INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 05 MELBOURNE, AUGUST 15-18, 2005

MANAGING DESIGN ALTERNATIVES: FROM THE ALTERNATIVES MODEL TOWARDS AN AIDED DESIGN SYSTEM

Pierre NOWAK, Benoît EYNARD

Keywords: Integrated Designing Environment, Information Model, Software Specifications, Computer Intensive Design

1 Introduction

Our overall objective is to specify an integrated environment for aiding designers to save, browse and reuse design information. [1] presents the ideal mechanical engineering design support system and lists 17 goals for it. Those goals highlight the need of integration between various kinds of information, and show the need to manage product, process and alternatives data. The expected environment has then to integrate product, process and alternatives data, and to take care of consistency relations in each situation of the design process. In [2] we specified an information model based on existing product, process and alternatives models. We combined them by formalising the relations between each of them using UML [3] facilities. We have thus specified the way of the consistency of the data could be kept. Based on this model, our purpose is to specify a computer system that could be used by designers without upsetting their usual working practices [4]. The benefits of the expected system are to allow the designer to keep in mind the various design solutions, and to easily reuse already specified solutions in the same or different projects [5]. Therefore this paper presents the specifications of the dynamic behaviour of the model and assesses the benefits and disadvantages of its implementation regarding to the expected behaviour on an illustration.

2 Research survey

As argued in [6], "a model is a formal or semiformal language to give an abstracted representation of a system, a software, a mechanical product, etc." According to this statement, the aim of our research work has been to create or use models in order to specify an alternative management environment based on product and process models.

The first goal is to aid the designers during their current project tasks and to enable the design creativity. Having a strong link between the design process, the alternatives, and the product specification allows the designer to keep in mind the various design solutions, and to easily reuse the complete definition of each solution. The designer is also free to use design methodologies such as TRIZ [7] or risk assessment approach [8]. Our second goal is to allow the reuse of already specified solutions in different projects. The definition of the solution is generally based on a product model [9], and the context could be given by process model and alternatives model. The expected environment is thus based on product, process and alternative modelling.

2.1 Alternatives modelling

As above-mentioned, several alternatives are generated during the design process. Pahl G. and Beitz W. assert in [5] that each step of the design process must be evaluated regarding to the overall objective. If the result is unsatisfactory, the step has to be repeated. As we may have to take numerous step back, keeping and reusing the design history and the definition of proposed alternatives is essential [10].

Toyota industry has presented its own design approach based on design alternatives [11]. This method is based in keeping a large number of alternatives until specific design steps where evaluation criteria are used. In a similar approach, Akgunduz A. et al. propose in [12] an assessment matrix in order to aid the choice of optimal solutions. Kitamura Y. and Mizoguchi R. describe in [13] the importance of the numerous functional breakdowns for reaching the technical domain. Moreover, Tichkiewitch S. and Roucoules L. explain in [14] the need of a very strong link between functional requirements, physical principles and product breakdown structure. Thus, each design solution can be physically justified and well embodied.

The suggested approach described in [15] manages a set of knowledge relative to the functional and the structural breakdowns of the product. Of course, it manages knowledge relative to an overview of the product definition, providing information about alternatives and not about the detailed definition of what an alternative is made of. The definition of a technology is thus possible using the product model. The approach is based on both knowledge base and graphical representations. The first one stores all the knowledge where as the second one provides as a filter according to each designer's point of view. With such a model, one design solution can be partially stored and reused later on according to new technology, new design context, etc.

Figure 1 shows an example of the alternative model. This graphical representation includes functional breakdowns represented on the disk, principle solutions pasted on fulfilled function, and technologies with their assessment criteria. Figure 1 presents the design alternatives of a water tap. We can identify 3 rings, thus meaning 3 functional breakdown levels. On the outer ring, we have the function "control output flow" which could be fulfilled by a "plug valve" or a "sliding valve". The sliding valve principle is used within the two technologies "Lever action tap LT#132" and "Lever action tap LT#224". Each technology is descrobed with a summary of its situation within the design process and its characteristics.

