which our contribution resides concerns invention. Our reflections take place with the organization of innovation and propose a reflection towards the fact that an efficient inventive activity will positively influence the overall result of innovation within an organization. To introduce our contribution we

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would like to start by stating on the major differences which separate innovation's paradigm from optimization one.

The orientation which engineering design undertakes since a few decades is turned towards optimization [1]. It tends to obtain the best possible result on the basis of a whole set of known elements. The example can be taken to optimize thickness of a part's walls respectfully to laws of mechanics, the best possible choice of a material constitutive of a mechanism. In the case, for example, of a design of a mechanism answering a precise set of requirements, Optimization Design (OD) will then employ a procedure based on the most efficient way, taking into consideration all elements at disposal of designers (from their respective knowledge) or resulting from their research findings (state of the art, surveys). This type of process is largely inspired by the reflex of compromise when choices in opposition are posed to designers (the body of a mechanism having to be both thick to be resistant mechanically and thin to be light). The criteria involved here are primarily mechanical laws, the use of a potential specific material in the design of the body and the restrictive specific conditions imposed by the situation of the object's life (space roominess, safety, norms to be respected,).

A contrario, Inventive Design (ID) identifies situations of opposed features as being sources of key-problems to be solved by the refusal of a compromise [2]. The compromise is here characterized as the acceptance to reduce ambitions of one of the dimensions of design orientation (to design a rigid body) for the limited benefit of the other (to design a body "not too heavy"). The objective of ID is thus to refuse compromise while formulating an inventive challenge and to assume the fact that the fruit of the act of design leads to "both" a resistant and light body. Let us add that elements of knowledge being able to become actor of the resolution are probably unknown to the designer or not highlighted by the sequencing of events in the design process. It is essential thus that an ID process assumes its two major difficulties: to assist the formulation of the whole set of problems raised by the act of design of an evolving object and to assist the revealing of non-existent elements of knowledge at the origin of the design process, allowing to refuse compromise and to solve the problem. In our example, physics of the soap bubble and in particular the study of the phenomena of tensile surface stress has opened a field of research (the concept of foam) as potentially a way to solve inventively the opposition between mechanical resistance and mass [3].

To finish on this subject, there are different postulates between OD and ID, the first remains the most legitimate reflex under the paradigm of quality (to improve the concept of value, to reduce costs, to ever assume new functionalities) whereas the second is proven to be useful under the paradigm of invention (to create the new, what does not exist yet). We can even go further in postulating that ID seems an unavoidable way as soon as OD shows an exhausted space of potential improvement when the best possible compromise is found and maintained [4].

In short, OD presupposes a problem well posed and documented, adapted to certain contexts, while ID is more adapted to situations where the problem is badly formulated, where a certain amount of interpretation are to be made and in a context where the willingness to innovate is strong. K Dorst in [4] is presenting a typology of design problems where the distinction between two types of problems is fundamental: those which presuppose the existence of a structure of the problem "objectified" existing a priori and the others who partially sees design rather as a co-evolution where the process consists in developing and simultaneously refining formulation and the ideas for synthesizing a solution.

This way of considering the situation has of course consequences on the way knowledge is gathered in ID.

1.2 Problem formulation in design

It is generally mentioned in contributions brought to the design science that problem formulation remains a disciplinary field poorly exploited by scientists [5]. Mc Guire goes even further advancing that one of the reasons is that researchers in design have concentrated their efforts on the phases of exploration, selection, implementation and evaluation. The paradox is that these same scientists do recognize the crucial aspect of problems formulation in a process of design. Even beyond scientists, it is of notoriety that a well formulated problem is half solved.

Whatever is the path adopted in design, the phase dedicated to problem formulation has a multidisciplinary character where social, economic and engineering (all disciplines potentially concerned) interfere with each others. The goal of this phase is to reveal problems in order to engage a resolution process in the appropriate direction. Some researchers, as Meijers, are even advancing that all possible spaces where the problems are situated and appears to the designers should be entirely specified [6].

Among contributions on this subject, let us note that Restrepo and Christiaans stressed the importance of the problems of designer's knowledge accumulation while postulating that the primary representations (often built upon a small quantity of data) attribute the degree of clearness of the problem in its future [7]. Lloyd and Scott even advanced that personal experiences observed as prerequisite are a determinant variable sometimes placing the designer under either the paradigm of problem or solution [8].

