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

INTERACTIONS MODELLING BETWEEN FACTORS INFLUENCING MANAGEMENT OF DESIGN SYSTEM EVOLUTION

V. Robin, S. Sperandio, S. Blanc and Ph. Girard

Abstract

The new stake in design today is to examine the global purpose of the design activities. In this perspective, project design management not only consists in allocating resources, but also in stimulating collaboration among the actors involved in the project. Objective is to increase the performance of design teams. In this paper, we are particularly interested in the factors influencing performance of the design process. We identify the elements of the design performance and the need for a framework to manage design activities. A modelling of design context is also provided to manage design process. An application to an industrial case is then studied through the use of software formalising the exchanges during a real design process.

Keywords: Engineering design, design system modelling, design system evolution, performance management.

1 Introduction

The complexity of engineering design processes increases continuously and objectives of cost, delay and quality are more and more restrictive. From now on, they have to integrate a great number of expertises based on collaboration between the different actors involved. In such a context, one purpose of design management is to define and to organise the system where the design transformation will take place, according to the needs of collaboration and design objectives. Approach that is frequently adopted is to decompose the strategies and objectives through a hierarchical structured organisation. ENAPS Performance Measurement Cube [1], Performance Pyramid [2], Pawar and Driva's framework for product development performance metrics [3] [4] or Integrated Performance Measurement Framework [5] permit this decomposition and describe interactions that exist between each operational activities of the design process. Moreover, they don't explain clearly nature of these interactions and as a consequence, reduce efficiency of the design management. Haffey and Duffy conclude that "*none approach recognise the need to co-ordinate the resources necessary to realise objectives, or reflect the need to monitor and understand an activity's context or factors that can contribute to attainable performance*" [6]. That's why, we propose a new approach to manage design process. Firstly, we focus on constitutive elements of the design context and on the interactions between them. Objective is to provide a framework to facilitate understanding of the design context and development of a performance measurement system. In a second part, we describe methodology, concepts and tools which are necessary to achieve the definition of this system. Lastly, an industrial case presents the use of the proposed concepts by the mean of a software application.

2 Modelling of the design system

O'Donnell and Duffy's generic model of design activity performance insists on the necessity to identify components of an activity and their relationships [7]. This identification is the first step of Performance Measurement System (PMS) designing. Many PMS models exist in literature but few of them provide a framework to achieve properly this step. Furthermore, most of them are centred on the business performance [8] or [9], but few of them are dedicated to the evaluation of the design system. The Perez *et al.*'s model [10] is one of these frameworks and it's symptomatic of the design process PMS lack. It provides a general framework for the assessment of design process performance but it doesn't give a very clear methodology, based on specific concepts and tools, to develop a PMS. In our approach we propose a specific model to analyse and describe the design system that will be a base for development of a PMS.

2.1 Factors influencing the design system

Nowadays performance evaluation of enterprises obliges to manage discretionary activities, which are more and more collaborative [11]. Therefore, it is not enough to measure and to manage product data or progress of the design process. Evaluation should focus on interactions, which are generating the design process. Hence, design management requires understanding of design process context in order to adapt actors' work if it's necessary [12]. Ostergaard and Summers [13] advocate that the description of the design context has to contain elements concerning: team composition, communication, distribution design approach, information and nature of problem. In this approach, we have only a general frame to define design context. It is Badke-Schaub and Frankenberger's researches that provide a more practical approach [14]. They studied mechanism leading to successful solution decisions in 82 collaborative design situations and proposed an analysis of the design projects (Figure 1).

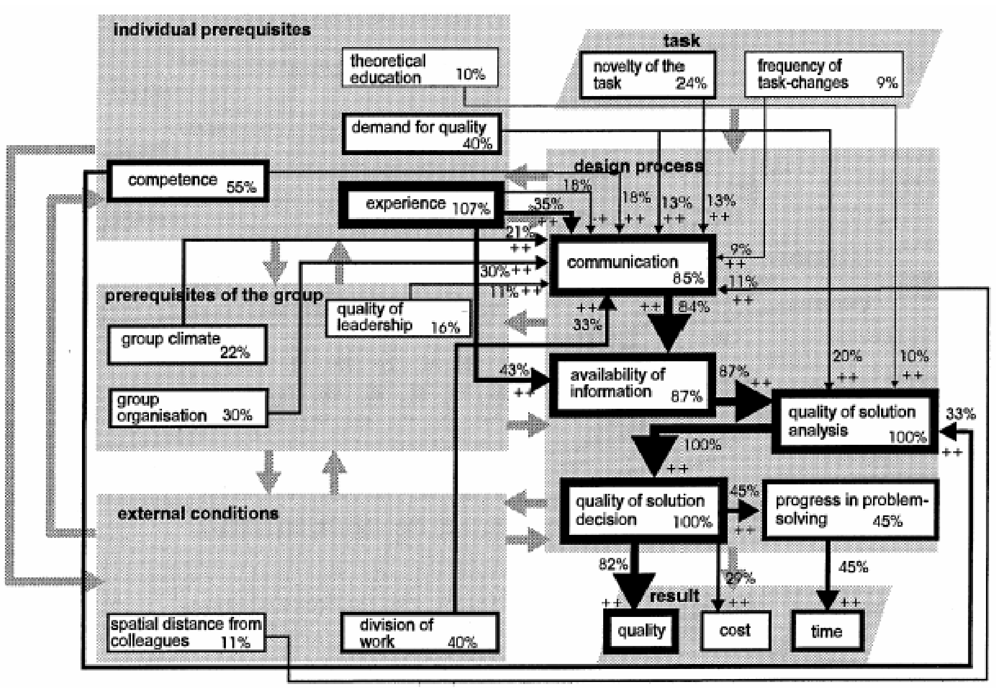

Figure 1. Mechanism leading to successful solution decisions [14]

This mechanism allows identifying the predominant factors that we have to take into account to manage efficiently design process: task, design process, external conditions, and the group and individual prerequisites. Nevertheless, this model is a very operational one and we propose to extend them to a more general vision of the design process. Rosenman and Gero [15] show that during design process progress, artefacts create a techno-physical environment interacting with the natural and socio-cultural environments, thanks to human. Eder [16] completes this viewpoint while describing the design engineering as the centre of several axes of human activities: the techno-scientific axis, the socio-cultural axis and the econo-organisational one (Figure 2).