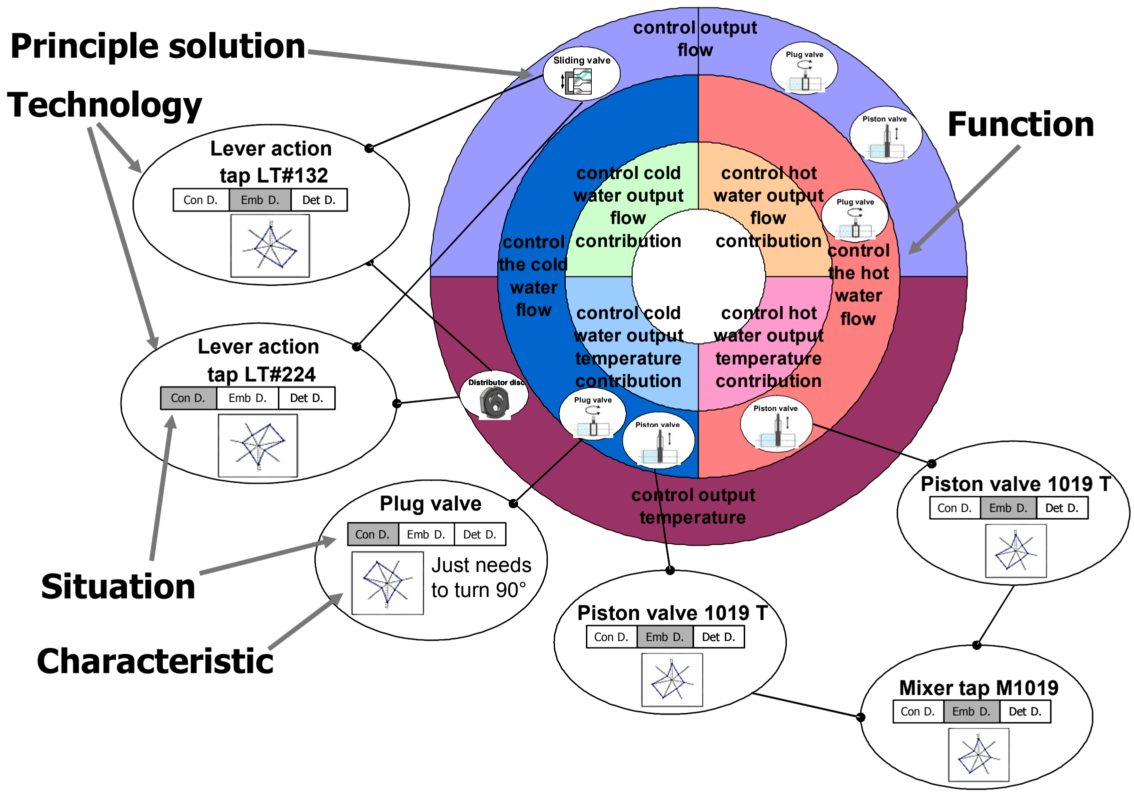

Figure 1. Alternatives management model: example of a water tap

2.2 Product modelling

Arzur, J. et al. define in [16] a product model as a way to obtain consistent information during the complete product life cycle and to allow the different designers to communicate. We have then to choose the most useful model for each design phase (conceptual, embodiment and detail design). Nevertheless, a link has to be made between several design domains such as functions, organs and parts according to the product development process progress.

So far in academic research, numerous research works have been focused on product models. During the eighties and the development of CAD systems, research studies were led by form features. Form features modelling is still studied but in the nineties and in a concurrent engineering context [17], feature based product models and knowledge based engineering have therefore been investigated [9-18-19-20-21-22-23]. Those models have been developed in order to manage product data from a functional specification at the conceptual design phase to the product breakdown structure at the detail design phase.

In this research work, we have chosen to use on one hand the Function-Structure and the Multiple point of view models together, and on the other hand the product model defined and used within the IPPOP project (Integration of Product – Process – Organisation for engineering Performance improvement) [24]. Function-Structure and the Multiple point of view product models have already been combined in [25]. Those models have been well studied and defined within numerous academic publications and we thus use them in order to show the static combination between models. The IPPOP product model [26] is based on similar concepts than the Function-Structure model and has multiple views abilities. Its main advantage is to be developed with the IPPOP software demonstrator. We will thus use this model for specifying the dynamic behaviour of our integrated environment and for aiding to the software development.

For conceptual and embodiment design, the Function-Structure model is used. This model stemming from the FBS (Function Behaviour Structure) model is also a mix of several models that describe an integration of the functional and structural aspects of the product. The model is on one hand based on bond-graph theory to take account of every kind of energetic field in the product. On the other hand the model includes graphics and rules coming from Value Engineering tools such as FAST diagram (Function Analysis System Technique) for ensuring the link with the functional analysis. The Function-Structure model as presented on Figure 2 is used to progressively map product functions to product structure [27]. Each function of the FAST diagram is associated to an energetic field that is kept coherent using the bond-graph theory. This model is fully described in [28] and [29].

For embodiment and detail design the Multiple point of view model is used. This representation allows multiple view breakdowns of the product and ensures the link with the geometric modelling. These feature-based breakdowns complete the product definition adding new data and new constraints from specific points of view as Machining, Structural Analysis, etc. The Multiple point of view model is fully described in [30]. As shown on Figure 2, this model represents on the one hand the product breakdown according to the Function-Structure product model. This view is called the Technologist view [27]. On the second hand, it is easy to create and to represent new views (new breakdowns) of the product (example: Machining view on the Figure 2).

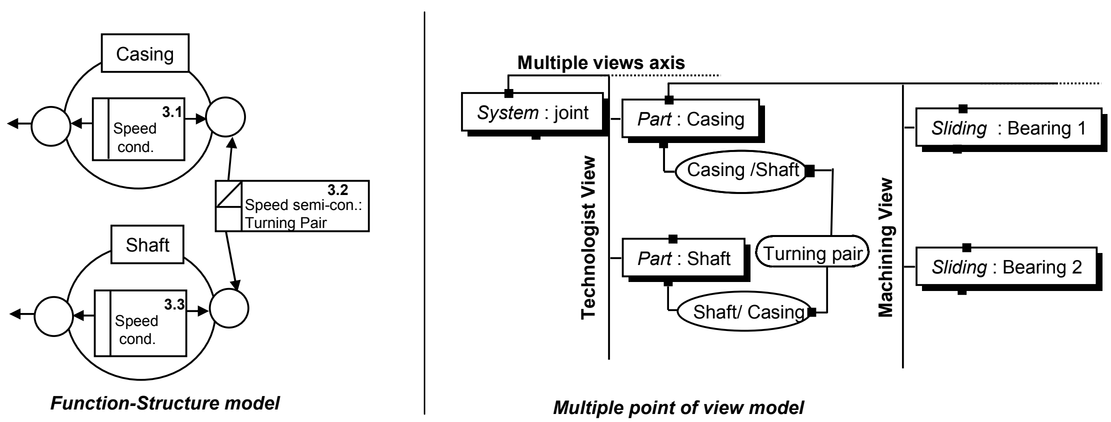

Figure 2. Product models : modelling example of a turning pair

2.3 Design process modelling

In order to have a better understanding of the company's processes, it is often necessary to give details of their organisation, progress and behaviour through activities of process modelling. Various methods exist regarding the aim of Business Process Reengineering (BPR) [31]. Eynard B. et al. present in [32] five modelling languages and detail a brief comparison. Those different modelling languages are relevant in different phases of the product development process. Cheol-Han Kim et al. show for example in [33] the differences between two modelling approaches IDEF (Integrated DEFinition) and UML (Unified Modelling Language). The authors present the benefits arising from the combined use of IDEF for describing a very complex system, and the use of UML for strongly structuring it.

