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DEVELOPMENT AND VALIDATION OF DESIGN TOOL FOR CONCEPT CHOICE ON ROBUSTNESS, RELIABILITY AND SAFETY CRITERIA

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Abstract. *A taxonomy with types of information about robustness, reliability and safety was expanded to include information about the end effects of failures and successes of working principles. A visual approach was then developed to display these types of information in a single view regarding characteristics of individual concepts. The tool was seen as naïve against preferences and political factors, yet worked as reference for their decision and propositions of improvement. Moreover, the tool provided designers content for refining their judgment throughout the decision task, through which designers avoided the reappearance of failures while replicating successful characteristics when reusing designs.*

Keywords: *Design tool, Concept design, Alternatives*

1. INTRODUCTION

New market opportunities create requirements that current designs cannot meet, thus motivating the development of new designs whose implementation is uncertain. Key design characteristics are established during early design stages, which determine the fitness and dependability of the intended solution to the market. These phases offer more freedom for designers to make decisions about how they see the product to meet customer needs (Andreasen & Olesen, 1990), and good practice of development activities in these stages leads to more effective solutions that enhance the competitiveness of the manufacturing organization.

As consequence, keeping good reputation will make customers to prefer their products. Performance attributes of the product, such as robustness, reliability and safety are widely acknowledged as relevant considerations through the design process. Yet they are more important in early design stages to ensure the feasibility of design requirements and reduce later design rework in the product lifecycle. Current methods of evaluating robustness, reliability and safety substantiate the addressing of design issues, because they relate characteristics of developing designs to matters regarding their implementation and use.

However, these methods also make significant demands on project resources and design expertise, hence there is insufficient understanding of how designers consider these attributes while designing concepts. Especially in these phases, uncertainty and ambiguity are inherent to the engineering design process; these get cascaded from the comparison of design requirements against customer needs, toward the negotiation of interfaces through the development of a design solution (De Weck, Eckert, & Clarkson, 2007).

From this standpoint, questions remain on the following aspects of engineering design practice: how design issues are elicited by project teams for the decision-making process; and how, the feedback from the verification of the same design issues is incorporated into the intended product development strategy. This makes it necessary to improve the use of engineering knowledge in supporting the verification of the feasibility of innovative designs and in deciding on a principle solution to be implemented in accordance with the design requirements for the ongoing project.

The endeavour to solve design issues depends upon the use of knowledge by designers when asking for information about a specific engineering matter (Court et al., 1998); this influences the choices taken to tackle engineering problems. Such requests for information trigger a chain of knowledge consolidation regarding how design issues are handled, distributed and solved. Hence, knowledge-based support to engineering design tasks becomes relevant to tackling problems.

In response to these issues, this paper aims to describe the development and verification of a knowledge-based design tool that supports the evaluation of concepts during early design phases.

2. BACKGROUND

Descriptions of the design process provide generic overviews about how the design process is to be carried out in form of methodologies (Pahl, Beitz, Feldhusen & Grote, 2007); or emphasize different views on engineering design activity: for instance, guidance to designing and its management through presenting the design activity as a nesting, multi-faceted set of tasks (Hales & Gooch, 2004), and optimization methodologies to evaluate and verify a design, with focus on dealing with variation (Yang & El-Haik, 2006). Here there is a difference in perspective, where the systematic design approach emphasizes the development of product functions and models, the optimization method approach favours the verification of product functionality. The focus on product functionality is justified by the perception that the occurrence of failures is linked to the lack of scrutiny on solution alternatives; nevertheless, this situation is also caused by the lack of awareness and/or concern to the losses from past engineering mistakes (Petroski, 1994).

There are four types of impediments precluding failure prediction in the engineering design practice: (1) there is too much effort to process information into meaningful matters; (2) there is bias to avoiding commitment on an engineering standpoint; (3) there is isolation and lack of coordination among practitioners and teams of different competences; and (4) there is lack of confidence on systematic and/or prescriptive methods (Busby & Strutt, 2001). The latter impediment to failure prediction in the engineering design activity is confirmed by the finding of little influence from formal and systematic methods to justify the decisions taken, of which a cause is the short time given in the decision-making activity to discuss the importance and the consequences of criteria (Girod, Elliott, Burns & Wright, 2003). Here, a major direction to support the assessment and management of risks throughout the engineering design process concerns the development and implementation of methodologies that allow engineering teams to build shared understanding of risks and uncertainties (McMahon & Busby, 2005).

