

TOOL CHARACTERISTICS TO SUPPORT ALL LIFECYCLE STAKEHOLDERS' REQUIREMENTS IN COLLABORATIVE ENGINEERING DESIGN

Maria Paz Claros Salinas, Guy Prudhomme and Daniel Brissaud
Laboratoire 3S, University of Grenoble, BP 53, 38041 Grenoble cedex 9
Email: maria-paz.claros_salinas@hmg.inpg.fr

This paper presents a work about characterizing tools supporting designers on requirement management. Indeed, in a concurrent engineering context requirements management has become a complex work because requirements are taken into account as soon as possible in the design process. We analyzed design process through different view point we built a three-dimensional grid to characterize requirement management tools. Our goal is to validate the capability of this grid to characterize and evaluate the capabilities and the lacks of requirement management tools on supporting designers during the design process.

1. INTRODUCTION

This work deals with the study of engineering product design, particularly industrial products. During the last years, the increasing market competition and pressures on quality, cost and lead-time have led to a change in the organizational mode of the industries. Indeed to tackle difficulties coming from competitiveness, the design process has become collective. Nowadays for example, the marketing, the design and the manufacturing departments can be seen working together to create a product. Even the users of the product can take an active part in the design process. The aim of this movement is to enable all the life cycle stakeholders to work together. A stakeholder of the design process is everyone involved in the design process of the product for what he has to do, so short it is. In this way, most of industrial organizations have shift from a hierarchical structure to a more transversal one. Concurrent Engineering is a model of this new organizational mode, where the design process of a product is a collective and simultaneous activity: needs and constraints of the all life cycle stakeholders should be considered and studied.

This new mode of organization produces a necessity for the development of new methods to efficiently structure the design process. The methods proposed by Palh & Beitz (Palh&Beitz, 1996) or Ulrich (Ulrich, 2000) describe the design process as the search of solutions to satisfy identified needs. In a concurrent engineering approach, meetings of designers working in synchronous activities to assess

proposed solutions alternate with asynchronous activities where designers work as experts to develop the solution or a part of it based on his discipline rules and experience. It is assumed here that the design process follows a co-evolutionary approach (Maher, 2003), (Lonchamp, 2006) in which problem and solution permanently evolve in a simultaneous manner.

In a co-evolutionary design process, we focus on the process of the clarification of the requirements to characterize the properties of the design tools supporting designers on this clarification. Main questions are:

- ♦ What is called a requirement?
- ♦ What are the advantages and limits of commercial tools to support designers in requirements expression throughout the design process?
- ♦ Which are the properties that these tools should have to support the requirement management?

This paper is organized as the following. Section 2 will clarify the requirement concepts and terms and propose a first classification of requirement management tools. In section 3, the space of the properties of the design process is explored to highlight the 3 dimensions characterizing the requirement management tools. Some tools are treated through this space analyzer to illustrate the relevance of the analyze grid to evaluate its capability to represent tools capabilities to support designers on taking into account requirements throughout the design process.

2. REQUIREMENTS IN AN INDUSTRIAL DESIGN PROCESS

2.1 Identifying the client

Many authors say that the design process consists in setting up activities to propose solutions to satisfy clients' needs. Based on this definition, we add that these activities are bi-directional: from clients' needs to solution and conversely. Let us define more accurately who are the clients in this process?

The first client talked about is the one for whom the product is developing. He generally works out of the organization, and is called 'external client'. The term 'needs' in the literature is generally related to the external client.

In a Concurrent Engineering context, the viewpoints of each product lifecycle stakeholder have to be considered. Each of them defines his own specifications on the project. For example, the manufacturing expert and the recycling expert will explicit their needs on the product from their expertise to make easy and profitable the manufacturing process and the recycling concerns. These experts of the life cycle product are called 'internal clients' since they are members of the 'extended company'. Internal clients are from the industrial organization point of view. The practical term for the internal client is 'constraints' instead of needs.

So, as a summary of our point of view, a concurrent engineering context brings two kinds of clients from who needs and constraints should be integrated and tackled in an efficient design process:

- ♦ The external client formulates the needs of the product initially and reformulates them throughout the design process and so is a stakeholder of the design process,

- ♦ The internal clients, industrial stakeholders of a design process, formulate their constraints that may also evolve throughout the design process.