Goel and Pirolli recall that most of research in problem solving was carried out, for practical reasons, on the basis of well structured tasks, semantically simple with clearly defined objectives. What makes axiomatization easy but differs from lived realities of designers in industry [9]. Last, Darke explains why in formulation, designers are exposed to interpretations when disclosing problems [10]. They unconsciously associate to the initial problematic images of possible solutions elaborated on the basis of their respective knowledge, making this process directly dependant on the designer's acquired know-how.

1.3 Structuring knowledge's in a « problem-oriented » model

Our objectives to contribute to Computer Aided Innovation (CAI) can be summarized as follows: The suggested model contributing to innovation activities management rely on the assumption that inventive activities must evolve towards the resolution of revealed "inventive challenges".

This is why we start from a set of notions posed *a priori* which have the role to drive knowledge acquisition process so as to facilitate innovation: the main concept advocates that a design problem must be associated to a contradiction oriented formalism which will be further detailed. In sort, a problem is a contradiction (as it is stated in [11]). A contradiction describes the problem precisely at its axiomatic level. A contradiction is representative of a clearly expressed inventive challenge to be solved for the concerned system. Then, the undertaken direction to assume inventiveness is to solve it without compromise. In priority, the whole set of contradictions useful for problems definition of the studied domain needs to be disclosed and the links between these contradictions established. The concept of contradiction is axiomatically described by E-N-V formalism (Element Name of the feature-Value) brought from OTSM-TRIZ[1] [12] so as influences parameters have between them: the modification of a value of a parameter in a given direction induces the modification of another. These components are to be extracted, completed and validate by the concerned domain experts so as by other actors of the project.

In the model suggested through this article, we start from the principle that the methodology employed must propose a problem representation formalism, formally defined in order to offer to designers a simple and shareable model (easy to manipulate by a computer). The attributes towards which we intend to move for this formulation phase are:

- Speed: the speed to which knowledge of the experts fields passes from tacit, to explicit then formalized stage;
- Universality: the capacity of the formalism to be accepted at various departments, services, persons of the company;
- Representativeness: the capacity of the model to give project actors a clear and reliable representation of the whole set of problems within the scope of the study.
- Dynamicity: the easiness of the model to be permanently updated.

2 Ontology building

2.1 Two fundamentals brought from TRIZ

For a few years TRIZ is observed and appreciated as a set of theoretical and methodological elements assisting the creative phases of the product/systems design process. Regarding this statement we would like to underline that current uses of elements of this theory of inventive problem solving associated with technical systems evolution, are only partial. Our approach borrowed from TRIZ two of its fundamental axioms:

The contradiction axiom: Proposes a dual formalism of problem’s expression. The interest we observe here is that contradiction breaks up in a pragmatic way the attributes, often confused in a problem statement. Its duality underlines and brings forward the opposite character between desirable but contradictory directions. Contradiction consequently becomes a simple and effective mode of expression problems, stakes and unsolved inventive challenges.

[1] OTSM TRIZ stands as the Russian acronym of General Theory of Powerful Thinking, as it is expressed in [16]

The axiom of laws of technical system's evolution [13]: It advances, in the same current of thought as Simondon [14], Deforges [15] and others that Technical Systems (TS) follow generic tendencies throughout their existence. These laws, at the grounding of TRIZ, were extracted consecutively to the analysis of thousands of systems. With at each step of their evolution, key patents protecting solutions resulting from problems having been solved an inventive way. These patents, analyzed by the founders of TRIZ, revealed similarities in the fact that at certain stages of the evolution of a TS, there are invariants generic and common to all TS. In our approach, laws become a mean of assistance to study orientations since there is a high probability that a technical system is invariably aiming at being in accordance with these laws in its intrinsic evolution.

The process of knowledge acquisition and manipulation will then be based on these two concepts to help reformulation of the initial problem statement through a net of problems as specified in [16], each one attached to a set of contradictions. The laws of TS evolutions are used to select among a large quantity of evoked parameters in the exchanges with domain experts which ones appears as a barrier to a logical evolution of the artefact and form important contradictions among which it will be necessary to select those needing to be solved. ID already possesses, through classical TRIZ Body of knowledge, methods and tools to solve a single contradiction.