In this context, design reuse has a role into mitigating risk in the engineering design process, stemming from the beneficial relationship between past designs and design projects: existing designs eligible for reuse allow variations of use and efficiency improvements of known solutions (McMahon, 1994); and, reusable designs offer 'templates' that facilitate the generation of new ideas and the navigation of designers through the engineering aspects of the developing product architecture (Eckert, Stacey, & Earl, 2005). However, the engagement of design reuse may backfire: changes to customize reusable chunks of existing product architectures may cause inconsistencies to emerge, thereby affecting nearby and related components in the new engineering solution (Eckert, Clarkson & Zanker, 2004). The lack of clarity regarding constructive relationships among engineering components may cause project delays due to emerging conflicts that require solution. Therefore, engineering practice has been trying to address this problem through treating whole solutions as sets of design chunks whose interfaces can be negotiated (Sobek, Ward & Liker, 1999).

Nevertheless, early design decisions often entail flawed predictions of later impacts from design parameter choices. The role of design parameters is very often missed and early activities most often cannot reasonably grasp the issues they deal with (Flanagan, Eckert, & Clarkson, 2003). When making decisions, designers branch out issues and alternatives in decision discussions: criteria are updated along the emergence of situations, while previously considered factors may be forgotten during the decision process (Dwakaranath & Wallace, 1995). Feedback from the decision activities is seen with two specific roles: evolving the internal design of modules to the search for intersections among subsystems; and developing the maturity of module and system designs by reducing the variety of alternatives. (Terwiesch, Loch, & De Meyer, 2002). However, the attributes in design alternatives motivating these efforts are less clarified, even though as models and illustrations represent attributes of form and construction in an invention supporting functionality claims to a utility (Clausing & Frey, 2005).

Some situations actually require designing experience to make sense of the available knowledge to addressing challenges in their developing solution (Wallace, Ahmed, & Bracewell, 2005). Designers are known to make references to prior facts related to the ongoing situation, that they were told by their peers or they have experienced themselves (Visser, 1995). To improve awareness by making information more accessible, engineering knowledge management can make it easier for designers to refer at ways to solve problems. In this context, taxonomies classify different types of information through ontologies, thereby enacting indexing mechanisms that will facilitate the acquisition and retrieval of design information that is relevant to given issues in the design process (Ahmed, 2005). The derivation of ontologies and taxonomies is carried out through empirical research, by extracting generic types of design information from the data that is contained in documentation, and from the eliciting the expertise of designers and managers involved in projects through interviews (Ahmed, Kim and Wallace, 2007).

Previous studies of our own revealed the incompleteness of information from early stages for using current methods for robustness, reliability and safety, mostly due to the extensive knowledge resources required to make reference to the relationships involved in the product design (Marini, Ahmed & Restrepo, 2010). In response to this conclusion, a longitudinal study was performed in collaboration with the manufacturer of an insulin injection pen. This study followed the development of 20 solution alternatives for a new design of such device, confirming the lack of systematic evaluations of robustness, reliability and safety during early stages (Marini, Ahmed-Kristensen & Restrepo, 2011). On those grounds, the process to decision-making and feedback about engineering design alternatives was elected as centre of attention for helping designers focus on the intended attributes of robustness, reliability and safety, from failures to correcting design flaws in earlier solutions in downstream design tasks (Marini & Ahmed-Kristensen, 2012).

3. EXPERIMENTAL PROCEDURE

The knowledge-based design tool is derived from the results of a longitudinal case study (Yin, 1994) that followed the early design phases in the development of an insulin injection pen, under which 20 concepts were generated. The insulin injection pen is characterized as a precision-mechanics device integrated with electronic components whose performance is especially sensitive to robustness, reliability and safety attributes. Compared to other engineering design categories, the insulin injection pen differs in being a product with stringent regulatory requirements due to the immediate risk to human life in the case of disturbances to its function.

Our study investigates the selection of alternatives and working principles, particularly with regard to design flaws in previous concepts. Feedback loops in the design process were found as critical for developing knowledge-based support to early design phases (Marini & Ahmed-Kristensen, 2012), with focus on how to facilitate the decision-making and feedback mechanism to solving problems in design alternatives on the attributes of robustness, reliability and safety. As its objective is to develop and validate support to design practice in concept development, it can be understood as a prescriptive study followed by a second descriptive study in the design research methodology (Blessing & Chakrabarti, 2002). Table 1 shows the data collection methods used for performing the study.

