CIRP Annals - Manufacturing Technology 65 (2016) 193–196

Contents lists available at ScienceDirect

CIRP Annals - Manufacturing Technology

journal homepage: http://ees.elsevier.com/cirp/default.asp

Engineering design memory for design rationale and change management toward innovation

Lionel Roucoules [a,*], Esma Yahia [a], Widad Es Soufi [a], Serge Tichkiewitch (1)[b]

[a] Arts et Métiers ParisTech, CNRS, LSIS, Aix en Provence, France
[b] Univ. Grenoble Alpes, G-SCOP, F-38000 Grenoble, France

ARTICLE INFO

Keywords:
Product development
Knowledge management
Decision making

ABSTRACT

As the metaphor of a film, engineering design is a process where stakeholders take decisions from product requirements to the final designed system. Unfortunately, industries lack of long term project memories to go back and forth in order to remember actions and decisions. That generates time consuming retrieval tasks that have definitively no added value since they aim at seeking past information. This paper proposes an extension of a design process meta-model that aims at tracing the project design memory. Instead of seeking past information, industries can look forward innovation and manage changes coming from new technologies, resources, KPI, etc.

1. Introduction to collaborative product design process

Nowadays in a highly competitive industrial environment, companies must respond to new market demands in term of improving quality, reducing costs, shortening time and increasing changes reactivity. Therefore enterprises must develop a comprehensive approach for mastering their products design phase in order to become more competitive and reactive and to save more time for innovation.

In order to meet these requirements, researchers and manufacturers, for approximately twenty years, offer to work on collaborative engineering environment to bring a large number of concepts: relations between product concepts related to function, structure or multiple views description [1–3].

1.1. Motivation of design rationale

The main industrial focus concerns the product design assessment and improvement. Nevertheless, many industrial experiences highlight the difficulty to retrieve information (i.e. decision) related to previous design solutions and therefore to adapt their solutions when the industrial environment is changing. For example, it is difficult to identify how and where do industrialists have to adapt the design when dealing with improvement and innovation? And to know if a new industrialization solution is better than the previous one?

When dealing with the companies where competitiveness decrease especially at the design phase, the following observations could be listed:

- Issue no. 1: Time loss when engineers are seeking for the necessary information needed to finalize their design activities

In fact, various studies [4] have shown that a considerable amount of time, spent by engineers during the design phase, is dedicated to research information. A recent study of DelphiGroup [5] made with 1030 engineer from large and medium-sized companies has shown that more than 65% indicates that they spend at least 15% of their working time looking for information, and approximately 40% spend at least 25%.

Thus, it is interesting to facilitate information search, in order to save this time and to exploit into innovation.

- Issue no. 2: Time loss when engineers are managing different changes

To ensure their place in the market, companies must also demonstrate capacities in identifying industrial context variations and abilities to manage changes as soon as possible in the product lifecycle and especially during the design phase. In fact, during this creative phase, it is important to master the impact of several changes that could be extremely costly if they are not properly propagated. Besides, Berliner and Brimson [6] argues that 85% of the decisions made during the design phase, impact more than 80% of the product final cost so it is more interesting to deal with change during the design phase.

In consequence, the main research objectives consist in mastering choices (i.e. decisions), taking by different stakeholders during the design and manufacturing phases and tracing them in order to infer knowledge and facilitating decisions. This will lead to the reduction of non added-value activities (i.e. lean design) as searching information, repeating mistakes, reinventing solutions, etc.

2. Orientation of the proposal and questions of research: decision making in product design process

Modeling the design rationale could answer the above research objectives. In fact, the authors assumed that it is important firstly,

* Corresponding author.
E-mail address: Lionel.Roucoules@ensam.eu (L. Roucoules).

http://dx.doi.org/10.1016/j.cirp.2016.04.046
0007-8506/© 2016 CIRP.

to trace how designers made choices during the design process and secondly, to reuse some patterns of the choice process in their future design processes. Besides, the authors assume that tracing and capitalizing the decision making will reduce the time loss for information retrieval and information exchange. Thus, the designers will have more time for innovation.