Moreover product design brings in numerous co-workers having various points of view on the product. The design process model thus requires fundamentals that will support the various points of view in order to allow a global understanding of the position of each person within the design project and highlights the need for synchronization.

The design process model used is developed within the IPPOP project [24]. This process model [34] is flexible enough to not impose a too rigid structure or methodology like in workflow approach and not constraint the modelling work. Figure 3 presents the meta-model showing the data handled by the IPPOP process model. This model is centred on the activity to perform. Activities are led by the versioned product data, and the transitions between the various activities are impacted by the maturity level of the data. The resources support the process while constraints, trigger and goals define further the activity and its context. Those constructs are modelled with classes and the relations between them are represented with explicitly named UML relations. This modelling provides a consistent meta-model allowing to synthesis and capture the product design process.

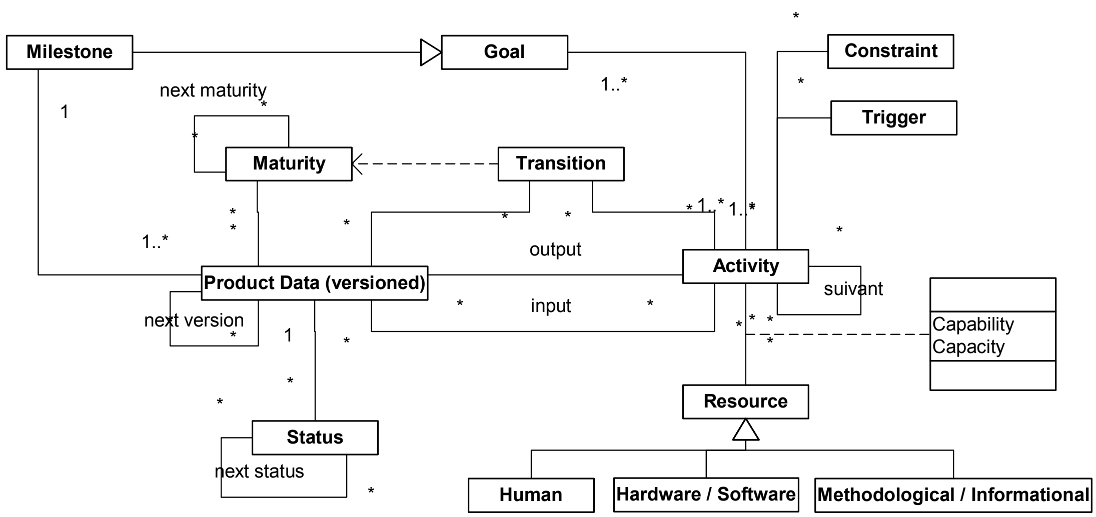

Figure 3. IPPOP Process meta-model

3 Static specifications

3.1 Improved alternatives model

Based on the research work presented in [15], the alternative management model has been improved. Main constructs and data modelled witch are necessary to assess and manage design alternatives are the same, but the model now involves all the constructs that are necessary to build up a data base. “Graph” and “Breakdown” classes have for example been added. Moreover, a particular attention has been paid to the consistency, the conciseness and the relevancy of the modelled knowledge.

The proposed model is mainly based on functional and technological features. Both features are linked in order to clarify the mapping between functional requirements and product breakdown structure. Features attributes have not to be redundant to process or product data featuring as studied in product models like [28-29-30]. The specified alternatives model only manages specific information while generic product and process definition are carried out by existing models. Thus, alternative features must set data that aid:

- The identification of each alternatives among the whole set of solutions (functional, physical or technological alternatives, solution parameters),
- The decision making among the alternatives at each design process step: conceptual, embodiment or detail design (solution assessment, choice argumentation).

First of all, the alternatives model has been specified based on an UML model (Unified Modeling Language) [3]. This data scheme allows a good structuring of each feature, each attribute and the existing relations among them. Figure 4 presents the design alternatives meta-model. Secondly, a database has been created based on this meta-model and is the kernel of the system.

