Design process and trace modelling for design rationale capture

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Abstract: To face the high industrial concurrence and to remain competitive, companies are asked to work in a context of collaborative engineering environment where design rationale is a prerogative to reduce their product development time. Design rationale aims to capture the knowledge from the product design at a very early stage as those decisions have higher impacts in terms of time, cost and quality in the later product lifecycle stages. We propose, in this paper, a three-layer framework to answer to the need to capture the process design knowledge and to use the construct captured to visualize the process performances and to derive rules in order to help and assist the designers.

Key words: Design process, design rationale, design trace, decision making, product design.

1- Introduction

Nowadays in a highly competitive industrial environment, companies must respond to new market demands in terms of improving quality, reducing costs, shortening time and increasing changes reactivity. Therefore enterprises must develop a comprehensive approach to master their products design phase in order to get 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 in a collaborative engineering environment to bring together a large number of professional skills within a project and to cooperate all together using these various expertise.

The paper is organized in four sections. In section 2, the research context related to the mastering of the decision making during virtual product development is presented. A bibliographic background, based on rationale modelling and tracing issues, is presented in section 3, it contributes to the definition of traceability, its objectives and its main approaches in the domain of product engineering. In the light of this state of art, a framework based on three-layer traceability approach is presented in section 4. Finally, in section 5, conclusion and further work are discussed.

2- Research context and orientation of the proposal

2.1 - Potential industrial improvement, issues and objective: design rationale modelling

Currently, different industries run their product development process in a collaborative way using well-known commercial solutions for PLM, CAD and CAX modelling. In this context, many researches ([G1], [KK1] and [T1]) have also been proposed to enrich this collaboration by identifying the relations between product concepts related to function, structure or multiple views description.

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's 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 competitiveness decrease especially at the design phase, the following observations could be listed:

- Issue n°1: Time loss when engineers are seeking for the necessary information needed to finalize their design activities

In fact, various studies [FG1] and [U1] have shown that a considerable amount of time, spent by engineers during the design phase, is dedicated to research information. Thus, it is interesting to facilitate information search, in order to save this time and to exploit into innovation.

- Issue n°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, [BB1] argues that 85 % of the decisions made during the design phase, impact more than 80 % of the product final cost.

- Issue n°3: Time loss when engineers are exchanging data

In fact, in the context of collaborative design, different employees with different background and skills are required to exchange data. Then, it is important to facilitate data exchange and to ensure coherence between all the exchanged data.

In consequence, the main research objectives consist in mastering choices (i.e. decisions), taking by different stakeholders during the design and manufacturing phases and adapting them when the industrial context is changing.

2.2 - Orientation of the proposal and questions of research: decision making in product design process

Modelling the design rationale could answer to the above research objectives. In fact, the authors assumed that it is important firstly, to trace how designer made choices during the design process and secondly, to reuse some pattern 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 and so far, many representations have been proposed by [HP1]. 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 [Z1]. 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 four functions (i.e. questions of research):

- 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 (Issue n° 1).
- F2. How to manage changes through the identification and simulation of the changes propagation? The use of dedicated algorithms to mastering changes and tools to simulate them will act on design agility and then reduce the time to change management. (Issue n° 2).
- F3. How to trace design rationale and capitalize learning processes. Those learnt situation will be used on future situations.
- F4. How to ameliorate design process by studying the change impact on the process?

Those two last functions assume to faster assess new design solutions and then to better go toward innovation.

Figures 1 describes the global view of each function (i.e. 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 modelling 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.

This paper deals, only, with functions 1, 2 and 3. Hence, the state of the art, presented in section 3, is structured according to those functions.

3- Background Literature

Within the collaborative engineering product development cycle, the design process is considered as a creative process [GP1]. It is a high added value process regarding its complexity and the various business expertise which is 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 [GP1] which is the traceability.

In this article 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 - Process modelling

A multitude of process meta-models have been proposed during those last decades. Based on [W1], the authors argue that those models are providing adequate concepts to tackle the issues introduced above:

- IDEF meta-model is based on ICOM concepts: Input, Control, Output and Mechanisms [RD1]. They are close to Six W's concepts. The "what" can be supported by I/O, "Who, How, Why" can be seen as Resources or Mechanism of IDEF. Finally the "When" is implicit to the meta-model as it provides sequential links among the process activities.
- UML activity diagram [F1] also provides concepts related to the design process (activity, data flows, synchronisation bar ...). However, its applications are more dedicated to business process used, for example, in manufacturing system control.
- BPMN provide also different concepts to answer to the Six W's one [B1]. It will not be more detailed since the activity diagram is very similar to the UML one (data flows and control flows).