The scientific community has already dealt with Design rationale [7,8] and so far, many representations have been proposed by Hu et al. [9]. This paper aims at identifying the main design rationale concepts and implementing them based on the Six W's (who, what, why, where, when and how) conceptual model [10]. By capturing those concepts during the collaborative design phase, the authors assume that information retrieval and change management will be faster. Therefore, in order to achieve the research objectives, the authors propose to answer to the following research functions:

- **F1**: How to model collaborative design information based on Six W's: who takes a decision, what is the decided information, when and where the decision has been taken, how and why the decision has been taken? The capitalizing of those concepts reduces the time of information retrieval
- **F2**: How to trace design rationale and capitalize learning processes. Those learnt situations will be used on future situations

Fig. 1 describes the global view of each questions of research in order to support decision making in engineering design. The authors assume that when the design is complex, several decisions have to be taken since all the solutions cannot be assessed and considered:

- Initial design space which is mastered using knowledge modeling that constrains the admissible solutions. Those constraints are related to the design context.
- Assessment of each admissible solution in the performance space.
- Final decision making using multi-criteria analysis.
- One decision, with respect to specific parameters, can be propagated to another decision making activity, etc.

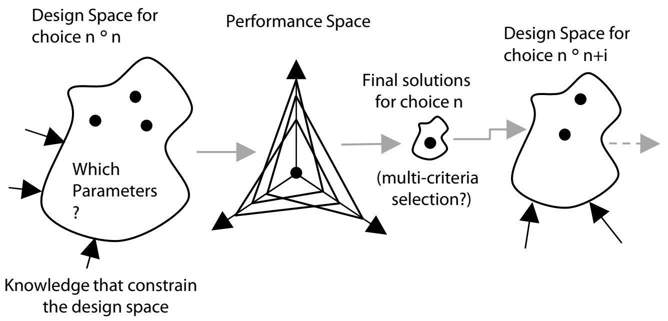

Fig. 1. Overview of decision making and main research questions of the proposal.

3. Background literature

Within the collaborative engineering product development cycle, the design process is considered as a creative process since it is not known only when the design starts [11]. It is a high added value process regarding its complexity and the various business expertises which are involved under a collaborative context with different specificities, actors and organizations. This creative process is also a dynamic process as it is adjusted and adapted frequently during its execution when answering to the recurrent modification demands. In order to master this creative and dynamic process, it is primordial to emphasize on a non-functional feature [11] which is the traceability.

In this section, we aim, at first, to define traceability and its objectives in the context of product design process and then to make a state of the art of the different traceability approaches.

3.1. Product design decision traceability

The concept of traceability evolved in different engineering context among computer science and product development. It refers to the action to follow or mark something (oxford dictionary). In the context of Product development process, traceability is the action to collect the diverse events occurring during the execution of a given process. It aims to record the process lifecycle history by capturing:

- The design routes and the evolution of design items [12]
- The information relative to the product and the process as well as their relations in the various product lifecycle phases [13]
- The important decisions and justifications during the process lifecycle [13]
- The diverse modifications that took place during the conception process lifecycle.

According to Ahmed [14], traces are then used to (a) understand lessons from previous experiences and to (b) reuse the "captured design knowledge to adapt past solution and apply them to current and future problems". This design knowledge is captured with respect to different design decision-making frameworks proposed by [13,15] which are adapted from Zachman's framework [10]. The latter structures the holistic enterprise mechanisms representation by answering to the basic communication interrogatives: Six W's.

The meta-model for achieving traceability proposed by [13,15] have been analysed as:

- *What* represents the design objects that correspond to I/O of the design process; it could correspond to requirements, technologies, functions, parts, etc.
- *Who* corresponds to the actors with different competencies that are creating and using the design objects.
- *How* and *Where* represent the 'sources' that documents the design objects between numerical documents, procedures and with different format types and formalization levels.
- *When* represents two 'time dimensions' related to the design object: the relative time that corresponds to the order of execution and the absolute time that corresponds to the version, state and the stage of the design object.
- *Why* represents the design rationale behind the creation, evolution and changing of the design. It corresponds to the decisions made and justified by the actors, which affect the selection and the evaluation of the design objects.

3.2. A comparison of different traceability approaches

Several researchers have proposed different approaches to capture and trace the design experience knowledge and to exploit, dynamically, those traceability constructs to infer some knowledge rules. The traces are supposed to facilitate the understanding of the design activities and their analyses by visualizing the "captured knowledge" [16] in order to evaluate the process performance and to detect the frequent sequences, delays and the eventual conflicts, etc.

The MUSETTE approach developed by Champin et al. [17], in the context of computer system use, exploits the interaction traces between the systems and its users in order to assist the Agent-Task Management. The approach, developed by Broisin et al. [18], aims to retrieve necessary and useful activities supervision information for the users involved in a context of Computer Learning Environments with heterogeneous tools. Besides, Pavkovic et al. [19] exploits the traces in the context of collaborative process to improve the communication between users and to contribute establishing common knowledge. Moreover, Karray et al. [20] approach aims at specifying and elaborating a knowledge oriented maintenance platform by exploiting the traceability constructs under the SBT (System Based on Traces) proposed by Settouti et al. [21].