2.2 Concepts Ontology brought to TRIZ

Knowledge acquisition will lead to the creation of a shared model and the model concept must then be clearly defined. The gathering of knowledge is carried out without a precise ordering, a parameter will appear perhaps initially without belonging to a contradiction, a contradiction will perhaps appear without mentioning its dependence to a problem etc… We currently develop a software prototype dedicated to knowledge acquisition, it fulfils for now only the function of memo pad (it does not yet allows reasoning on acquired knowledge). To elaborate this software, it was necessary to clearly define the concepts implemented and the relations that they present, it consists in providing assistance to the detection of possible inconsistencies and eventual missing items. To clarify relations between TRIZ associated concepts is a need; the elaborated model must be sharable, targeting a semantic integration of all useful sources of information. These information's might be extracted either from the speech of an expert (interviews, working sessions…) or captured in texts (patents, list of requirements, norms).

The starting point of our contribution consists in giving a representation of the used concepts borrowed to TRIZ for the development of the ontology in question. This ontology has been built for the moment with PROTÉGÉ. Here, our choice is to describe it using UML formalism, for readability reasons. Figure 1 gives a partial UML representation of this ontology.

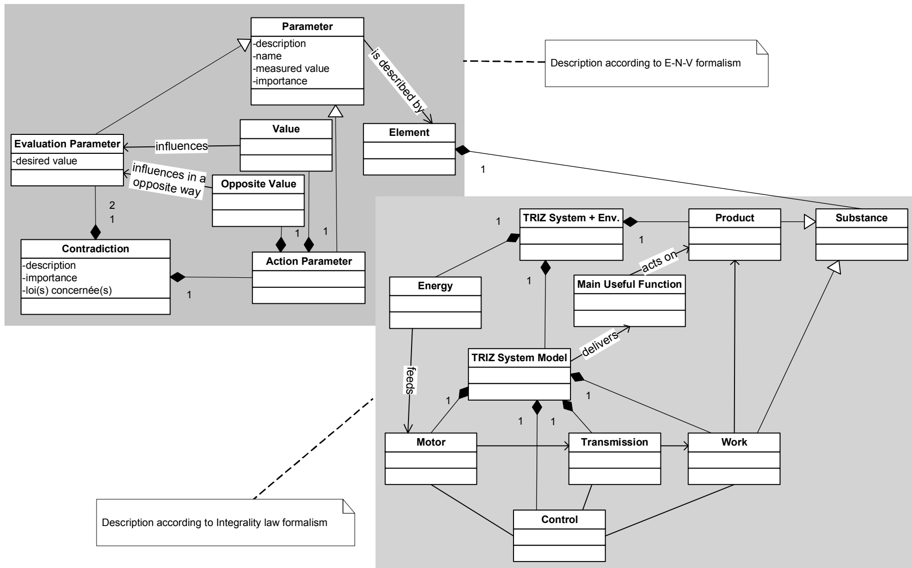

Fig. 1. Partial ontology of TRIZ concepts used in our approach

During knowledge acquisition, the entering point towards contradictions is a systemic model used by TRIZ. It has the aim of provoking discussion between participants of the design project and to invite them to objectively specify a certain amount of concepts. This prerequisite can at first appear useless since a company obviously knows what they are manufacturing, but it often appears that domain experts of the same company are carrying different perceptions concerning the same object. This will invariably lead to description difficulties. Our analysis for the description of a technical system can be observed like the notion of artefact (what man built entirely or partially) this artefact being associated to a **Main Useful Function** (MUF) which justifies its existence. This artefact can be considered as a **System** and thus its MUF acts on an **object** which is identified as the receptor receiving the MUF. The decomposition must then be done in coherence with Altshuller's law of completeness by identifying the key components co-producing this MUF. These components are four (**Engine**, **Transmission**, **Work and Control**). The engine is powered by an **energy** coming from outside.

Contradiction formalism is an association of three different types of components: elements, parameters and values.

Elements are components of a system. If one analyses sentences where they are mentioned, elements are generally subjects, or simply names or nominal groups or complements of object (for example: the hammer hits the nail; E=hammer). The nature of elements can constantly switch between different systemic levels depending on the description attributed to it. Thus the hammer hits the nail can become, the <anvil> inserts the nail under the point of view of another expert. In this second case, E=anvil. For a third one <man> inserts the nail, etc…. It is important, when identical situations are described with divergent viewpoints, to organize a consensus by forcing the reformulation (for instance within the meaning of physics) using the systemic decomposition stated beforehand. The principal interest of the systemic model is thus to unify viewpoints and at the same time formulations of the concerned elements while building a model composed of physical objects in their respective roles.