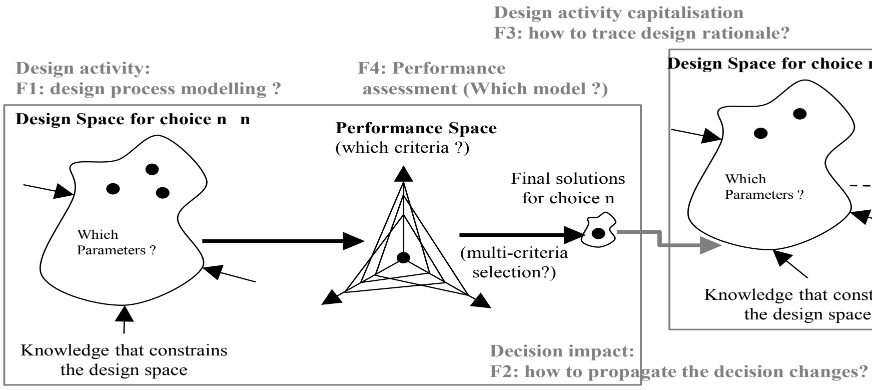

Figure 1: overview of decision making and main functions of the proposal.

As presented by [GP1], a process can be classified in three categories: creative, interactive and automatic. Those three categories rank the level of autonomy in running a process. Therefore, the authors argue that the design process is a creative process since the design process of a complex system is not known when the design starts. The process is, then, created dynamically.

3.2 - Change management

Change management represents a recurrent activity in collaborative design process that occupy between 20% to 30% of the project global time [K1] and [BS1]. To reduce this time loss, it is important to master the impact of the different modifications that concerns the input, control, and the process mechanisms. One major issue concerns the identification of the impacted modifications area in order to localise the specific activity to be executed without acting the modifications on all the process activities. The other issue concerns the simulation and the propagation of these modifications through the identified activities.

Different approaches, methods and tools were developed to master the change management. The following state of art (table 1) allows the comparison of these approaches based on their capability to identify, simulate and propagate the change.

Methods and tools	Change identification	Change simulation	Change propagation
CREOPS2 (Multi-agent distributed system) [C1]	Yes		
Architecture based agent to support the collaborative design process [CM1]	Yes	Yes	Yes
SHARED-Design Recommendation and Intel Management System (SHARED –DRIMS) [PSL1]	Yes	Yes	Yes
Protocol for change simulation [LN1]	Yes	Yes	
COllaborative COnflict Management in Engineering Design (CO2MED) [R1]	Yes	Yes	
What if design approaches [HL1]	Yes	Yes	Yes
Impact analyses method : CSP solver [OG1]	Yes		Yes
Monte Carlo method [JE1]	Yes	Yes	Yes
Algorithm to validate the parameters modification [RC1]	Yes		Yes
Dependences Graph describing the existing relations between the entities and impact and Analysis based on probability estimation [OS1]	Yes		
Probability of modification matrix, impact matrix, risk matrix [CS1]	Yes		Yes
DEPNET(product Data dEPendencies NETwork identification and qualification [OB1]	Yes	Yes	Yes
Propagation algorithm, identification and change impact algorithm [B1]	Yes	Yes	Yes

Table 1: Change management state of the art synthesis

3.3 - Traces for Product Design Process

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 [M1]. It aims to record the process lifecycle history by capturing:

- The design routes and the evolution of design items [S1].
- The information relative to the product and the process as well as their relations in the various product lifecycle phases [OB1]
- The important decisions and justification during the process lifecycle [OB1]
- The diverse modifications that took place during the conception process lifecycle

According to [A1], 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 [HA1], [OB1] which are adapted from the Zachman framework [Z1]. 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 [HA1] describes different constructs:

- 'What' represents the design objects that correspond to I/O of the design process, it could correspond to requirements, technologies, functions, parts…
- 'Who' corresponds to the actors with different competencies that are creating and using the design object.
- '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.

The traceability constructs proposed by [OB1] rely on the design product knowledge.