Table 1 – Characteristics of the methodology for developing and validating the design tool.

	Analysis and modelling	Protocol analyses	Interviews and questions	Reverse engineering
Conceptualization	Scenarios and terminology modelling to suit the expected use. Modelling of fields and user interface to carry evidence of design issues.		Two semi-structured group interviews for evaluating usage characteristics of the design tool.	Decomposition of information from the industrial case following R2S taxonomy.
Testing		Task simulation to assess the use of the tool for decision-making among solution alternatives.	Task simulation to assess the use of the tool to provide feedback about outstanding issues in chosen alternatives.	
Evaluation			A questionnaire to participants of the observed workshop about their impressions of the tool.	Comparison between outcome of the exercise with the characteristics identified in the original project.

Analysis and modelling were performed at the beginning of the process, with first designing the concept and interface of the design tool. These were presented as a software mock-up for evaluating the user interface on the ability to collect and register data. Terminology and scenarios of use were modelled to suit the industrial context, with internal evaluations were carried out by the research team, and the external evaluations were carried out in collaboration with the manufacturer. Then, focus group interviews were carried out to elicit input about organizing information about solution alternatives, which supported the choice of user interface to the design tool. After this choice, data from the longitudinal study (Marini, Ahmed-Kristensen, & Restrepo, 2011) was parsed into the format of the tool, and presented in form of records.

The proposed design tool was used in a simulated design decision meeting with feedback to further development. This was carried out in two sessions of 45 minutes each, with an interval of 10 minutes, and three designers from the company were involved in the task along with the risk specialist. With exception of the latter, the other participants had no role in the project previously observed. Reverse engineering was used to identify the functions performed by design alternatives, their working principles and similarity between these, to assemble the information units by the tool, and to evaluate the expected outcomes out of designers' ideas to solve the outstanding issues the found in the chosen alternative. Finally, questions were asked with focus on the use of the tool, to assess the viewpoint of designers regarding the use of the tool.

4. RESULTS AND DISCUSSION

As the project observed was developing technical attributes for the product, it provided basis for developing the design tool. This was motivated by the findings from previous research that the decision-making-to-design-feedback mechanism was flawed: designers were reusing working principles that were shown to be sensitive to disturbances. Relationships between the alternatives, and the reasons for their rejection, were examined in the data; these revealed how design methods were used to generate information, and how this information was used to select alternatives and improve those that remained.

To define the focus of development for the design tool, two aspects were considered: first, the types of information being used in and through these transactions; and, second, the information transactions between design tasks during concept development. Knowledge about these elements uncovered the following issues: the essential information needed to establish a basis for judging the value of alternatives and improving their feasibility; and, the benefit to be gained by connecting the verification of alternatives towards decision-making and the courses of action to be taken.

4.1 Development of task workflow through scenario-making

The development of the tool has first begun with addressing the information transactions, through employing a process view to analyse the design tasks. To clarify the order and dependencies between tasks in design cycles, a description of design cycles is formalized as shown in Figure 1. Early design tasks have been divided into four main sets on their use and treatment of information: *reference (Re)* tasks involve the search and consideration of past designs and templates for design activities; *generation (Ge)* tasks comprise the creation and development of solution alternatives; *evaluation (Ev)* tasks involve the use of methods, standards and procedure to assess the suitability of solution alternatives; and *selection (Se)* tasks include the gathering of information and its processing towards decision-making on alternatives to be rejected or developed through. The scope of work for the design tool is also outlined.