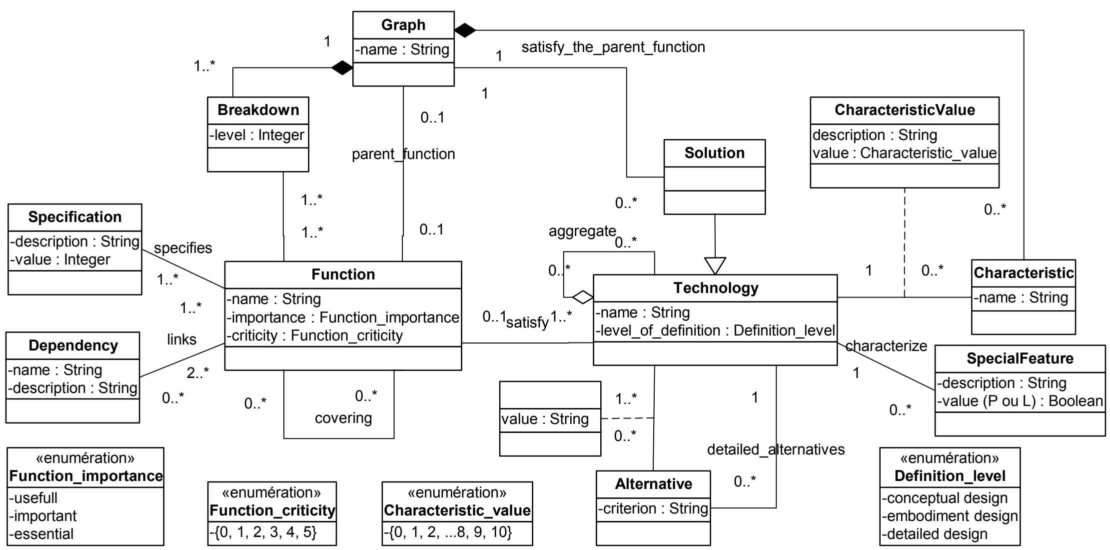

Figure 4. Alternatives meta-model

Some of the advances proposed on this new model are the possibility to characterize several technological alternatives using independent criteria and to asses several alternatives regarding to common characteristics. As the “Characteristic” class is an aggregate from the “Graph” class; characteristics are then common to the numerous technologies of the graph. The “Characteristic Value” class is a relation class between the “Technology” and the “Characteristic” and thus provides an assessment of the technology regarding to the characteristic. Concerning the alternatives criterion, we are able to value each alternative regarding to all defined criterion. We can thus use formalized criteria, combine them, and have more than a simple two choices knot. Moreover, we formalized the modelling of the functional merging, the parent / child graph link, and every enumeration used.

3.2 Combining models

We defined in [2] the chosen way for combining the above models in order to establish strong links between them and to enable their use within an integrated environment. Thus we just give here a brief description of the chosen approach and of the used tools.

As we already mentioned in the introduction, Ullman D.G. shows in [1] the need to manage product, process and alternatives data within an integrated environment. Such an environment would enable a designer to retrieve an already proposed alternative solution. It would also provide information about the context of creation and give the justification of the made decision. Moreover, the integration with the product definition allows the reuse of the alternative. An integrated environment could thus be useful to take several steps back in the design process, but also to provide an analysis tool including a synthetic view of the alternatives and their assessment as well as a complete definition of those alternatives. This could enhance the creativity of designers or help them to make a decision.

Many works have been carried out regarding the integration of models [10-35-36]. Ouazzani-Touhami M.A. proposes in [10] a method for product design based on the integration of an already known as relevant product model with a design process model. An alternative's matrix provides a view of the selected alternatives along the design process, or a view of the alternatives related to a component. Hong N.K. and Hong S.G. present in [36] an approach integrating with a unified representation the product, process and alternatives dimensions. This approach involves product and process alternatives concepts, and is dedicated to a top-down structural design process. Finally, we can mention the IPPOP project [24] which makes an effort for integrating product process and organisation dimensions.

Our approach is different because based on relevant models for the three domains: product, process and alternatives. The relation consistency is then ensured by a combination based on meta-modelling (Figure 5). This solution is allowed by the use of meta-models for defining each domain model. Thus we are able at a "meta" level to combine the models, in other words to specify new models making up formalised links between concepts which are similar or in relation. In our viewpoint, this methodology is more effective than to define a global model. In fact, as modules of our integrated environment are already specified and even developed, it is easier to develop the missing module and to manage the existing and the newly developed module to work together than to develop the whole environment. The flexibility is thus very important, and is a warranty for an open and reusable work.

Our approach uses the meta-model tool. In this research work, we use the meta-model tool for creating a schema for semantic data that need to be exchanged and at enabling the interoperability between previously presented models. As currently considered a model is an abstraction view of a system built for being easier to handle, understand and communicate. The conventional four-level of abstraction architecture of modelling are M0 (User objects), M1 (Model), M2 (Meta-model) and M3 (Meta meta-model) (Figure 5). In this study, we only use the levels M0, M1 and M2. Various modelling languages could be used for meta-modelling but UML [3] is of the most frequently used. The main UML diagram used for meta-modelling is the class diagram. Indeed this diagram provides many possibilities for describing models like aggregations or dependency relations. In some cases, UML is not sufficient for specifying the system in an unambiguous way. Ndiaye D. et al. propose in [37] to describe some additional constraints based on OCL (Object Constraint Language).

According to the method previously explained, a combination meta-model is used to describe in a formalised way the links between our numerous models. As shown on Figure 5, the combination between concepts from two different models is made using an association class. Operations of the association class are used to model and formalise the impact that could have the modification of an attribute or the use of an operation of one concept on the other. The obtained relation is thus bidirectional and insures the consistency between both models.

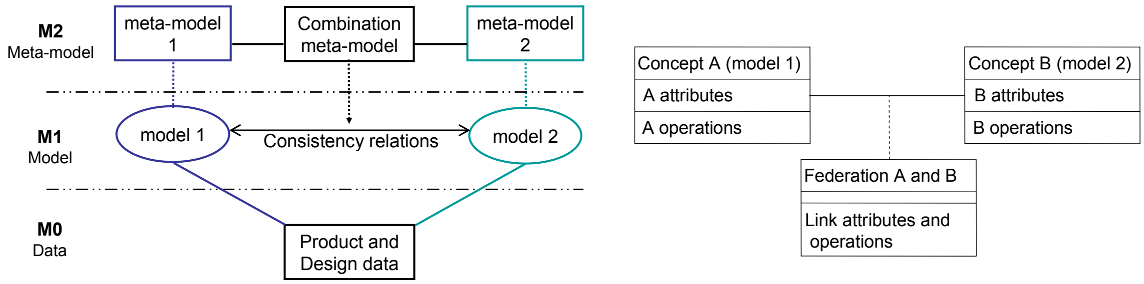

Figure 5. Mapping of the model levels, and combination using association class

4 Dynamic specifications

This section aims to specify the behaviour of the system based on the previously defined models. As introduced in section 2, an integrated environment supporting product and process modelling is already being defined within the IPPOP project. According to the IPPOP approach, a kernel of product, process and organisation data is shared between project team members. Then each expert does his tasks using shared information from IPPOP and checking in the IPPOP information that need to be shared. If he uses specific software, this software is called "expert tool". The alternative management application is then viewed as an expert tool from IPPOP, and as IPPOP is open source, we will be able to develop the API (Application Program Interface) enabling the integration between IPPOP and the real alternative management system.