- 'What' refers to the product knowledge such as the design elements, constraints...
- 'Who' represents the actors creating, using and modifying the product knowledge.
- 'Where' identifies the activity that handles the product knowledge.
- 'When' informs about the time and date of creation or modification of the product knowledge.
- 'Why'corresponds to the objectives of the activity creation or modification.
- 'How' represents the justification or the design rationale behind the decision of the product Knowledge creation or modification.

3.4 - 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' [RL1] in order to evaluate the process performance and to detect the frequent sequences, delays and the eventual conflicts …

The MUSETTE approach developed by [CP1], in the context of computer system use, exploit the interaction traces between the systems and its users in order to assist the Agent-Task Management. The approach, developed by [BV1], aims to retrieve necessary and useful activities supervision information for the users involved in a context of Computer Learning Environments with heterogeneous tools. Besides, [PS1] exploit the traces, in the context of collaborative process, to improve the communication between users and to contribute to the establishing of a common knowledge. Moreover, [KC1] approach aims to specify and elaborate a knowledge oriented maintenance platform by exploiting the traceability constructs under the SBT (System Based on Traces) proposed by [SP1].

4- Discussion of the state of the art and proposal overview

Despite their different contexts of use, the studied traceability approaches are mainly articulated around three major connected phases: (a) traceability constructs collection based on the design process observation, (b) traces generation with respect to the objective of use and (c) traces visualization and exploitation.

In order to trace the process rationale in the context of collaborative design, the authors propose a framework based on the three-layer traceability approach (figure 2).

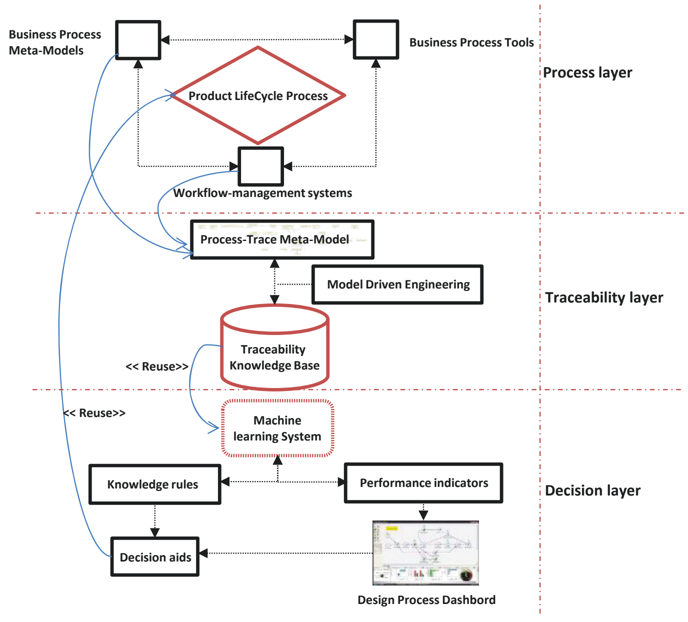

Figure 2: Overview of the proposal.

4.1 – Framework Process Layer

The first layer depicts the observation phase of process design which is characterized by different process models and tools and workflow execution tools.

IDEF0 is selected by the authors to model design process. Figure 3 shows how each of the IDEF concept answer modelling the Six W's concepts expected in a design process. As presented on figure 3, IDEF0 process model will be also used to identify relation among decision making activity and to propagate some change from one decision to another.

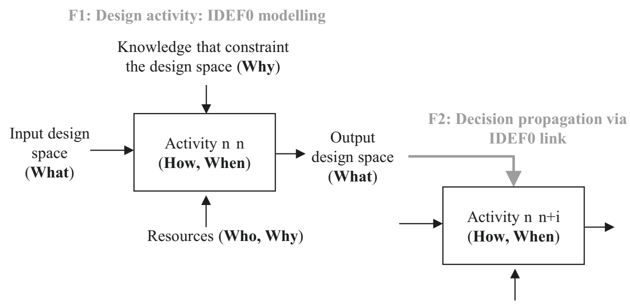

Figure 3: Process modelling with IDEF0

Figure 4 shows in UML formalism the design rationale model describing all the constructs that contribute to the creation of product knowledge during the design phase.

Figure 5 presents an illustration of the design process modelling on a simple example that aims at selecting four parameters in the design space. It has proven that changes can be propagated via concepts and relations identified in the process model. As far as IDEF0 constraints, resources or outputs are changing; only impacted activities can be re-computed.