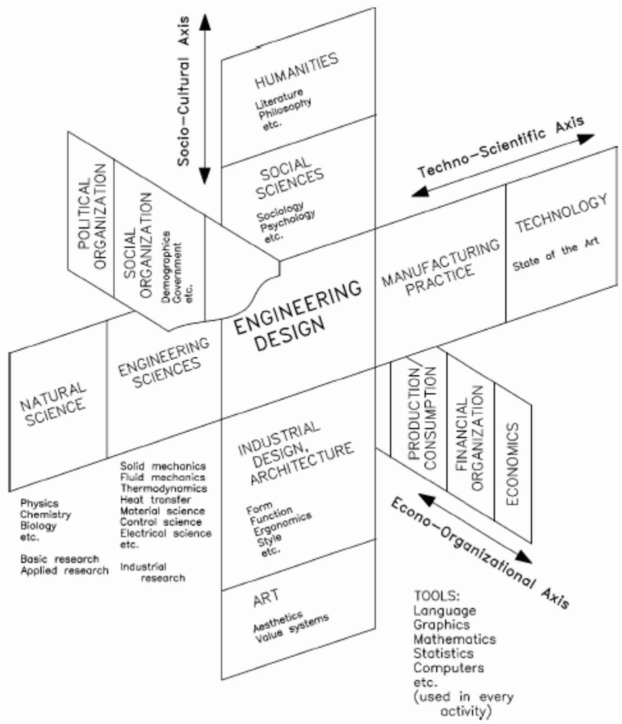

Figure 2. Design engineering in Techno-Scientific, Socio-Cultural and Econo-Organisational context [16]

The Eder’s description is pertinent since it provides a high level of specification and integrates elements identified by Ostergaard and Summers or Badke-Schaub and Frankenberger. The whole of these considerations leads to take into account three factors influencing the design system to follow and manage suitably the design process:

- The technological factor that concerns the techno-physical environment (*scientific and technological knowledge*).
- The context in which the design process takes place. It includes natural, socio-cultural and econo-organisational environments (*external and internal environments*).
- Human and his different activities during design process (*human*).

Scientific and technologic knowledge regroups elements of the Eder’s techno-scientific axis. It contains scientific knowledge based on the natural science and on the engineering sciences, and technologic knowledge that concerns the manufacturing practices and the technology. Interest is to have a global vision of the knowledge possessed and usable by the enterprise and to identify a potential lack of knowledge in some design tasks.

External environment concerns the global context in which enterprise is placed (its market, its rivals, its subcontractors…). Internal environment describes the enterprise itself: its structure, its functions and its organisation. This environment is decomposed according to three viewpoints which represent three different decisional levels (Table 1). Strategic level defines the global organisation of the enterprise. The tactical level provides a vision of the functional structure of the enterprise. And the operational level represents the project organisation.

Table 1. Example of elements describing internal and external environments

Strategic level (enterprise)	• Internal : – Enterprise infrastructure : premise, implantation, logistic,… – Strategic Industrial Plan – Available resources, capacities and potential of the enterprise,… • External : – Subcontractors – Rivalry : benchmarking, marketing studies,… – Socio-cultural aspects that influence enterprise, the market, the products…
Tactical level (department)	• Internal : – Enterprise functional structure – Objectives assigned to each department,… – Available resources in each department • External : – Contractual relationships with subcontractors – Results of benchmarking, of market studies,… – Socio-cultural aspects that influence actors of the design system
Operational level (project)	• Internal : – Role of each actor in a specific project – Activities to achieve – Work conditions, context of work,… • External : – Specific relationship with subcontractors – Influences of the external context, socio-cultural aspects – …

Human aspects have to consider multi-facets of the designers. Human resources will be described with classical indicators (availability of a resource, hierarchical position, possible role in a project, training plan…). But we will also have to take into account factors very close to the actor's personality. Girard *et al.* [17] specify that these factors have to be defined according to interactions between the actor and his context of work. These interactions take four forms: actor/design object, actor/actor, actor/group and iteration of the group of actors. First form concerns interactions between actor and the design object. In this case, it's necessary to analyse actor's impacts on the evolution of the design artefact definition (capacity and manner to realise a design activity). Other point of view considers actor's interactions with the group. In one hand, we are taking into account actor's individual relationships with others members of the group. It will be relevant here to identify his capacity to collaborate (collaborative ability). In the other hand, we describe actor's capacity to influence the general dynamic of the group (state of mind and motivation). Last form permits to identify interactions between the actor (or the group) and the design context. Intern and extern factors, which have an influence on the group and on each actor, and each evolution step of the group (or of the actor), have to be defined according to different viewpoints. We represent these influences on a technological axis, an environment axis and a human one (figure 4). Then specific objectives, action levers and performance indicators have to be identified according to these four types of interactions. They put in evidence objectives and action levers associated to the design system. PMS has to consider interactions between these objectives, action levers and performance indicators, to supply pertinent information to decision-makers. These interactions are a composition of each component and of relationships between them [18]. They must be described with a view to the product, the process, the organisation and the management style of the design process. They influence actors' deeds and decisions and are action inductors during the progress of the design process.

To manage these interactions we propose to use the GRAI model [19] because it offers a frame to control the definition, the deployment, the follow-up and the evolution of the design system. As the GRAI reference model describes the engineering design system as composed of 3 subsystems (the *decision system*, the *technological system* and the *information system*) it could integrated all the aspects of our design system modelling (Figure 3). Interests of this model are to follow the evolution of the design process and to evaluate its performance to support engineering management according to structuring of decisions making.