Finally stakeholders of the design process could be internal clients, external clients and designers.

2.2 From needs to requirements

The literature was reviewed to understand the terminology. The conclusion of this survey is a reformulation of the concepts to make them clear in the paper.

Needs

The needs can be expressed by any stakeholder but mainly by the external client. It is a lack or an expectation expressed in a natural language. Very often external clients do not know how to express their needs and are not aware of both the interest and the techniques of their expression.. It is generally assumed that most of the needs appear at the beginning of the design process.

For example, let us take the design of new car doors. The client would express his needs by “My car doors must have a good appearance and should be easy to open and close”.

Constraint

A constraint is a restriction, a limit or a regulation imposed on a product, a project or a process. It is a type of prerequisite or design feature that cannot be trade off, a condition to be respected. These constraints are related to standards or rules proposed by external organizations or to expertise of downstream steps of the product life cycle stakeholders. It also comes from the business strategy of the company.

For example, at least 70 percent of the car components must be recyclable; or the door components should be manufactured by the company facilities.

Requirements

From literature review, different definitions of the requirement concept were found. American standards (IEEE,1999) define requirement as “a statement that identifies a product or process operational, functional, or design characteristic or constraint, which is unambiguous, testable or measurable, and necessary for product or process acceptability (by consumers or internal quality assurance guidelines)” . For Harwell (Harwell, 1993) “a requirement is something that must be accomplished, transformed, produced, or provided”. Lin (Lin, 1996) defines requirement as “something that specifies the properties (functional, structural, physical, etc.) of the artifact being designed”.

The conclusion based on the review, industrial practices and design efficiency, is that a requirement is a need or constraint expressed in a standard language in terms that stakeholders can understand without ambiguities because its meaning was previously discussed and shared. Let us mentioned that in the Concurrent Engineering context, a requirement is more than just a translation of the needs and

constraints. It results from a long process of exchanges, discussions and negotiations among the stakeholders.

A requirement can be expressed by one sentence including "have to or shall be". European standards propose functional language to explicit a requirement as a function with criteria and levels associated. See Table 1 for continuing the example of the car doors specification process.

Table 1- Requirement Formulation (European Standards)

Function	Criteria	Level
Easy to close from outside	Energy to close the door	12ft-lb
	Peak closing force	13 lb
Easy to open from outside	Energy to open the door	10 ft-lb
Good Appearance	Non plastic look	

Of course as needs and constraints are, requirements will be evolving throughout the design project.

2.3 First classification of aided requirement tools

In this context, supporting designers during the requirements definition process all over the life cycle by computer-aided tools and methods is a great challenge. A research of tools able to support designers' activities on the requirements expression during a collaborative design process was made. Two main sources of information were used to select the tools to be studied. At first the web was looked at then industry discussions were carried out.

Requirement management tools were extracted to be the most convenient to illustrate the work done so far. SuiteTDCⁱ is a set of tools based on design methods. Two of them; TDCNeeds and TDCStructures focus on requirement management respectively from functional and structural point of views. Only TDCNeeds is analyzed in the paper. DOORSⁱⁱ has been developed by Telelogic, and has the leadership on the requirement management tools in industry today. It has functionalities that help designers to gather, analyze and visualize requirements.

Requirement management tools are classified in three groups by practitioners and industrialists:

Requirements Definition Assistant

Tools that assist designers and engineers to define the requirements from the identification of the needs to the formal expression.

Requirements Transformation Assistant

Tools that assist designers and engineers to follow-up and support the evolution and transformation of requirements during the design process.

Requirements Monitoring Assistant

Tools that assist designers and managers to regulate, control and check requirements throughout the design process.

This classification is too loose for a good characterization of requirement management tools. The dimensions enabling the performance of requirement management tools have been studied then to scientifically classify them.

3. THE THREE-DIMENSIONAL ANALYZER

In this section the three-dimensional space highlighted by our work to analyze the performance of requirement management tools throughout the design process is presented. The three dimensions are: the project view, the representation of the product and the design process properties. They are described in detail in the following.

3.1 The project stage dimension

This dimension is a project management view of the design process. Most of the companies organize their work by projects. A project is a temporary endeavor undertaken to create a product or service. It has a deadline and from a management viewpoint goes from a milestone to the next. So this dimension contains the different stages of a project which will be separated by assessment or decisional meeting.