4.1 Software technology choices

As we develop at the same time the alternative expert tool and the API allowing the communication with IPPOP, it is relevant to make a compatible software technology choice. IPPOP is based on OpenCascade technology for the kernel, and on a PHP (Php Hypertext Preprocessor) for the man machine interface. The communication between the kernel and the interface is made by a specific executable file. Moreover, using OpenCascade facilities, IPPOP is able to export the information within an XML (eXtended Markup Language) file.

Our alternative application needs also a data base, we have thus made the choice to use MySQL with a PHP interface and to communicate with product and process definition using IPPOP XML files.

4.2 Modelling the environment behaviour

The integrated environment provides a knowledge base of technical solutions and insures a capture of the design history. Moreover, it allows highlighting previously developed alternatives before decision making. Within the alternative expert tool, alternatives are shown in their most complete specification state and their functional and technological viewpoints are linked to the product breakdown structure. Our proposal is close to the concept of project memory [38] in only considering of the product modelling and management.

In order to specify the dynamic behaviour of the integrated environment, we use UML [3] use case and sequence diagrams. Those diagrams are both used to specify the behaviour on a different granularity level. Indeed, the use case diagram is used to show the various possibilities you have to interact with the system, while the sequence diagram is able to detail the process of one of the possible interactions. Thus we define a global use case diagram, and each use case is detailed using a sequence diagram. Figure 6 shows a partial view of the use case diagram modelling the behaviour of the alternative expert tool. A second diagram is used to model the functionalities added to IPPOP by the use of our expert tool. By the way, we defined the possibilities to interact with the whole environment in a goal of managing design alternatives.

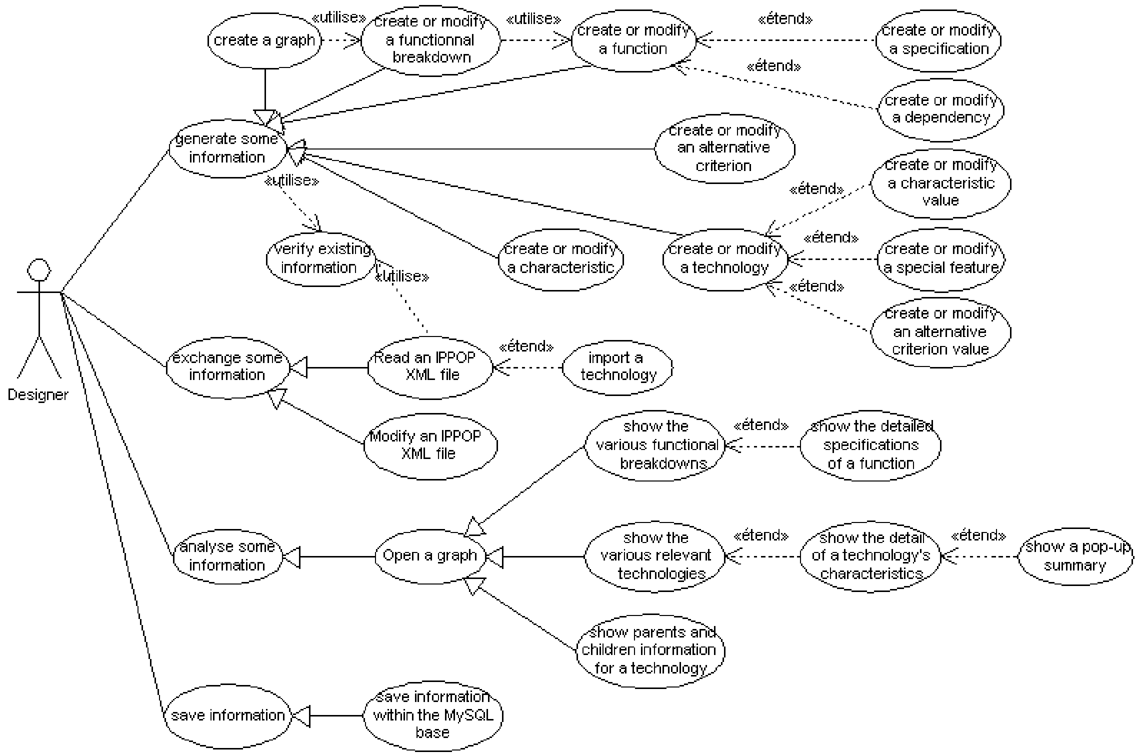

Figure 6. Partial Use Case diagram

Figure 7 shows the example of the sequence diagram for the use case “create or modify a function”. This diagram specifies the fields the user will have to fulfil for creating a new function. An illustration of this window is available within the section 4.3. More complex sequence diagrams have to be specified when the sequence is not a simple definite list of actions. The import “read an IPPOP XML file” and export “modify an IPPOP XML file” use cases involves whole algorithms and need mathematical rules formulations to be specified.