- Parameters qualify elements while allocating them a specificity which, associated to elements, represent an explicit knowledge of the field observed. The forms of their expression are multiple; they are mainly names, complements of objects or adverbs. They are divided in two categories:
  - Action Parameters: they represent parameters on which the designer has a capacity of state modifications (the designer can make a design choice, an anvil of large volume or a small one, in this case volume = AP).
  - Evaluation Parameters: Their nature lies in the capacity to evaluate the positive aspect resulting from a choice of the designer. The consequence to design an anvil with an important mass is that an ease of insertion is a logical consequence; (in this case Ease of driving = EP).
- Values are mainly adjectives employed to qualify a parameter (the volume of the anvil must be important; in this case Important = Va). Let us note that the fundamental aspect of the concept of contradiction lies in the opposition of the values and the fact that if V, in a specific state, involves positive aspects, then to lead to a contradiction, it is essential to investigate the opposite of V ($V\bar{a}$) generally forgotten in the description, to highlight it and to validate that the contradictory aspects of the analysis are true. Thus, an anvil of large volume involves an ease of insertion and a small volume of anvil involves an ease of handling (in this case Va = important and $V\bar{a}$ = small).

Finally, a last stage to highlight the concept of contradiction is to check the reversibility of the assertions. Will an important mass of anvil invariably involve a bad ease of handling? Will a low mass invariably involve a bad ease of insertion? If the answer is yes in both cases, the contradiction can be validated and stored, becoming a partial representation of the knowledge associated to the description of the problems involved in the evolution of the hammer.

The use we make out of ENV formalism will consist in extracting, according to its frame, the whole set of knowledge held by available experts and contained in various available documents of the studied domain.

2.3 Aims and usages of the ontology

The direction we intend to give to our work through this article, in particular concerning the use of the ontology’s results, can be summarized in 3 points:

One of the original goals of an ontology is to clarify the concepts of a domain of knowledge. In our case, TRIZ has almost never been subjected to an ontological description except in [17]. This statement can easily be perceived when observing the divergences of viewpoint concerning its contents and goals. However, the uses which we intend to build, resulting from TRIZ, require establishing one.

Thereafter, we intend to contribute to the efficiency of inventive design processes by fast and reliable gathering of ENV elements of given knowledge domain. This efficiency could be reached only if formalized elements allowing computerization and measurement are established.

Finally the formalism employed must be pursued until it reaches exhaustively in problem's perception for an R&D decision maker. We further plan to be respectful to this ontology for data manipulation and to give them exploitable forms within the meaning of Inventive Design's efficiency.
The realization of a software prototype uses this ontology and takes part in the construction of the implied models; it guarantees certain coherence and makes it possible to point out on imprecise situations (incomplete contradictions etc). The software, based on internal representation of knowledge, allows visualization of missing or badly structured elements and assists the construction of a model commonly built and shared. The construction proceeds by iteration, reformulation, gathering of new parameters, etc. Only when everything appears stabilized and contradictions considered as fundamental are extracted, we possess a modelized domain which reflects realities and is now ready to be analysed for engaging Inventive Problem Solving Activities.

3 Case example

3.1 Situation's description

Due to paper's length limitation, this section will be limited to discuss about the results of our gathering stage. The presented case is treating the overall problematic of lowering energy to release a Door Latch System. The concept of Low Energy Release (LRE) is an actual concern in automotive industry, mostly in supplier's R&D where permanently innovative solutions must be proposed to car constructors. In appendix 1, is proposed a schematic illustration of the overall contradictions gathered questioning domain experts during 3 sessions of half a day. In total, 58 contradictions have been gathered and organized so as to illustrate which challenge are to be addressed within this domain.
For instance a contradiction is read the following way:
TC12.2 [AP12]"Distance" between [E]"claw axis and pawl engagement radius" should be both [Va]"small" for lowering [EP16]"walkout risks" and [Vā]"large" for maximizing [EP23]"crash retention capacity".
Such expressed problematic is still unsolved and as a decision for engaging R&D Inventive Activities would disserve to be considered. To add pertinence for decision purposes, contradictions have been weighted and priorized according to company's strategy.