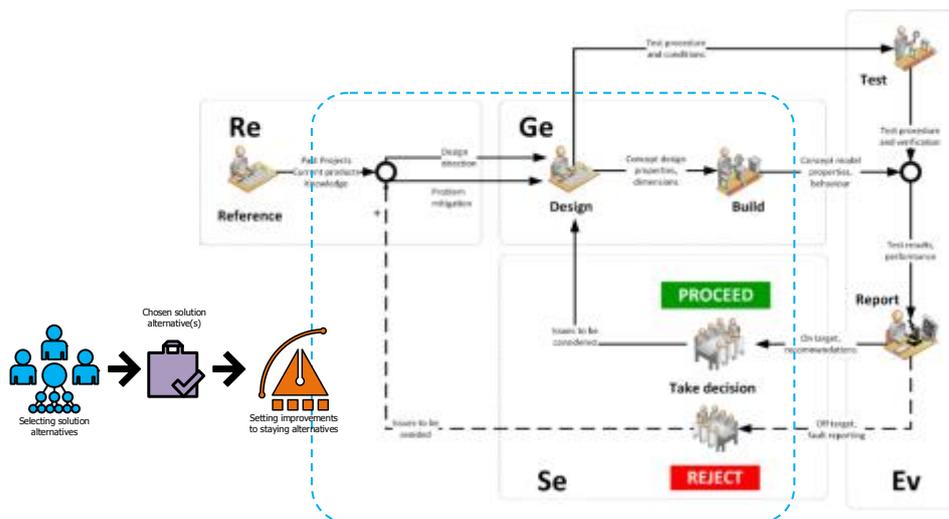


Figure 1 – Workflow representation of design tasks in early design stages.

Relationships between tasks are depicted by arrows: design direction means the intended strategy for fulfilling the design requirements, which can be a preferred type of working principle or a product architecture. As failure modes and their considerations unfolded from the project documentation, it was found that the following relationships were essential to evolving solution alternatives towards the principle solution:

- Firstly, that evaluation (Ev) provides recommendations on the quality of solution alternatives or reports on their weak points towards the alternative selection (Se) process; and,
- Secondly, that decision-making through the selection (Se) process gives feedback to guiding the search for new references (Re) or functional improvements (Ge) to staying alternatives.

Both involve forming the basis for a design task from documentation about product designs, with focus on the transaction from evaluation methods to decision-making. Considering the *evaluations* performed and made available through the original project, these relationships guided the scenario development for use of the design tool onto a single routine, where designers would *select* the best alternatives, and then *generate* improvements to the staying alternatives after the selection.

4.2 Criteria for appraisal of solution alternatives

Development of the tool evolved to focus the types of information required for judging about robustness, reliability and safety, and the modelling approaches to represent alternatives on these attributes. In that level, the taxonomy for robustness, reliability and safety that was developed under the preliminary study (Marini, Ahmed & Restrepo, 2010) supported the verification of types of knowledge commonly used through dependencies between design tasks in the industrial case study. The types of information considered for the design tool are shown in Figure 2.

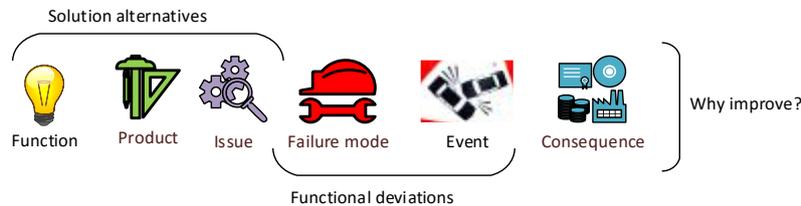


Figure 2 – Scope of work defined for design tool supportive to design selection and improvement.

These types of information concerned the characterization of *solution alternatives* from their purpose to their behaviour (*Function, Product, Issue*), and the characterization of *functional deviations* of the designs that could prevent the satisfaction of design requirements (*Failure Mode, Event*). The classification of categories evolved because the current version of the taxonomy was incomplete towards indexing of information linked to incidents from design issues with the design of the medical device. For instance, the statement about ‘problems in the sensor’ considers the inability of the electronic system to follow the cursor accurately. This example demonstrates that functional requirements of the insulin pen are linked to the architecture of the product and its use.

This pointed out to the need of an extra category, namely ‘consequence’, whose information entails the characterization of probable outcomes from the failure to solve issues in solution alternatives – which provided *motivation for improvement (Consequence)* into treating the design issues involving functional deviations. Thus came the updated taxonomy for design information about robustness, reliability and safety as it is shown in Table 2.

Table 2 – Updated taxonomy used as basis for design tool.