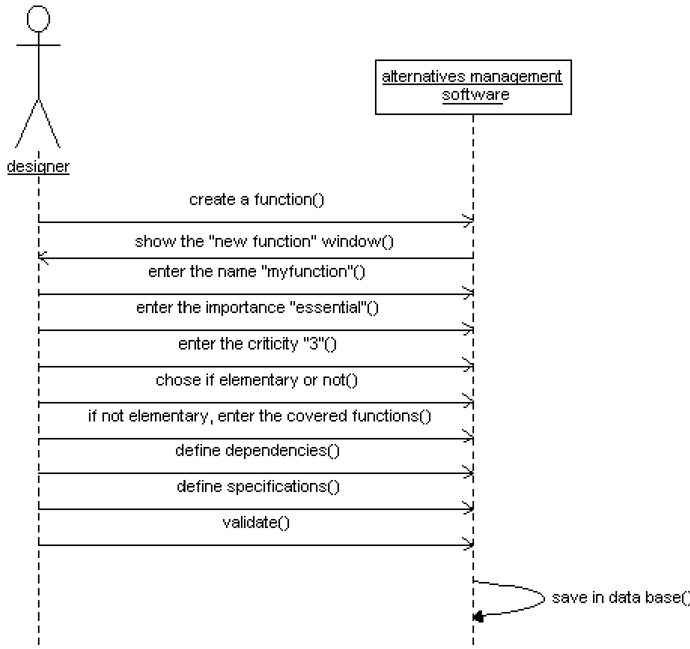

Figure 7. Sequence diagram of the use case “create or modify a function”

4.3 Illustration of the proposed approach

This section describes an illustration of the behaviour of the system based on a student project. The aim of this work was to design a speed reducer to adapt a diesel engine on an aircraft. The main functionalities of the expected product are to transmit the power from the engine to the propeller and to transmit the traction strength from the propeller to the aircraft structure, but is also to absorb the rotating shocks between the engine and the propeller. The student found several principle solutions, and also specified several FAST diagrams in order to represent the various links between functional specifications and product breakdown structure. He then proposed a belt based solution which could answer to the transmission of power function and to the absorption of shocks. Later in the project, he received some documents about joints able to absorb rotating shocks, and had to define criteria to assess and make a choice between the alternatives. All this work has been done on paper and common MS-Office software. By the way, the probability to lose information, to forget the meaning of the structure used within a document, or just to forget what was one parameter for, are increased.

The student did not encountered blocking points, but by having a closer look to the process followed by the student, we can notice that the problems he had to solve could be helped by a dedicated tool that would allow him to formalise his work and to reuse it without missing information. Moreover, numerous key steps of his project match the objectives of our alternative management software. As an example, the Figures 8 and 9 shows what could be the dashboard of the student if he has been using the alternative management software.

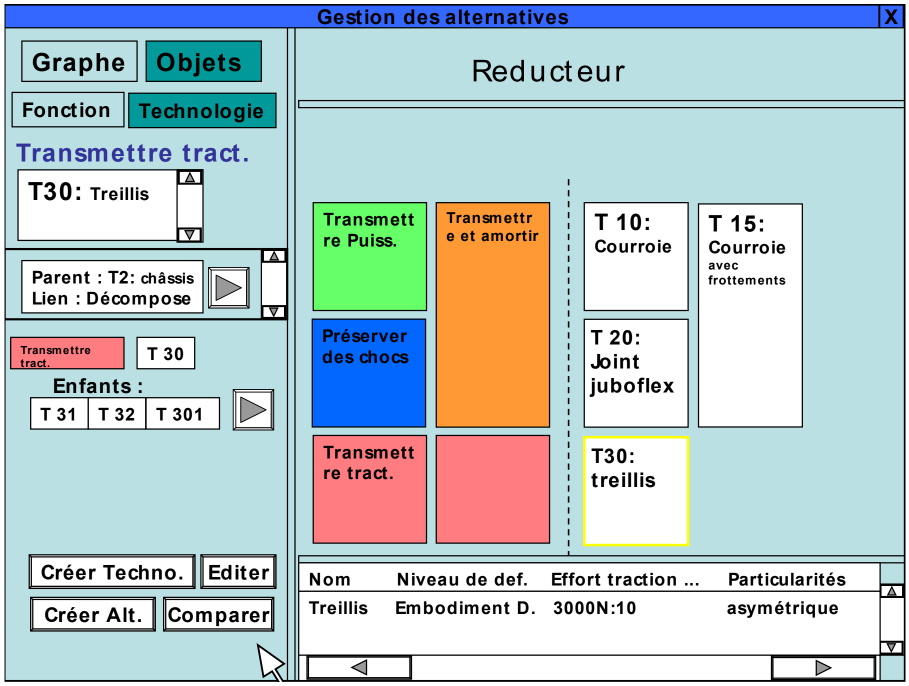

Figure 8. Expected screen shot of the alternative management software : function and relevant technologies

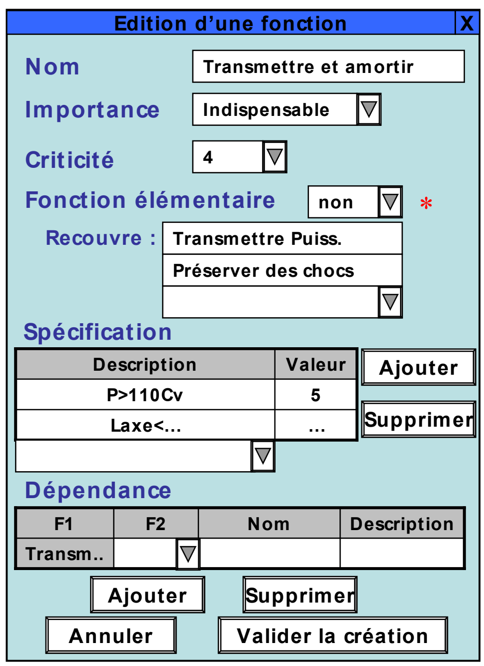

Figure 9. Expected screen shot for creating or modifying a function

5 Preliminary assessment

Based on the student project and on the described behaviour of our alternative management software, we are able to identify various steps of the "as-is" process that could have been carried out in an easier and thus faster way or simply with less error probability. However the student would have to familiarize himself with this new tool and to formalize a large part of his work. Based on criteria proposed in [4], we can highlight some advantages and disadvantages of the use of such a tool at an operational level:

Advantages:

- Execution time of design activities: even if at the beginning this execution time will probably be increased, once the user familiarized with the system, information will be easier to find and reuse.
- The probability of errors detected in product design due to problem related to KM will decrease with the formalisation.
- Capacity of proposing innovative solutions.
- The probability of requests for modifications of the design that might occur because of problems related to KM are also minimised.