3.2 Case analysis and partial conclusions

The methodology developed in [18] demonstrates that in a set of contradictions covering a knowledge domain, it is crucial for an R&D decision maker to have a clear vision of the targeted objectives when launching an inventive solving activity. Among others, at the level of engineers, it has been observed that the benefit of such a representation adds traceability to the generated concepts, therefore providing them a structured approach (arguments) when defending their concepts in front of company's deciders. Contradictions treated are clearly expressed problems they have tackled and EPs are positively improved engineering issues. In addition, the fact that their concept (if this one is respectful to TRIZ's groundings) is not resulting of a compromise (Both EP's are improved), inventiveness is appearing significantly.

4 Discussions

4.1 Questionings

The first point we wanted to emphasize relates to the benefit and limitations of contradiction formalism. In the introduction paragraph, we postulated that contradiction formalism could contribute to complexity reduction and therefore ease complex problems representation and data manipulation. In light of several case study results, we have observed that a large amount of data's were investigated and disclosed in a short amount of time. Comparatively, engineers having tackled the same problem during several years have noticed that on the same knowledge domain, what was traditionally a set of disharmonized vision of actors resulting in a fuzzy set of data's for qualifying which problems to address, has been transformed into a clear shared model of expressing their know-how.

A second point to discuss is the paradigm shift in design from "assuming functional specifications" to "problem to be inventively solved" proposed by our model. In light of the testimonies received by engineers, they have had difficulties to enter into this mode of thinking (defining goals through problems). Nevertheless, after a day of practice, all engineers (except one) have entered pro-actively into this process and added the result of their reflections and know-how. In light of these observations, we can draw the hypothesis that problem thinking has not been sufficiently exploited in Design Science and particularly in R&D structures.

Another point to discuss is the improvement of the ratio between concept quantity and inventive findings. In ArvinMeritor classical innovation workshop's structure, priority was given to the obtaining of a large quantity of ideas. Despite this indicator has already been argued by [19], it is still a criterion of performance in many companies. What we have observed in our case was the prolific aspect of the idea generation stage but not in terms of quantity but in terms of technical disclosure of the same idea. This resulted in a few categories of concepts where each concept was significantly described by diverse engineering solutions interpreted by each member and their personal competence fields. As a result, the quantity of concept categories was lower but the robustness of each developed idea has resulted in additional confidence from engineers and directly affected the quantity of patent filled. Out of these observations, we can postulate that targeting quantity of ideas may not be the only way of efficiently addressing inventivity in groups. Addressing the right problem, with a more exhaustive definition of the challenge seems promising. In other terms, contradiction formalism has helped to clearly define what was expected from each participant, resulting consequently in a more pro-active attitude from them.

4.2 Addressing limitations

A first an obvious limitation resides on the fact that a specific domain is presupposed modelized in terms of contradictions. Each contradiction, in our approach, represents a domain problem (most probably unsolved). Nevertheless, at no moment we can ensure that all problems have been disclosed. Assuming that contradictions have been synthesized from available texts and experts questioning (plus verification and validation), nothing is ensuring a total domain coverage. A first direction possibly employable to improve this statement is to boost contradiction revealing automation through a finer reasoning. The expected result is that more documents browsed and complied would lead to wider domain coverage.

Second limitation, still unsolved, is grounded on the difference of an approach, "problem-oriented" and a more traditional one "functions-to-be-assumed", most often accepting compromise as a solution. This leads us to the problematic to link Inventive Design and classically employed Optimization Design, omnipresent in industry nowadays. We strongly believe that this is the most predominant bottleneck to solve in order for CAI to be on a next level of its own "S" curve: the high development segment.

5 Conclusions and perspectives

As it has been written and argued many times, differences in people's mind between creativity, innovation, invention and problems solving are unclear. Is Inventing a Problem Solving activity? Should "Functional requirements" or "problem definition" drive the design process? Nowadays, it is almost impossible to draw a state of the art of what innovation is. We can even postulate: "one man, one definition of innovation". Therefore, this paper was aiming at addressing the problematic of innovation's organization through a more structured way to succeed in Inventive Problem Solving Activities inherent to any Inventive Design process. We have underlined the problematic of knowledge structuring for efficient problem statement and proposed a model for addressing this task. The proposed model is based on a partially automated text analysis eased by both contradiction formalism and E-N-V model. The ontology built and tested during an industrial application provided interesting results and leads us to claim that this ontology has significantly improved the speed of contradiction revealing while diminishing the necessary time for domain expert to validate and complete the set of contradictions.