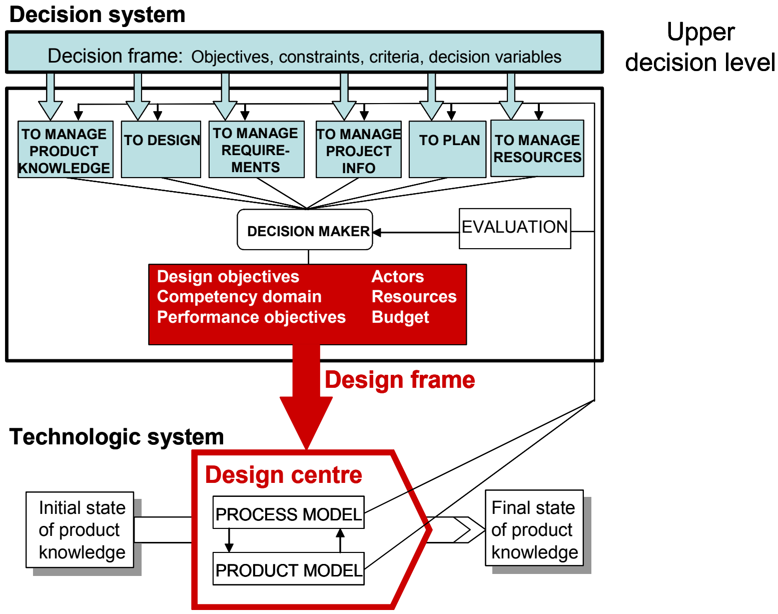

Figure 3. Reference model, relationship between the decision centre of a decision level and a design centre [19]

2.2 Interactions between the factors influencing design system

To identify and manage relationships between factors influencing design process performance we propose to use product, process and organisational models (Figure 4). Product model acts as a link between knowledge and external / internal environments (link 1, Figure 4). Product is the expression of the scientific and technologic knowledge of an enterprise. It permits to evaluate the position of an enterprise and of its rivals on a market. It's a technical nature indicator for a firm which allows to make evolve enterprise or to identify a possible lack of competency to be competitive on a market. As process corresponds to the place where the knowledge is created and used by the actors to develop the product, it connects human and knowledge (link 2, Figure 4). Finally, we consider that influences of environments on human resources could be taking into account only by the mean of an organisational model. So, this model joins up human and external / internal environments (link 3, Figure 4). Organisation has to favour allocation of adapted human resources to a specific situation in a particular context. Interactions between these models provide a vision of the design project evolution (links 4 to 6, figure 4). On many aspects, integration of these models in a global model could be draw nearer to the Design Co-ordination Framework (DCF) developed by the CIMDEV group [20]. Even though the two approaches have many common points, difference between them results in the more general vision of our viewpoint. DCF is integrated in our model and could be considered as an operational vision of them.

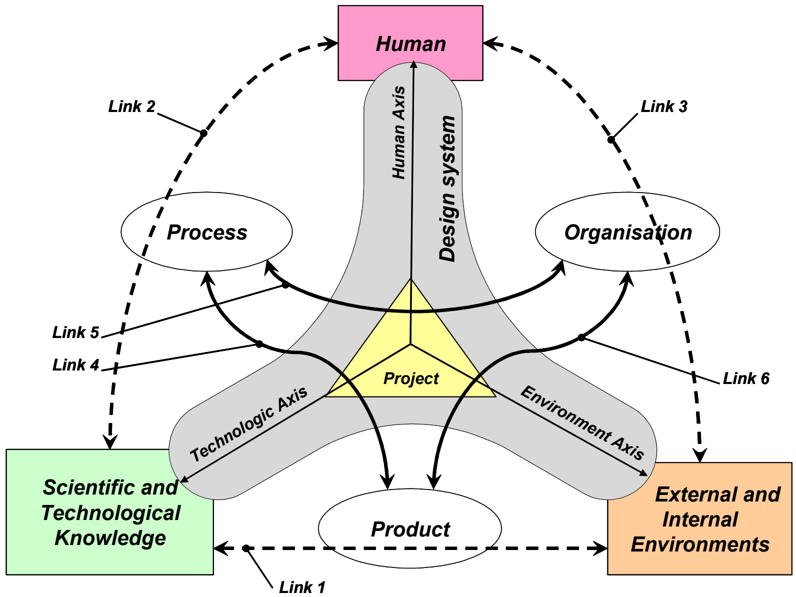

Figure 4. Interactions modelling between factors influencing the design system

In the provided model, it's the account of each factor influencing the design system, at each decision level (strategic, tactical and operational), which allows to obtain a global description of the design context. Then, interactions between each one give a vision of the possible evolution of this context. Design system regroups many projects and each one is defined as a specific composition of environment, technologic and human aspects (see different axis, Figure 4). Specificity of each project comes from its positioning on each axis. Hence, thanks to such a representation of the design context, the manager can easily analyse the design situation and identify particularities of each project. He can observe the degree of implication of each component (environment, technologic and human one) and consequently adapt his project management method by taking the right decision of management to satisfy objectives.

3 Evolution of the design system

Design project evaluation along its unfolding, will be done according to evolution of all design system aspects that we have described before. Concerning evolution of the design system, Waggoner *et al.* [21] have underlined that four forces could impacted its performances: internal and external influences, process issues and transformational issues. All these influences are in our model, so managing our model implies managing the design system but also the PMS evolution and change. We identify that we have to follow three forms of evolution:

- ✓ evolution of the system in a global context (strategic vision),
- ✓ evolution of the system according to the internal and external influences (tactical vision),
- ✓ evolution of the design process in the design system (operational vision).

Each form has relationships, interactions and influence on the others. Objective is to integrate these forms in a general approach of the design system management. The literature review shows that it doesn't exist any approach that could be able to take into account a general vision of the design system evolution. As a consequence, we propose to develop our approach around three research works, all based on the GRAI model [19]. Our choice is justified since it will be easier to federate different approaches if they use the same concepts.