Keyword	Reference	Definition	Source	Example in project
Function	Functional basis (Hirtz et al., 2002)	Structured actions and system flows achieving a definite technical purpose	Feature definition	“The purpose of the feature is to allow the user to set and reset the desired dose size”
Product	EDIT (Ahmed, 2005)	Constructive elements, characteristics and relations from the designed product	Product rendering	“Dose setting: concept A1 consists of a torsion spring being tightened while setting the desired dose size”
Issue	EDIT (Ahmed, 2005)	Relations, characteristics and requirements to be considered during product design	Interview w/ engineer	“The needed torque for setting and resetting a dose is higher than the needed torque on current product”
Failure mode	Mechanical failure (Collins, 2006)	Processes and phenomena causing degradation of performance or failure	Evaluation reports	“Risk: “More than one IU resetting at the time; Mitigation: Optimisation of the click mechanism”
Event	Pilot study (Marini, Ahmed & Restrepo, 2010)	An occurrence where system properties and/or the functional state is changed	Evaluation reports, interview w/ engineer	“When a dose is set, a dosage tube is rotated up. When the dose is injected, the dosage tube, biased by a centrally placed dosage spring, advances.”
<u>Consequence</u>	<i>Product dataset (Industrial case)</i>	<i>Outcome for people, assets and environment from the change of system properties and/or functional state</i>	<i>Evaluation reports</i>	<i>“[If there is] some dust or if the temperature changes or the humidity is high, then the sensor may have problems”</i>

4.3 User interface in the design tool

In looking to address the mismatch between the reasons for discarding alternatives during earlier concept selections and the feedback to further development, it was found that design issues were at best, characterized in terms of issue-to-product and that functions are implicitly considered in the form of component names. This generates ambiguity across designs, as a standard component name such as ‘ratchet’ – for indexing increments – is used to define several component geometries in different alternatives. To solve issues like this on the run-up to selection, the design tool focuses on the types of information needed and on the structured communication of how alternatives performed.

Methods to robustness, reliability and safety are understood to cueing designers onto a thought process to formulate and propose provisions against failure. Based on this, the design tool was intended to display several characteristics of the product and at the same time towards declaring several aspects to individual design issues in single views. The design tool was originally designed for use with tablets with the interface at the left of Figure 3, and it was implemented for a paper-based evaluation with the layout by the right.

In the first step, a preliminary layout was evaluated under expert review (open-ended interview), focusing upon the types of information to communicate design issues and the attributes affected. The expert acted as a company-wide consulting reference for risk and reliability topics, facilitating risk assessments and improving current practices. On receiving his feedback, the tool was prepared for a team-based expert review (semi-structured interview) on the information format and how it could be used during concept development. These meetings resulted in the selection of the record format shown in Figure 3 below.

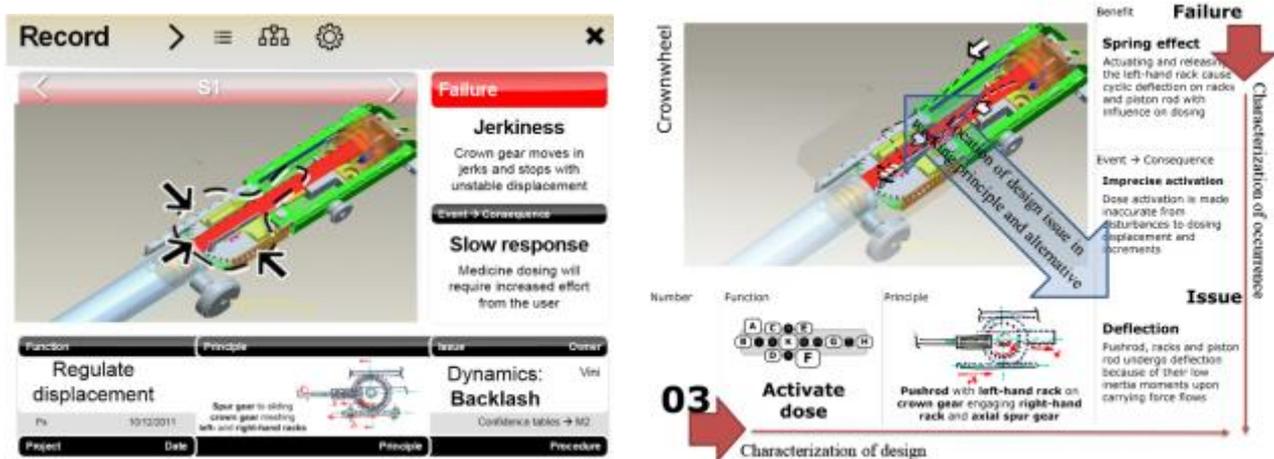


Figure 3 – Display of issues in design tool: preliminary UI layout and design task layout

From the link between function/working principle pairs and the product architecture, the layout of the design tool was intended to represent the working principle as part of the alternative and as associated with a functional module in the physical assembly of the system – aiming at informing how a single function/working principle works in a specific design issue. Individual records about design issues in alternatives (as depicted in Figure 3) were intended to suggest relationships between different types of information in individual design issues, to provide an overview of why they occur and of the effect they have on functional requirements; at the same time, the visual format was intended to enable comparison among several cases being presented.