The perspectives of this work are now leading us to analyze the problematic of linking a problem-driven process with actual industrial practices. Nevertheless, we are inclined to address our future research orientations in engineering design science with the following observation. Obtaining the best from what is known cannot be managed as the holistic synthesis what is still unknown.

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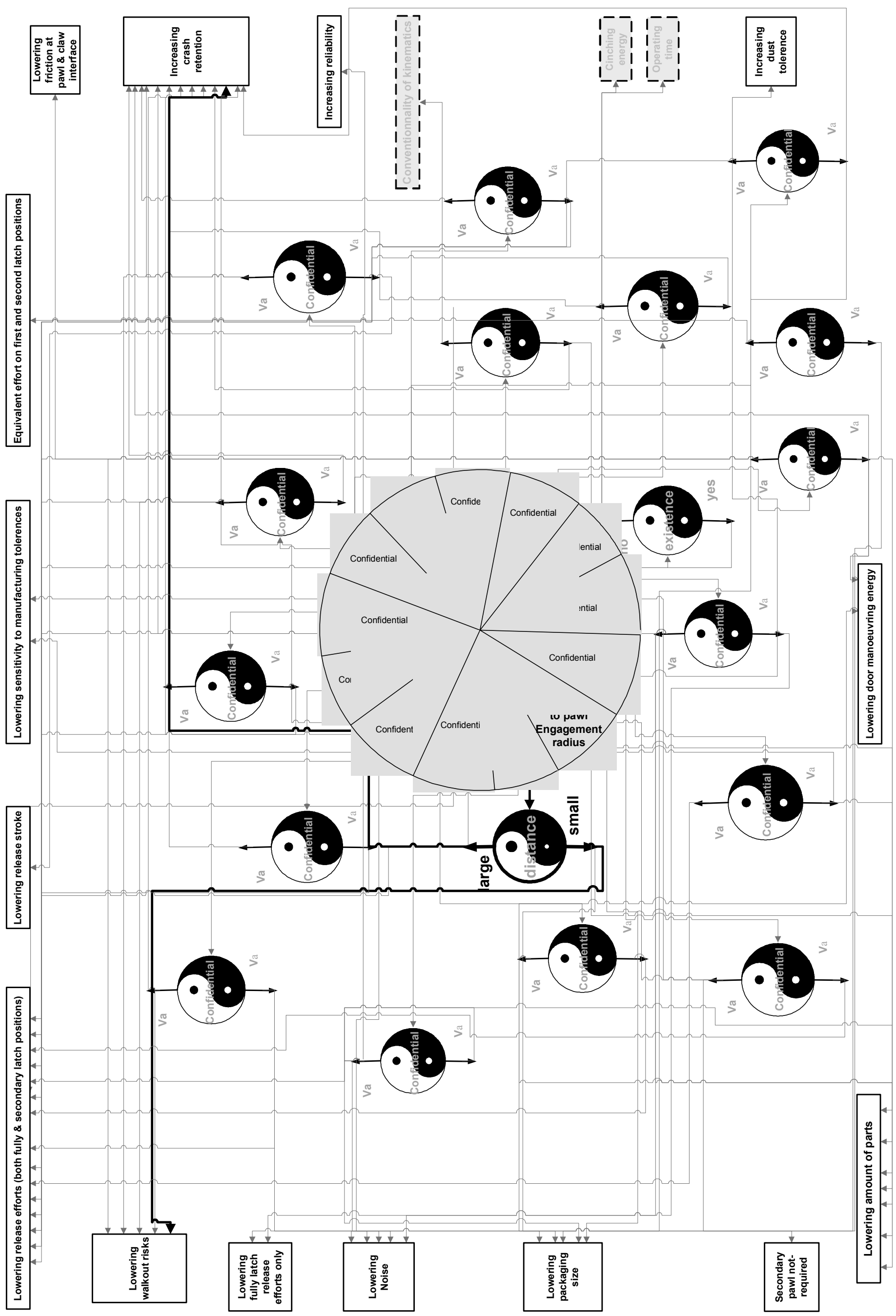

Appendix 1. Overview of Low Release Energy domain's challenges

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