Disadvantages

- Execution time of design activities longer at the beginning.
- The time dedicated to the use of the system is important.

At a strategic level we can firstly identify the lack of collaboration facilities. Moreover, as the system is not yet fully developed and has not been tested even virtually on a multi actor case study, all strategic aspects of the brought advantages of the software can not be assessed. Nevertheless, from a manager point of view we can point out the reusability of collected information as an advantage of the "to-be" process. Another interesting criterion is the quality of design interactions that we can expect due to the user friendliness of the human-machine interface. This last point should be the best perceived advantage from a designer or a technician point of view. At the same time, using the software will gently disturb designers in their working practices because they need to devote time to learn the software behaviour and to capture in a detailed and formalised way the results of their work.

6 Conclusion

This paper presents the specifications for an alternatives centred integrated environment for designing and details and illustrates its implementation. We presented existing models and the combining methodology used. An implementation of the alternative meta-model and dynamic specification of the expected integrated environment are proposed. The dynamic specification of the environment is really important because in our opinion we can not claim that we help designer if we have no idea of the way designers will use the system. Moreover the proposed illustration is useful for reinforcing and validating the specifications of the dynamic management of the model. Nevertheless, due to its characteristic of a single student project, it brings in some lacks. Indeed, there is no collaboration situation, and not either any past project which we could browse for reusing already designed and assessed solutions.

Further works could deal with the finalisation of the implementation of the software demonstrator and with a real case study. Another point which is not to be ignored is the ergonomic of the system. This point could certainly be improved if we change our PHP interface for a real programming language based software.

References

[1] Ullman, D.G., "Toward the Ideal Mechanical Engineering Design Support System", Research and Engineering Design, Vol. 13, n° 2, 2002, pp. 55-64.

[2] Nowak, P., Eynard, B., and Roucoules, L., "Design Alternatives Management Based on Product and Process Modelling", Proceedings of the Fifth International Symposium on Tools and Methods of Competitive Engineering (TMCE 2004), Millpress, Lausanne, Switzerland, April 13-17, 2004, pp 1099-1100.

[3] Booch, G., Rumbaugh, J., and Jacobson, I., "The Unified Modeling Language User guide", Addison-Wesley, Boston, 1999.

[4] Bordegoni, M., Cascini, G., Filippi, S., and Mandorli, F., "A Methodology for Evaluating the Adoption of Knowledge and Innovation Management Tools in a Product Development Process", Proceedings of the ASME Computers and Information in Engineering Conference (DETC'03), Chicago, Illinois, USA, September 2-6, 2003.

[5] Pahl, G., and Beitz, W., "Engineering Design: A Systematic Approach", Springer-Verlag, London, 2nd edition, 1996.

[6] Rieu, D., Bounaas, F., Morat, O., and Tamzalit, D., "De la méta-circularité au service de la méta-modélisation", Proceedings of INFORSID'97 Congres, Toulouse, France, June 10-13, 1997, pp. 577-599.

[7] Altshuller, G., "Creativity as an Exact Science", Gordon and Breach, New York, 1988.

[8] Larson, N., and Kusiak A., "Managing Design Processes: A Risk Assessment Approach", IEEE Transactions on systems, man, and cybernetics-part A: systems and humans, Vol. 26, n° 6, 1996, pp. 749-759.

[9] Krause, F.-L., Kimura, F., Kjelberg, T., and Lu, S. C.-Y., "Product modelling", Annals of the CIRP, Vol. 42, n° 2, 1993, pp. 695-706.

[10] Ouazzani, A., "La méthode SAGEP pour l'aide à la gestion de l'historique de conception", PhD Thesis, Ecole Centrale de Paris, France, 1999.

[11] Ward, A., Liker, J.K., Cristiano, J.J., and Sobek, D.K., "The second Toyota Paradox: How delaying decision can make better car faster", Sloan Management Review, Spring, Vol. 36, n° 3, 1995, pp. 43-61.

[12] Akgunduz, A., Zetu, D., Banerjee, P., and Liang, D., "Evaluation of sub-component alternatives in product design processes", Robotics and Computer Integrated Manufacturing, Vol. 18, n° 1, 2002, pp. 69-81.

[13] Kitamura, Y., and Mizoguchi, R. "Organizing Knowledge about Functional Decomposition", Proceedings of the International Conference on Engineering Design (ICED 03), Stockholm, Sweden, August 19-21, 2003.

[14] Tichkiewitch, S., and Roucoules, L., "Methodology for innovative design", Integration of process knowledge into design support systems, Kluwer Academic Publishers, Dordrecht, 1999, pp 81-90.

[15] Nowak, P., Eynard, B., and Roucoules, L., "A Design Alternatives Assessment and Management Approach", Proceedings of the ASME Design Automation Conference (DETC'03), Chicago, Illinois, USA, September 2-6, 2003.