3.1 Evolution in a global context

In the extended enterprise context, influences of the global context on the design system have to be put in evidence and to be managed. To do that, we are going to consider evolution management of an isolated enterprise, to manage after the combined evolution of several enterprises to obtain a global vision of external influences on the design system. To manage this evolution, we use the Blanc's research work [22] based on the Malhene's one (GEM approach) [23]. Malhene's works concern evolution of an isolated enterprise and Blanc adapts them to the extended enterprise context. Blanc's approach builds system evolution like continuous processes and describes evolution process management of industrial systems. This approach is firstly dedicated to production system but could be apply to the design system. In practice, the evolution process is made of a sequence of steps representing the evolution of the system status (Figure 5). The *As Is* system represents the model of existing system. The components of the system are here described and formalised: it is possible to understand better how the system is running and also to detect the points to improve. The *Should Be* corresponds to the strategic objectives of the system, and in Blanc's approach it is described through the Business Plan of the enterprise. The *Next Step* is an intermediate stage between the *As Is* and the *Should Be*. It corresponds to the future system which will be implemented. *User Specifications* correspond to the comparison between the *Next Step* and the *As Is* models. From this, the *Technical Specifications* are deduced which include the Organisation, the Information Technology and eventually, the Physical part. The *Action Plan* determines several evolution projects with a limited duration and investment. To complete this approach, the human aspects will be taken into account. Indeed, these aspects are often those that bring problems during the evolution.

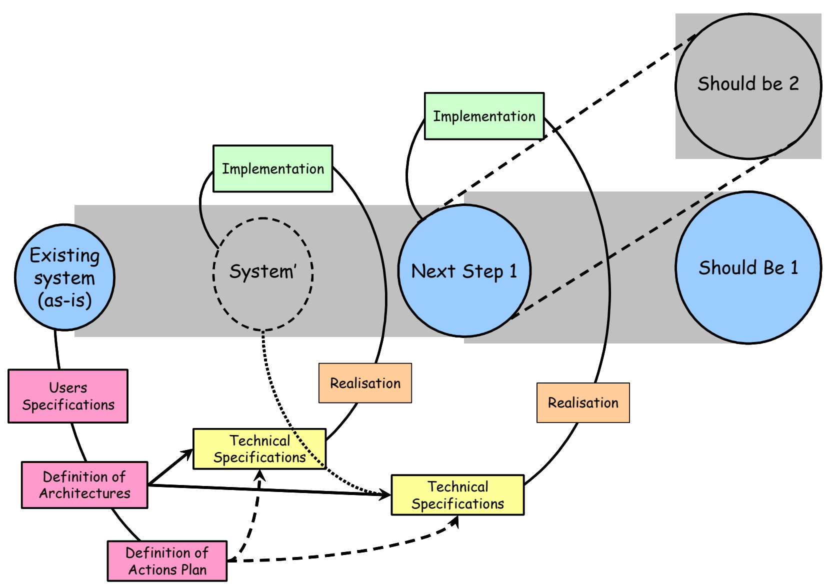

Figure 5. GEM approach [23]

Interest of this approach resides in the integration of the interactions between the performance of each actor and the system one as a whole to manage its performance. Concerning design system, it permits to take into account evolution of the external strategic factors (customers' needs evolution, subcontractors' evolution, rival enterprises' evolution, market evolution…). It will give a general framework to identify evolutionary strategic objectives, constraints and associated action levers and performance indicators that will influence the design activities.

3.2 Evolution according to internal and external influences

To manage design system evolution according to internal and external influences we propose to use the Sperandio *et al.*'s approach [24]. It is firstly developed to model the production system but we will show that it's possible to adapt it to the design system. Sperandio bases her model on the integration of three models: *functional model*, *organic model* and *operating* one. *Functional model*, based on GRAI model (GRAI grids especially), is developed to situate the system with its environment in order to identify relationships between them. In our design system modelling, it could represent a tactical vision of the external environment and its interactions with the system. *Organic model* is a more precise description of the system. In this model, elements of the *decision system* are defined and relationships between them are identified (hierarchical and/or co-operation relations). It provides multi-levels view of the system thanks to aggregation facilities. It corresponds to the structural architecture of the internal environment of our model. *Operating model* represents a projection of the design process, how design process could be (Figure 6).

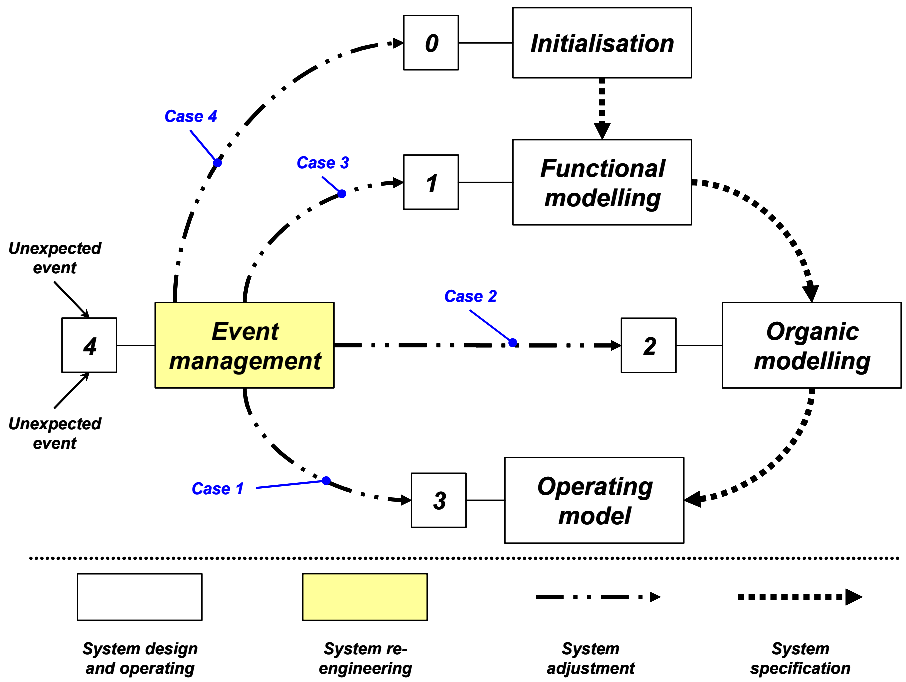

Figure 6. System life-cycle modelling [24]

Evolution system management is effective thanks to an event management procedure. It's developed around four cases: slightly disturbing (no impact on the system structure) (case1), fairly disturbing (modifications only on the structure but not on the functionalities) (case 2), strongly disturbing (it requires strategic system adjustments) (case 3) and fatal (the system is obsolete) (case 4). This approach provides a tactical vision of the design system since it puts on evidence functional and organisational structures of the design system. Internal and external evolutionist mechanisms are also described that allow project manager to have a global vision of the design system. Management of simultaneous projects and concurrent design activities is possible and facilitated since relationships and influences between them are identified. Despite, as it has been developed to model the production system, this approach has to be completed to integrate design system particularities. It will be possible by adding a more specific dimension centred on the design process activities.