4.4 Verification of the design tool

With the design tool implemented along the design issues found in the observed development project, the evaluation task was performed with the aim of verifying the usefulness of the proposal and collecting feedback on the fitness of the tool to the purpose of supporting the mechanism between the selection of alternatives (decision-making) and the generation of improvements to staying alternatives (design feedback). The task simulation was performed by one seasoned mechanical designer with more than 10 years expertise, and two other mechanical designers with up to 4 years expertise with support of the risk specialist. The design exercise involved two steps:

- Selection of the alternatives best suitable to the designers’ understanding about robustness, reliability and safety, from using information in the records supplied; and,
- Generation of improvement ideas to robustness, reliability and safety by designers aiming to address outstanding issues in the alternatives that remained.

On the selection alternatives, the task simulation was set up to evaluate records of failure and benefit that were extracted from early alternatives in the original project. Designers were given help sheets with example definitions and clarified of the exercise before beginning the task given. Information about alternatives was given in the form of individual card views, accompanied by original pictures of solution alternatives selected from the corporate product database. Designers documented their decisions, stating the main reason for rejecting each alternative and its ranking. A decision timeline, shown in Figure 4, was generated upon the analysing how participants navigated about individual issues (alternatives coded as letter-number pairs, S2/A31) and their originals (Or), along with references participants made to taxonomy definitions (Df) and their consultations with the risk specialist (Fa).

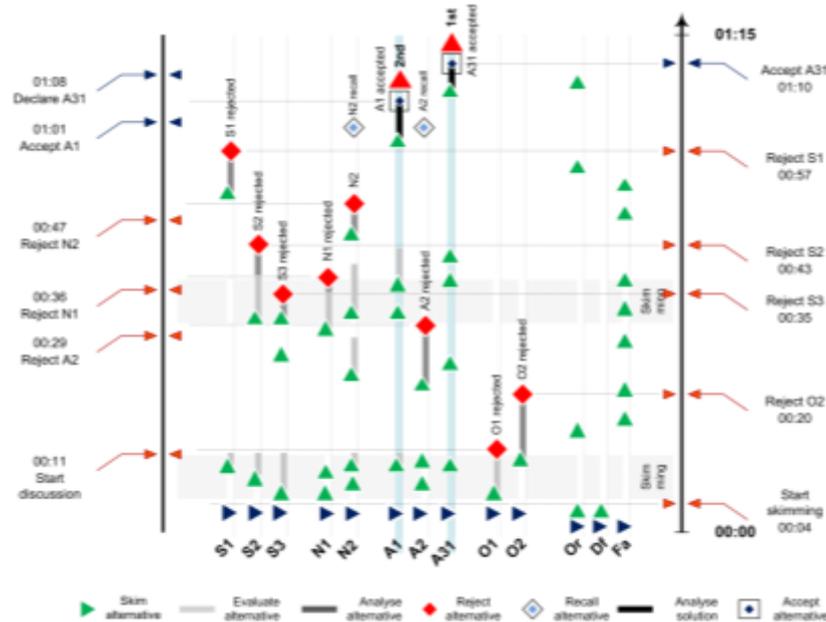


Figure 4 – Decision timeline across alternatives with designers using the tool.

The figure shows the actions of participants while using the tool to assess and take decisions, as follows:

- *Browse alternative*: participants browse through different cases of the same alternative and visualize the records with models and text to obtain a preliminary overview on qualities of the alternatives;
- *Analyse alternative*: designers read the issues in the records and seek to ascertain their impact on requirements as they need to consolidate their judgment; and,
- *Evaluate alternative*: designers observe the cases of individual alternatives more intently, with increased focus on the effect to the feasibility of functional requirements.