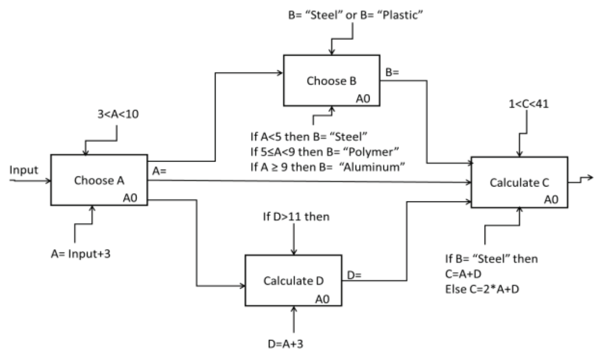

Figure 5: Change management based on process modelling.

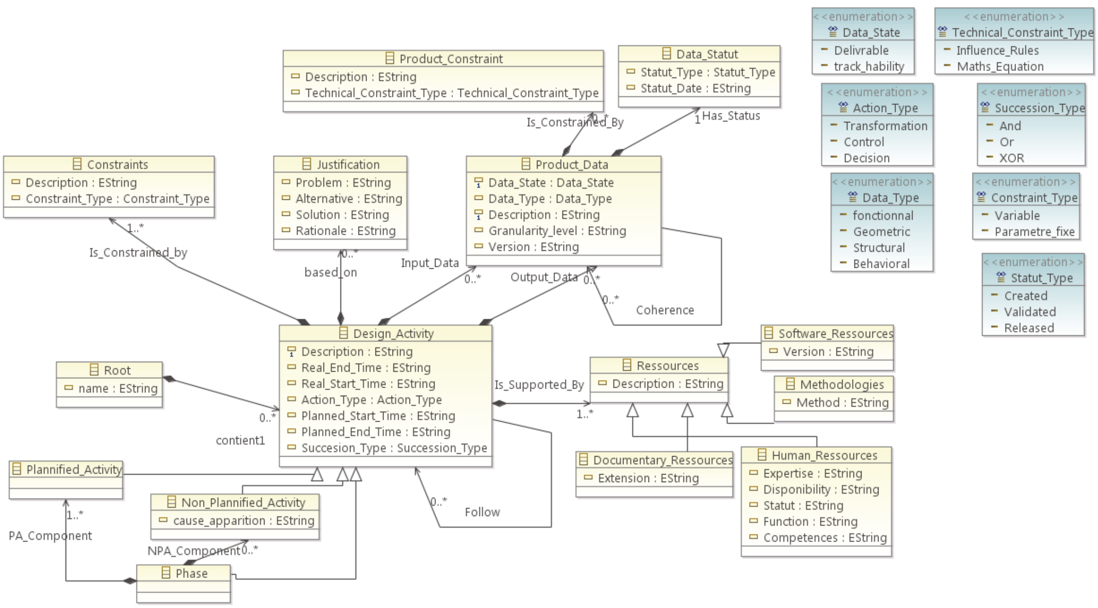

Figure 4: Proposed UML formalism to identify knowledge construct for design rationale

4.2 – Framework traceability Layer

The challenge of this layer is to identify the process trace constructs in order to build the traceability knowledge base. The authors assume that the trace process model corresponds to all the knowledge constructs identified under the process design model and to all the constructs related to the workflow execution such as the real time process start and end.

This traceability model was implemented under the Eclipse environment in order to derive automatically an Excel table that could be exploited in the framework decision layer to establish the performance keys.

4.3 – Framework decision Layer

This layer corresponds to the exploitation and reuse of the collected traces. It consists of two parts:

- Performance key generation and process design dashboard.
- Design rules deduction using machine learning. Those rules could be used automatically by the software resources in the design process or by the actors themselves and this according to their experiences feedbacks

5- Conclusion and recommendation for further work

This paper proposes a process model based design rationale capture. This allows modeling the Six W’s concepts, supporting the design change identification and tracing the decision making. The three-layer traceability approach is currently partly implemented (process modelling, trace modelling).

Future works will consist in deploying design example and to couple the two first layers with learning approach in order to support decision making based on capitalized design situation. Those examples will also be benchmarked with current approach in order to validate all the assumptions of this work:

- Accelerate information retrieval
- Accelerate change propagation
- Support decision making and alternatives performances assessment

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