3.3 Evolution of the design process

Two previous approaches are taking into account of the design system evolution but it's not enough to manage the design activity. As design activities of the process are more and more collaborative and discretionary, design control has also to be focused on interactions that will create the design process. These interactions concerns product, process and organisational viewpoints but also human aspects and management style of design process. They appear in the design system, but especially in the activities of the design process. In the context of extended enterprise, design control should be more reactive and taking into account external constraints. Therefore, the collaborative design processes control requires understanding of context those processes take place in order to modify them to facilitate actors' work. So, we propose a framework, based on our design system modelling and centred on the actor, to manage and evaluate the design process. GRAI model permits to control design process but not specific design activities. Furthermore, it offers opportunity to describe the design context but it's not enough precise and doesn't bring over to much reactivity to be used in the case of the management of collaborative design activities. As aim is to influence the design context to favour collaborative design situations between actors, we have developed the concept of design environment [25]. A design environment is defined as the context in which the project manager decides to place design actors to achieve the assigned objectives. This concept completes the existing GRAI model and gives it a new dynamic in term of management of collaborative design activities. Dynamic management of collaborative design process with design environment is based on four principal phases (Figure 7):

1. Identification of a need for collaboration,
2. Description of the as-is design situation,
3. Analysis of the as-is situation and comparison with the objectives of the design system, in order to decide whether or not a parameter needs to be introduced or changed,
4. Implementation of a design environment adapted to the design situation, in order to efficiently change the design context.

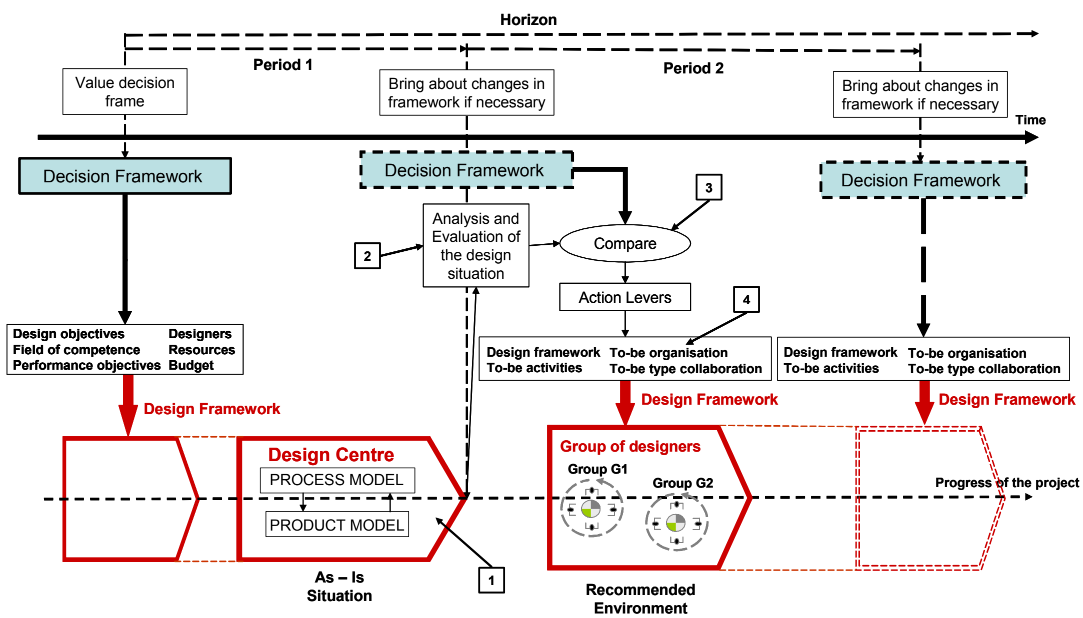

Figure 7. Reference model for a design environment [25]

At each period and according to a description of the as-is situation, the performance indicators and identification of a need for collaboration, decision-maker compares the performance indicators with the objectives assigned to them and then decides whether or not the design context needs to be developed. Thanks to the design environment, the project manager in charge of the design centre being considered will be able to encourage appropriate collaboration.

The three different approaches provide a general framework to manage design system evolution and design process. Blanc's approach gives a strategic vision of the evolution of the design system and of its context. Sperandio's model is more operational than Blanc's one and so it helps decision makers to manage design system at a tactical decisional level. It also allows to identify general action levers adapted to each objective according to specific performance indicators. Lastly, to manage design process at an operational decisional level, we complete the GRAI model with the concept of design environment. Contrary to the two others approaches, this one is dedicated to design process management and it's really centred on control of the design activities. Despite, a design environment couldn't be developed properly without an analysis of the design system provide by Blanc's and Sperandio's models. Each model is dedicated to a specific decisional level and co-ordination between them could be done be the mean of the GRAI model. This model permits to identify functional and organisational structure of enterprises (static vision). Our design system modelling (figure 4) creates dynamic of the system thanks to the identification and the follow-up of interactions between each element. At each decisional level, these models allow to put in evidence and to manage specific objectives, action levers and performance indicators that will be integrate in a PMS. The following section presents an example of the possibilities for action available to the project manager during the design of an element of the Airbus A380 wing.

4 Industrial case study

In this industrial case we are going to consider the design phase of the reaction engine mast of the Airbus A380 wing. The reaction engine mast is the interface between the reaction engine and the wing (figure 8). This element is designed at Toulouse and has interactions with the wing (designed by Airbus Industry in England) and with the reaction engine (designed by Rolls Royce in United States). This example could illustrate the use of IPPOP.