[16] Arzur, J., Lombard, M., and Bernard, A., "Proposition of a federative product model", Proceedings of the International Conference on Integrated Design and Manufacturing in Mechanical Engineering (IDMME'00), Montréal, Canada, May 16-20, 2000.

[17] Sohlenius, G., "Concurrent Engineering", Annals of the CIRP, Vol. 41, n° 2, 1992, pp. 645-655.

[18] Kjelberg, T., and Scmelkel, H., "Product Modelling and Information Integrated Engineering Systems", Annals of the CIRP, Vol. 41, n° 1, 1992, pp. 201-204.

[19] Anderl, R., and Mendgen, R., "Modelling with constraints: theoretical foundation and applications", Computer Aided Design, Vol. 28, n° 3, 1996, pp. 155-166.

[20] Vancza, J., "Artificial intelligence support in design: a survey", Integration of process knowledge into design support systems, Kluwer Academic Publishers, Dordrecht, 1999, pp. 121-124.

[21] Bernard, A., "Modèles et approches pour la conception et la production intégrées", Journal Européen des Systèmes Automatisés, Vol. 34, n° 2-3, 2000, pp. 163-193.

[22] Smith, J., and Duffy, A., "Re-using Knowledge - why, what and where", Proceedings of the 13th International Conference on Engineering Design (ICED 01), Glasgow, UK, August 21-23, 2001.

[23] Nomaguchi, Y., Tomiyama, T., and Yoshioka, M., "Design knowledge management based on a model of synthesis", Proceedings of the 5th IFIP WG5.2 Workshop on Knowledge Intensive CAD (KIC'5), St Julians, Malta, July 23-25, 2002.

[24] Girard, P., and Eynard, B., "Integration of product – process – organisation for advanced engineering design", Perspectives from Europe and Asia on Engineering Design and Manufacture, Kluwer Academic Publishers, Dordrecht, 2004, pp. 587-598.

[25] Nowak, P., Roucoules, L., and Eynard, B., "Product Meta-Modelling : An Approach for Linking Product Models", Proceedings of the IEEE Conference on Systems Man and Cybernetics (SMC'02), Hammamet, Tunisia, October 6-9, 2002.

[26] Noël, F., Roucoules, L., and Teissandier, D., "Specification of Product Modelling Concepts Dedicated to Information Sharing in a Collaborative Design Context", Proceedings of the International Conference on Integrated Design and Manufacturing in Mechanical Engineering (IDMME 2004), Bath, UK, April 5-7, 2004.

[27] Roucoules, L., Eynard, B., "Background and specifications for a computer co-operative design environment for concurrent engineering", Proceedings of the ISPE International Conference on Concurrent Engineering (CE 2001), California, USA, July 28 - August 1, 2001.

[28] Eynard, B., "Modélisation du produit et des activités de conception. Contribution à la conduite et à la traçabilité du processus d'ingénierie", PhD Thesis, Université Bordeaux 1, France, 1999.

[29] Roucoules, L., "Méthodes et connaissances : contribution au développement d'un environnement de conception intégrée", PhD Thesis, Institut National Polytechnique de Grenoble, France, 1999.

[30] Tichkiewitch, S., "Specification on integrated design methodology using a multi-view product model", Proceedings of the ASME Engineering System Design and Analysis Conference, Montpellier, France, July 1-4, 1996.

[31] Vernadat, F.B., “Enterprise modelling and integration : Principles and applications”, Chapman & Hall, London, 1996.

[32] Eynard, B., Merlo, C., and Carratt, B., “Aeronautics Product Development and Certification Workflow based on Process Modelling”, Proceedings of the International Conference on Concurrent Enterprising (ICE’02), Rome, Italy, June 17-19, 2002, pp. 439-442.

[33] Cheol-Han, Kim, Weston, R.H., Hodgson, A., and Kyung-Huy, L., “The Complementary Use of IDEF and UML Modelling Approaches”, Computers in Industry, Vol. 50, n° 1, 2003, pp. 35-56.

[34] Nowak P., Rose B., Saint-Marc L., Callot M., Eynard B., Gzara-Yesilbas L., and Lombard M., “Towards a Design Process Model Enabling the Integration of Product, Process and Organisation”, Proceedings of the International Conference on Integrated Design and Manufacturing in Mechanical Engineering (IDMME 2004), Bath, UK, April 5-7, 2004.

[35] Kovacks, Z., Le Gof, J.M., and McClatchey, R., “Support for Product Data From Design to Production”, Computer Integrated Manufacturing Systems, Vol. 11, n°4, 1998, pp. 285-290.

[36] Hong, N. K., and Hong, S.-G., “Application of Entity-Based Approach for Unified Representation of Design Alternatives for Structural Design”, in Advances in Engineering Software, Vol. 32, n° 8, 2001, pp. 599-610.

[37] Ndiaye, D., Bigand, M., Corbeel, D., and Bourey, J.P., “Information System for Production Engineering: Contribution to Maintaining Consistency of Composite Data Using an Object-Oriented Approach”, International Journal of Computer Integrated Manufacturing, Vol. 15, n° 3, 2002, pp. 233-241.

[38] Matta, N., Ribière, M., Corby, O., Lewkowicz, M., and Zacklad, M., “Project Memory in Design”, Industrial Knowledge Management - A Micro Level Approach, Springer-Verlag, Berlin, 2000.

Corresponding author’s name: Pierre NOWAK
Troyes University of Technology
Laboratory of Mechanical Systems and Concurrent Engineering (LASMIS)
12, rue Marie Curie - BP 2060
F.10010 TROYES CEDEX – FRANCE
Phone: +33 6.75.31.31.38 - Fax: +33 3.25.71.56.75
E-mail: pierre.nowak@utt.fr