Two browsing loops were carried out during the task simulation: the first was done in order to make an overview of all alternatives available and look for opportunities in the alternatives with obvious non-solvable issues; and, the second involved evaluation and analyses of individual issues to generate a basis for rejecting alternatives designers deem too difficult to implement successfully. Other behaviours by participants concern attaining shared judgment on alternatives:

- *Reject alternative*: participants conclude about rejecting an alternative, with confidence that it is not worth pursuing because it costs too much effort to solve its problems;
- *Analyse solution*: designers view more intently the issues of the remaining alternatives to assess how their performance is more satisfying, closer to requirements, and that their problems are easier to solve;
- *Recall alternative*: participants return to an previously rejected alternative to close in on their judgment as they need to make sure of their interpretation of the records;

Reasons to reject solution alternatives usually originated by designers’ perceiving deficiencies up to functional requirements. The consolidation of their judgments in rejecting alternatives like S2 and N2 was carried out after analysing individual cases and consulting the specialist about their mechanism. After consolidating the judgments on which alternatives to *reject*, designers moved on from discarding alternatives that did not work well to comparing those that were closer to functional requirements. This resulted into confirming alternatives with desired benefits and rejecting alternatives manifesting failures too expensive to solve with further work. Design benefits were linked to fine-tuning design details such as the characteristics of material and component interfaces, as a single benefit was carried over from the choice in the task simulation.

In the second part of the task simulation, participants were asked to assess the outstanding issues in the chosen alternative and suggest design improvements to them, referred to as countermeasures as shown in Figure 5. These were intended to prevent the repetition of mechanisms of failure which could be reasons for rejecting further solution alternatives, by forcing designers to learn and assess mechanisms of failure they consider solvable in winning alternatives from prior decisions.

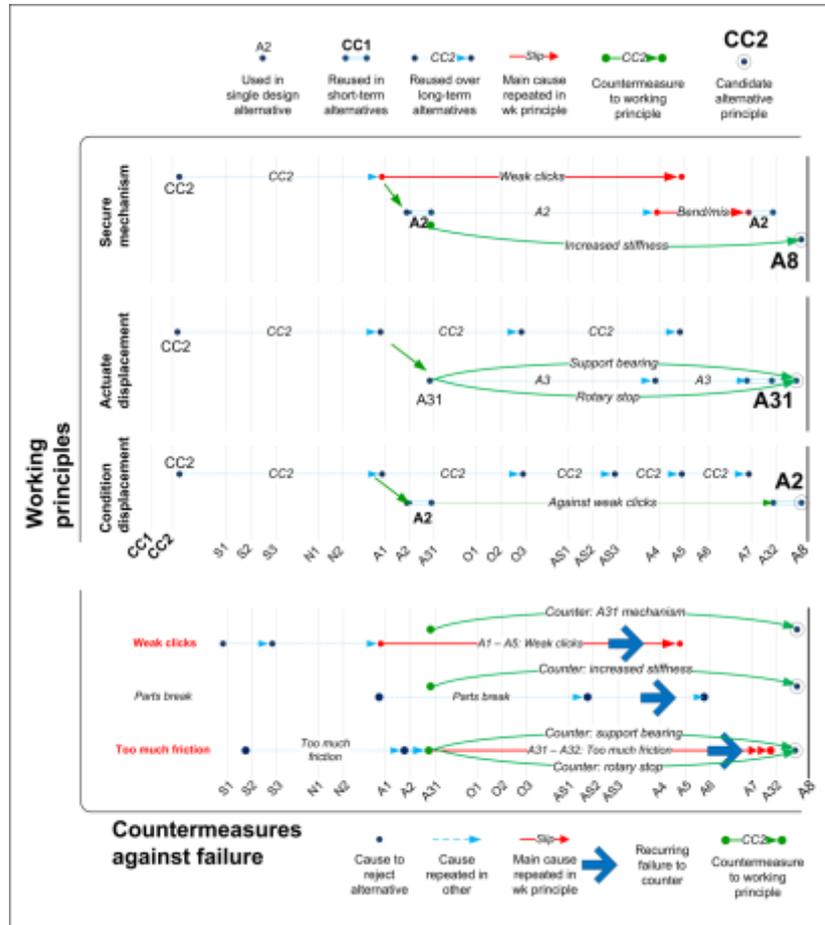


Figure 5 – Reliability attributes solved with using the tool.