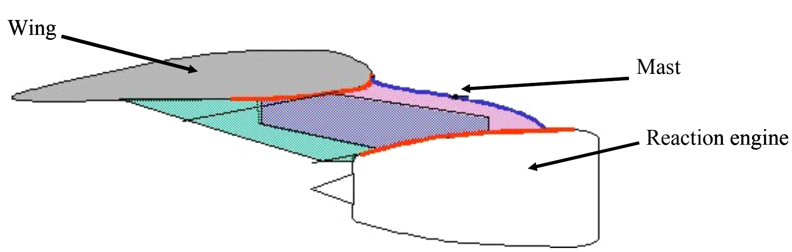

Figure 8. Mast position on the wing

At an operational level, collaborative activities regroup actors distributed in each partners. Each actor's task is defined and each one knows his context of work (human and material resources, distribution of these resources, objectives, constraints, influence of the others actors…). This decisional level provides tangible results on the product and information about collaboration to upper decisional levels.

In this case, it will be also pertinent to manage information about aspects described in interactions defined by Girard *et al.* [17] (shared knowledge, capacity to collaborate, mind opening…). It will be possible only if we have offer to actors the possibility to collaborate, and if we favour this collaboration by the mean of design environments (§3.3, Figure 7). IPPOP is a software allowing to help decision-makers to manage design process at each decisional. Many of concepts described before are developed in the software. Creation and implementation of design environments will be done at a tactical level. To create design environment, project manager has to identify human and material resources that have to collaborate to achieve design of mast activity. He has to have information about design process, design system and functional structure of the enterprise and of the others partners (functional model, Figure 6). Furthermore, to evaluate and to manage all these elements and their interactions, he could use the organic and the operational models (Figure 6). Integration of these models proposed by Sperandio *et al.* (§3.2) provides design manager with a relative decisional freedom. Even though this freedom is necessary because the design process is very complex, it's control by the strategic level. This decisional level has a global vision of the design system. It defines departments that have to work together but couldn't manage all interactions between them. So, tactical project manager of each department know the others project manager and has to initialise internal or external collaboration identified by the upper decisional level. He has especially to create and control work groups according to knowledge, distribution, culture, collaborative capacities, interoperability of each human and material resources Strategic level gives a functional vision of the design system and tactic level completes this vision with a procedural one by creating effective collaborations (Figure 9).

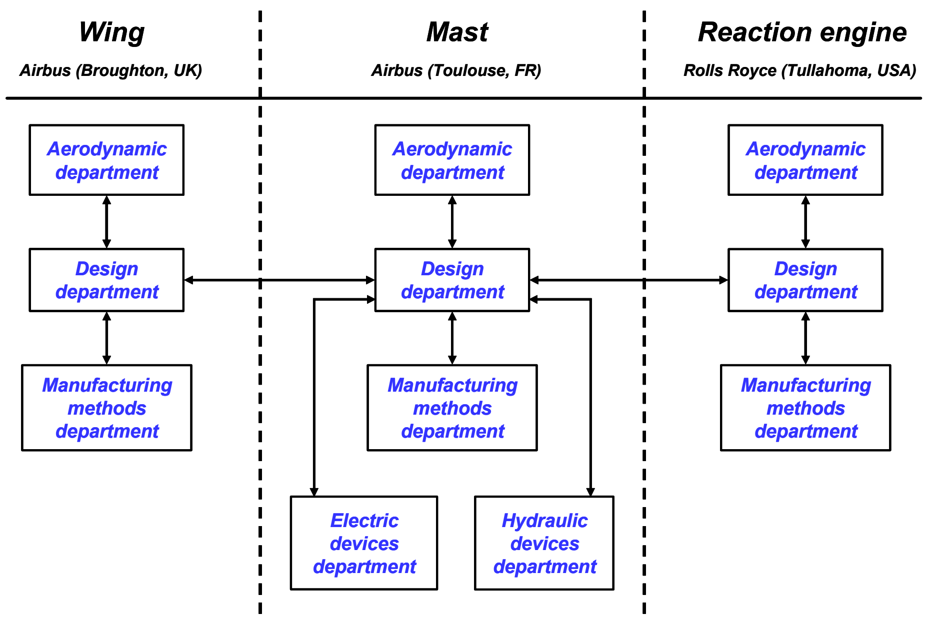

Figure 9. Identification of collaborations and functional vision of the mast design process

This description of the design process is based on a global description of the design system at a strategic decisional level. Strategic project managers have to define the general functional structure of the plane in order to identify which design departments have to work together. Experience of Airbus allows to define a global structure of the plane, which depends on the decisional and organisational structure of the enterprise.

The structure of the enterprise is based on integration of GRAI grids dedicated to each plant of the enterprise which is modelling in the IPPOP software (Figure 10). That permits to identify relationships and influences between each plant and each department of them. So, strategic decisional level has to define global objectives of the design, interoperability and collaboration between departments. When all these elements are identified, it’s possible to focus on evolution perspectives of the design system to judge on the pertinence of the decisions (Blanc’s approach, §3.1). This step makes appear action levers that could influence the system. If it’s conclusive, objectives and performance indicators, adapted to action levers, could be deployed to the lower decisional levels.