According to Palh & Beitz, the first stage to start a design process is to identify the needs. These needs will evolve to requirements during the clarification of the task, then to structural proposition in the conceptual design phase, then to solution definition in the embodiment phase and details in the detail design phase. Furthermore are the stages of industrialization, production... recycling...

This project view is useful to manage the design process. This axis is therefore relevant to identify which stage of the project is supported.

3.2 The product representation dimension

During the project development, designers use different product representations: functional, structural and physical ones. At the beginning of the design process, the representation of the product is mostly functional, then its representation will turn structural then finally physical. The product representation will pass from an abstract representation to a concrete one. But, from a cognitive and co-evolutionary point of view, this evolution does not happen sequentially (Darses, 1997): the designers work simultaneously on the three levels of representations through a kind of zigzagging across the three representation levels. This axis is relevant to identify the type of representation supported.

Functional Representation

This representation includes functions that the product must fulfill and constraints to be respected. Functions and constraints are characterized by criteria and levels associated. Functional representation is external describing an answer to the customer demand or technical describing the functional

possibilities to fit the external functions. For example, a specification list or a QFD matrix are functional representations.

Structural Representation

It is a representation that describes the possible structure of a product. It can be a schematic representation like a cinematic scheme or a diagram including components and links among them. A block diagram from value analysis is a good example of this group.

Physical Representation

A physical representation describes geometrical and technological properties of the product. The numerical representations with CAD tools, prototyping are included in this representation level.

3.3 The properties-of-the-design-process dimension

This axis is relevant to identify the capabilities to support the properties of the design process. As mentioned at the beginning of the paper, the design process is no longer an individual work but collective one. In a Concurrent Engineering context, the team of designers is composed of people coming from different companies and expertise fields. Each one has its own viewpoint and requirements against the product, and expresses their needs to the team, who has to build a common sense of them (processes of elicitation and formalization). Once the first level of requirements is formalized, designers use them as baselines to look at solutions. But these requirements are not definitively fixed since they co-evolve throughout the design process related to new constraints and candidates. Stakeholders concerned by the requirement changes must be aware of them: the design process has properties of dynamics and propagation. And of course requirements should be consistent at any time of the design process (properties of correlation) and across product families (properties of traceability).

This axis is composed of six main properties of the design process: elicitation, formalization, propagation, dynamic, correlation and traceability processes.

Elicitation

Eliciting means to bring something out, calling forth or drawing out (information or response). Methods are needed to help designers to be the more rigorous and exhaustive during this activity. For example 6WH method (Who, What, When, Which, Why, Where, How) can be seen as a possible method helping designers to elicitate requirements.

Formalization

Formalization is the action of setting requirements in a formal language. This language must enable all stakeholders to express their own requirements, to share viewpoints and to negotiate. Functional analysis is a formal language standing for being a method to help designers to formalize requirements.

Propagation

During the requirements definition, requirements are not independent from each others and relate among them. A modification of a requirement impact and affect other requirements. The propagation is the capability to build relations among the requirements and to propagate the impact of changes onto requirements impacted upstream and downstream in the design process.

Dynamic

A requirement can be added or removed at any stage of the design process: the list of requirements is dynamic. The consequence is that new dependence links are going to appear and disappear. This connection among requirements impact the possibility to create or abandon requirements when designing. The Quality Function Deployment method can support the property of criteria propagation thanks to the matrix relation. Unfortunately these matrixes are static ones because requirements cannot easily and quickly be added or removed.

Correlation

The correlation is a causal, complementary, parallel, or reciprocal relationship, especially a structural, functional, or qualitative relation between two comparable entities. It is the relation between two variables which varies one according to the other. It is the dependency between two events, a reciprocal relation between two or more things. Correlation stands for requirements at the same stage of the design process. The roof of the QFD matrix enables designers to make this sort of correlation.

Traceability

Requirements should be traced forward from an initial statement to specifications and design components, and backward from design components to their motivating requirements. Backward tracing is necessary for system modification and maintenance, while forward traceability is used in managing development from requirements to implementation. It is the ability to trace the history, application or location of an entity by means of recorded identifications.

The content of the three-dimensional analyzer is summarized on figure 1.