Countermeasures involve switching from one working principle that originates a mechanism of failure to another working principle that is known to prevent that mechanism – shown by green arrows in the upper part. The other arrows confirm the character of the working principle selected, in its relationship to the working principle from the final solution principle from the original project. The similarity between the suggested countermeasure and the winning design (by the partner company) was assessed from the output generated by participants in the second part of the task. Three types of countermeasures were found this exercise:

- First, a change in working principle to a construction similar to that found in solution principle A8;
- Second, switching from one accepted working principle towards the winning alternative;
- Third, improvements in working principles of the winning alternative.

The first countermeasure involved taking advantage of material properties of an internal component, which was not associated with the working principle. The second countermeasure involved comparing the acceptable alternatives and determining the best in regard to functional requirements. The third countermeasure was carried out by intensive examination of component and interface characteristics of the current working principle, whose shortcomings were to be alleviated.

All countermeasures proposed in the exercise were found to be effective in incorporating the knowledge from design records as reference about outstanding failures, and in eliciting characteristics of the solution principle that were effective in solving the issues described in the records. Designers effectively used the records as sources of consultation and reference in their proposed countermeasures. These results motivate a positive assessment of the approach of design records, an approach whose performance in preventing recurring failures was found to be valid.

4.5 Evaluation of the design tool

The evaluation of the tool is carried out on four aspects (Boyle & Cosby, 1998):

Reaction: The visual representation of concepts and their design issues prompted participants to think about the alternative concepts, and improve the designs they chose: designers present at the evaluations found that the layout and the navigation was appropriate to searching and retrieving information about solution alternatives. Compared to other recently developed methods, designers saw the tool as supportive to reasoning based on confidence and on informal knowledge of the parameters and data that characterize product designs. Designers wanted more information about the relationships between neighbour components and pointed out the need to authenticate individual issues by providing personal references.

Learning: Participants could use individual cases as a direct source for their thoughts about generating the solution: they found the grouping of several information fields about individual issues into solution alternatives to be a useful reproduction of their thinking. Participants felt the tool offered sufficient information for their task, as they used references to individual design issues to justify their decisions. Towards improvement of staying alternatives, designers felt the tool to guide them on adopting a particular strategy to solve an individual design problem, due to the characterization of individual issues by a single escalation mechanism (per the individual cards as shown in Figure 3). At the same time, this escalation pattern helped designers to make intuitive assessments about the degree of solvability of individual issues.

Behaviour: Designers observed the tool as facilitating feedback for improving designs, based upon the recognition of working principles and their association to cases of failure and benefit. Designers engaged into systematic behaviour of searching and interpreting design issues, which has occurred in an iterative pattern (*Browse/Analyse/Evaluate*) comparing alternatives, recognizing design issues and evaluation their criticality to requirements. Through this search, designers had first discarded the alternatives with easiest recognizable issues, then turned to problems on alternatives with more detailed construction. This required designers to carry on another iterative pattern regarding their judgment (*Reject/Analyse/Recall*), by concluding an alternative is no longer worth, evaluating more complex issues by their mechanism or acting componentry, and recalling given alternative not so complicated to solve.

Results: Designers ended up confirming alternatives with desired benefits and rejecting alternatives manifesting failures they saw as too expensive to solve with further work. Reasons to reject were linked to designers' perceiving deficiencies up to functional requirements, and design benefits were linked to design details that provided opportunities of fine-tuning to match desired performance. All countermeasures proposed in the exercise were found to be effective in incorporating the knowledge from design records as reference about outstanding failures, and in eliciting characteristics of the solution principle that were effective in solving the issues described in the records.

5. CONCLUSION

This paper aimed to describe the development and verification of a knowledge-based design tool that supports the evaluation of concepts during early design phases. The development of the tool has first begun with addressing the information transactions, through employing a process view to analyse the design tasks. Methods to robustness, reliability and safety are understood to cueing designers onto a thought process to formulate and propose provisions against failure. Based on this, the design tool was intended to display several characteristics of the product and at the same time towards declaring several aspects to individual design issues in single views.

With the design tool implemented, the evaluation task was performed to verify the usefulness of the tool supporting the selection of alternatives (decision-making) and the generation of improvements (design feedback). After consolidating the judgments on which alternatives to *reject*, designers confirmed alternatives with desired benefits and rejected alternatives too expensive to solve. The countermeasures proposed as feedback were found to be effective in incorporating the knowledge from design records as reference about outstanding failures, and in eliciting characteristics of the solution principle that were effective in solving the issues described in the records.

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