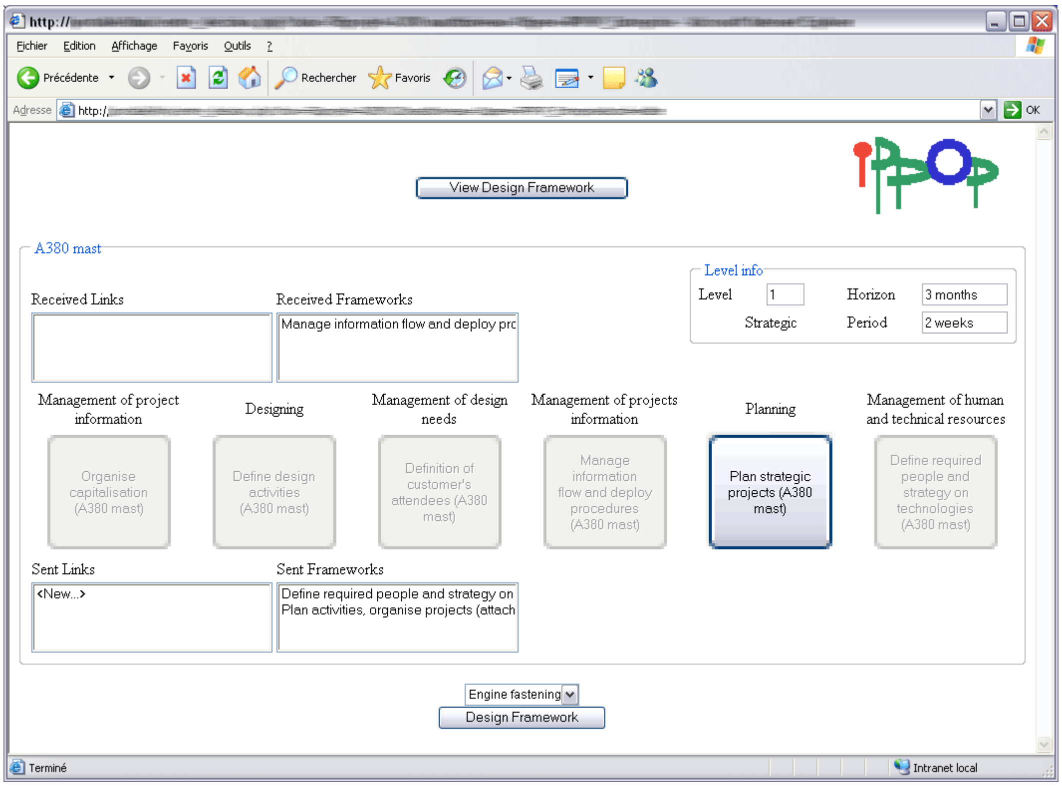

Figure 10. Example of IPPOP GUI dedicated to a decision-maker at a strategic level

It is combination between the design system description, the adapted PMS definition and the management of the design process thanks to the design environment that provides to design managers opportunity to follow and evaluate the design system. IPPOP permits control of collaborative activities by the mean of an adapted product model based on FBS Framework [26] and a specific collaborative design process model. All these elements are contained in an organisational model constructed on the design environment concept, manage in IPPOP too. IPPOP helps decision-makers, at each decisional level, to manage his activity. Implementation of IPPOP is based on an enterprise modelling by the mean of the GRAI grids that makes appear decisional and functional structures. Each actor is identified in the GRAI grid that implies IPPOP could provide to each user a specific Graphical User Interface (GUI) on which he finds all information necessary to achieve his task (Figure 11). This description is completed with a PMS and an integrated model of product, process and organisational models to obtain a dynamic system of design process management.

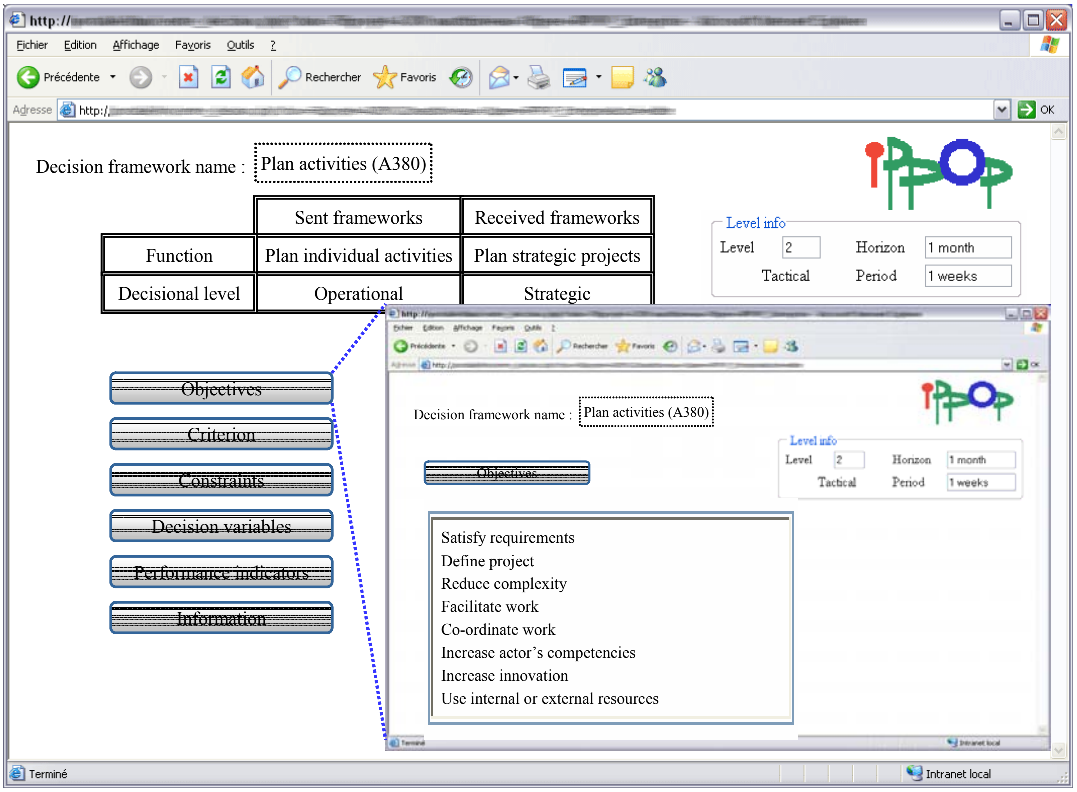

Figure 11. Example of IPPOP GUI dedicated to a decision-maker at a tactical level

5 Conclusion

Product design today requires new interaction forms between the various stakeholders involved in this specific process. Management of the design processes is today complex and to improve processes performances, it's necessary to focus not only on the artefact but also on the actor's relations. Therefore, organisation has to integrate aspects centred on the actors in order to be reactive and efficient considering the design process evolution and framework. Software tools must be set up in order to support those aspects. This paper focuses on the construction of a model describing the elements influencing the design context of engineering design actors and interactions between them. It presents global trends while considering the design actors, and shows that management has to be develop around three principal phases. In a first time, the decision-making structure of enterprise has to be defined precisely to put in evidence all links between each design centre. Objective of this phase is to underline the rule of each actor, at each decisional level, and to judge his influence on the design system. The proposed interactions modelling between factors influencing the design system and the integration of Blanc and Sperandio's approaches offer a framework to achieve this phase. Secondly, a performance measurement system has to be developed according to the decision-making structure and previous different models. It has also to integrate actors' influences. Lastly, the reference model of a design environment gives the frame to implement the result of the two previous phases and to control design process. In order to validate this framework, we implemented it within a real-case industrial application. The goal of this work is to support decision makers managing design projects.