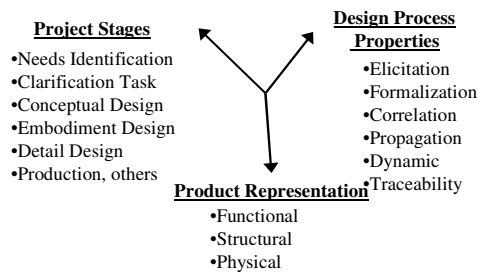


Figure 1- Three-dimensional analyzer content

~

4. APPLICATION OF THE ANALYZER

Let us apply the three dimensional analyzer on two commercial tools of requirement management. It would help to understand the analysis framework and highlight the properties that are not covered yet.

4.1 Project Stages

TDCNeeds: The first information to introduce in the tool addresses the project definition. Designers must answer a list of questions coming from the AFNOR standards (AFNOR, 1990), (AFNOR, 1991). Then, the identified needs are introduced in the form of functions. These functions are introduced in the table of characterization proposed by the Function Analysis method. TDCNeeds takes place on the two first stages of the axis.

DOORS: Baseline requirements must be identified and defined before beginning the work on DOORS. These requirements are introduced in DOORS. After this, designers can use the tool to support requirements evolution in the other stages of the project. It covers most of the stages of the axis.

4.2 Product representation

TDCNeeds mainly supports the functional representation of the product because of the external Function Analysis method. This functional representation only addresses the first level of product requirements definitions: the external clients needs expressed on functional terms.

DOORS supports the functional representation of the product all over the product life cycle.

4.3 Properties of the design process

TDCNeeds: The design method included gives the tool the capability to support designers on the requirements expression and formalization. It allows saving the different versions of requirements. This traceability and propagation properties only address the functional aspect.

DOORS: This tool has the capability to support designers during requirement formalization. It helps also to define the links between requirements and allows propagation. DOORS enables the designers a general view over the changes and evolutions (add, change, delete...) of requirements.

These properties are summarized in Figure 2. The analyzing space proposed is finer than the rough classification made by the industrials. Indeed, according to their classification, Requirement Definition tools spot the intersection between Elicitation and Needs Identification; Requirement Transformation tools spot several categories of the space; Requirement Monitoring tools spot the surface between Project Stages and Design Process. As visualized on Figure 2, the two tools do not support the same activities: DOORS is mainly a Requirement Monitoring tool and TDCNeeds a Requirement Definition tool. Both of them mainly address the functional representation of product. They are complementary tools and do not cover the whole space together.

2. Harwell R., Aslaksen, E., Hooks, I., Mengot, R., Ptack, K., "What is a Requirement?" in Proceedings of the Third International Symposium of the NCOSE, 1993. Retrieved September 2001, from http://www.incose.org/rwg/what_is.html
3. Jinxin Lin, Mark S. Fox and Taner Bilgic, "A Requirement Ontology for Engineering Design", Enterprise Integration Laboratory, Dept. of Industrial Engineering, August 1996
4. Pahl G. and Beitz W., *Engineering Design: A Systematic Approach*, Springer Verlag, 1996 (2nde éd.).
5. Lonchamp P, Prudhomme G, Brissaud D, "Supporting Problem Expression within a Co-Evolutionary Design Framework", in *Advances in Design*, ElMaraghy, Hoda A.; ElMaraghy, Waguih H. (Eds.), pp 185-194, Springer, 2006, ISBN: 1-84628-004-
6. Maher M.L., Tang H.T., "Co-evolution as a computational and cognitive model of design", *Research in Engineering Design*, 14, 1, 2003.
7. Software Engineering Standards Committee of the IEEE Computer Society, IEEE Std 1220-1998, IEEE Standard for Application and Management of the Systems Engineering Process, January 1999, p34-42. Retrieved October 2001,
8. Ulrich K.T. and Eppinger S.D., *Product design and development*, Second edition, McGraw Hill International editions, 2000
9. AFNOR NF X 50-150, Vocabulaire de l'analyse de la valeur et de l'analyse fonctionnelle, Association Française de Normalisation, 1990
10. AFNOR NF X 50-151, L'analyse fonctionnelle, Association Française de Normalisation, 1991

ⁱ www.tdc.fr

ⁱⁱ www.telelogic.com