Acknowledgements

All the concepts presented in this paper are parts of the IPPOP project. It is a national project and it's encourage by the industry and research ministry in the framework of the RNTL program. More information is available on the web site http://www.opencascade.org/IPPOP/. We thank Mrs Martine Callot, research engineer from EADS CCR, for information about mast design process that have allow us to illustrate pertinence of our research work.

References

[1] Bradley P., Jordan P., "An agreed business model identifying a set of generic business processes". 1996, CIMRU, University College Galway, Ireland.

[2] Judson A.S., "Making strategy happens, transforming plans into reality". 1990, Basil Blackwell, London.

[3] Pawar K., Driva H., "Performance measurement for product design and development in a manufacturing environment". International Journal of Production Economics, Vol. 60-61, 1999, pp. 61-68.

[4] Driva H., Pawar K. and Menon U., "A framework for product development performance metrics", International Journal Business Performance Management, Vol.1/3, 1999, pp. 312-326.

[5] Nanni, A.J., Dixon J.R. and Vollman T.E., "Integrated Performance Measurement: Management Accounting to Support the New Manufacturing Realities". Journal of Management Accounting Research, 1992, pp. 1-19.

[6] Haffey M.K.D., Duffy A.H.B., "Design process performance management support". International Conference on Engineering Design, 2003, ICED 03, Stockholm.

[7] O'Donnell F.J.O., Duffy A.H.B., "Modelling product development performance". International Conference on Engineering Design, 1999, ICED 99, Munich.

[8] Wisner J.D., Fawcett S.E., "Link firm strategy to operating decisions through performance measurement". Production and Inventory Management Journal, Third Quarter, 1991, pp. 5-11.

[9] Neely A., Mills J., Platts K., Richards H., Gregory M., Bourne M. and Kennerley M.P., "Performance measurement system design: developing and testing a process-based approach". International Journal of Operations & Production Management, Vol. 20/10, 2000, pp. 1119-1145.

[10] Perez R.L., Ogliari A., Back N. and Martins R.A., "Development of a model for assessment of design". International Conference on Engineering Design, 2003, ICED 03, Stockholm.

[11] Sénéchal O., Girard Ph., Tomala F. and Trentesaux D., "Le cycle de vie du système de production". Evaluation de la performance des systèmes de production, Hermès, 2003, pp. 81-104.

[12] Chiu M. L., "Design moves in situated design with case-based reasoning". Design Studies, Vol. 24, 2003, pp.1-25.

[13] Ostergaard K., Summers J. D., "A taxonomic classification of collaborative design process". International Conference on Engineering Design, 2003, ICED 03, Stockholm.

[14] Badke-Schaub P., Frankenberger E., "Analysis of design projects". Design Studies, Vol. 20, 1999, pp. 465–480.

[15] Rosenman M.A., Gero J.S., "Purpose and function in design: from the social-cultural to the techno-physical". Design Studies, Vol. 19/2, 1998, pp. 161-186.

[16] Eder E., "Integration of theories to assist practice". International Conference on Integrated Design and Manufacturing in Mechanical Engineering, 2004, IDMME 04, Bath.

[17] Girard Ph., Merlo C. and Doumeingts G., "Approche de la performance en conduite de l'ingénierie de la conception". 4th International Conference on Integrated Design and Manufacturing in Mechanical Engineering, 2002, IDMME02, Clermont-Ferrand.

[18] Love T., "Constructing a coherent cross-disciplinary body of theory about designing and designs: some philosophical issues". Design Studies, Vol. 23/3, 2002, pp. 345-361.

[19] Girard Ph., Doumeingts G., "Modelling of the engineering design system to improve performance". Computers & Industrial Engineering, Vol. 46/1, 2004, pp. 43-67.

[20] Duffy A.H.B., Andreasen M.M. and O'Donnell F.J.O., "Design co-ordination". International Conference on Engineering Design, 1999, ICED 99, Munich.

[21] Waggoner D.B., Neely A.D. and Kennerley M.P., "The forces that shape organisational performance measurement systems: An interdisciplinary review". International Journal of Production Economics, Vol. 60–61, 1999, pp. 53–60.

[22] Blanc S., "Interoperability problems: Management of evolution of collaborative enterprises". INTEROP-ESA'05, February 23-25, 2005, Geneva.

[23] Malhene N., "Gestion du processus d'évolution des systèmes industriels – Conduite et méthode". Thesis of University of Bordeaux 1, January 2000.

[24] Sperandio S., Pereyrol F. and Bourrières J.P., "Production system life-cycle modelling for control assessment". International Conference on Systems, Man and Cybernetics, 2004, IEEE SMC 2004, The Hague.

[25] Robin V., Girard Ph. and Barandiaran D., "A model of design environments to support collaborative design management". 5th International Conference on Integrated Design and Manufacturing in Mechanical Engineering, 2004, IDMME04, Bath.

[26] Gero J.S., Kannengiesser U., "The situated function–behaviour–structure framework ». Design Studies, Vol. 25, 2004, pp. 373–391.

Corresponding author:
Vincent ROBIN
LAPS/GRAI, UMR 5131,
Université Bordeaux 1, 351 Cours de la Libération, Talence 33405 France
Tel.: +33 5 40 00 24 07 - Fax: +33 5 40 00 66 44
E-mail: vincent.robin@laps.u-bordeaux1.fr