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Principles and recommendations for implementation of design methods in the product development process of companies

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ABSTRACT. This paper aims to present a study on the implantation of design methods in the Product Development Process (PDP) of companies, with the intention of generating a set of decision support principles and recommendations for deployment of these resources in the industry. This study was classified as applied research, as it aims to apply knowledge in industry's product development. On the approach, it was classified as a qualitative research because it used interviews, document examinations and has a descriptive character. As for the goals, it was classified as exploratory and descriptive, having a practical application. The technical procedures used were literature review, field study and action research. The main result of this research is a group of systematic character propositions that are the foundation to guide the implementation of design methods in the industry, consisting of Selecting the Appropriate method to be implemented in accordance with PDP, Planning the Implantation of the method selected, Applying the Method and control and actions to improve the implementation. The research offers a synthesis of various experiences about the implantation of design methods in the industry, redeeming values of human wisdom that previously had not received great attention.

Keywords: field study, action research, selection, adaptation.

Princípios e recomendações para implantação de métodos de projeto no processo de desenvolvimento de produtos de empresas

RESUMO. Este artigo tem por objetivo apresentar um estudo de implantação de métodos de projeto no Processo de Desenvolvimento de Produtos (PDP) de empresas, com intenção de gerar um conjunto de princípios e recomendações de apoio à decisão para implantação destes recursos na indústria. Este estudo foi classificado como uma pesquisa aplicada, uma vez que visou aplicar conhecimentos no desenvolvimento de produtos na indústria. Sobre a abordagem, foi classificado como pesquisa qualitativa por que utilizou entrevistas, exames de documentos e tem um caráter descritivo. Quanto aos objetivos, foi classificada como exploratória e descritiva, devido ser uma aplicação prática. Os procedimentos técnicos utilizados foram revisão da literatura, estudo de campo e pesquisa-ação. O principal resultado desta pesquisa foi um grupo de proposições de caráter sistemático que servem de base para orientar a aplicação de métodos de projeto na indústria, que consiste em selecionar o método adequado para ser aplicado em conformidade ao PDP, planejamento da implantação do método escolhido, aplicação do método de projeto e controle das ações para melhorar a implantação. A pesquisa oferece uma síntese de várias experiências sobre a implantação de métodos de projeto na indústria, resgatando valores da sabedoria humana que anteriormente não havia recebido grande atenção.

Palavras-chave: estudo de campo, pesquisa-ação, seleção, adaptação.

Introduction

Constant technological development, focusing on product innovation, has provided competitive advantage and survival requirements for companies in an increasingly globalized market, as shown by Koch (2011). Studies carried out in Brazil by IBGE (Instituto Brasileiro de Geografia e Estatística, 2008) show that companies that innovate their products represent only 1.7% from a total of 72,000 companies and are responsible for 25.9% of industrial revenues and 13.2% of employment

generated. Cooper, Edgett and Kleinschmidt (2004) mention that the 'market war' between companies requires innovation in products as a vital aspect, in other words, the companies innovate or die.

According to Chipulu, Neoh, Ojako and Williams (2013) and Henard and McFadyen (2012) studies, investment in the application of design methods has helped in developing professionals' skills in product development, creating competitive advantages for companies.

According to Bylund, Grante and López-Meza (2003), although there are different project

support methods, the amount used by the industry is relatively low. One element of this issue is that the academic environment, where most of the methods have been developed, is different from the industrial environment, where they are tested and applied.

Bylund et al. (2003) in their study on selection and use of design methods at Volvo Car Corporation, the major reasons for low usage frequency of these methods in the industry are due to the following aspects:

- Incorrect selection and/or use of the methods, producing unsatisfactory results;
- Some methods are absorbed based on their popularity and do not solve the problem that led to their selection;
- Project team's lack of time to learn how to use new methods.

Birkhofer (2011) report that the ability to reason and systematic operation are essential for the application of design methods with success in the industry. According to Bylund et al. (2003) for the acceptance of methods or design methods, it is necessary for two barriers to be overcome: acceptance of the method and its successful use. Therefore, it is necessary that managers and projects coordinators are convinced that the use of the method will benefit the company's performance. For Lindemann and Maurer (2006), a basic prerequisite for application of design methods in the industry is the technical knowledge (know-how) to use them in different situations.

Analyzing the importance of the Product Development Process, the methods for technological innovation and increase of companies competitiveness, as well as the problems faced in the implementation and use of these methods in the industry, this paper presents a study on the implementation of design methods to support the PDP of companies, aiming to provide a set of decision support principles and recommendations for deployment of such resources in the industry.

Material and methods

Based on the concepts of Campomar (1991) and Gil (2002), this study was classified as applied research, as it aimed to apply knowledge to product development in the industry. On the approach, it was classified as a qualitative research because it used interviews, document examinations and presents a descriptive character. Regarding the goals, it was classified as exploratory and descriptive, as it provides a practical application.

The technical procedures used were: literature review, related to the state of the art on PDP and design methods (item 2 above); field study to collect information about the use of design methods in the industry; and action research, support for the implementation of design methods in the company. The flow of execution of methodological procedures and their activities are illustrated in Figure 1.

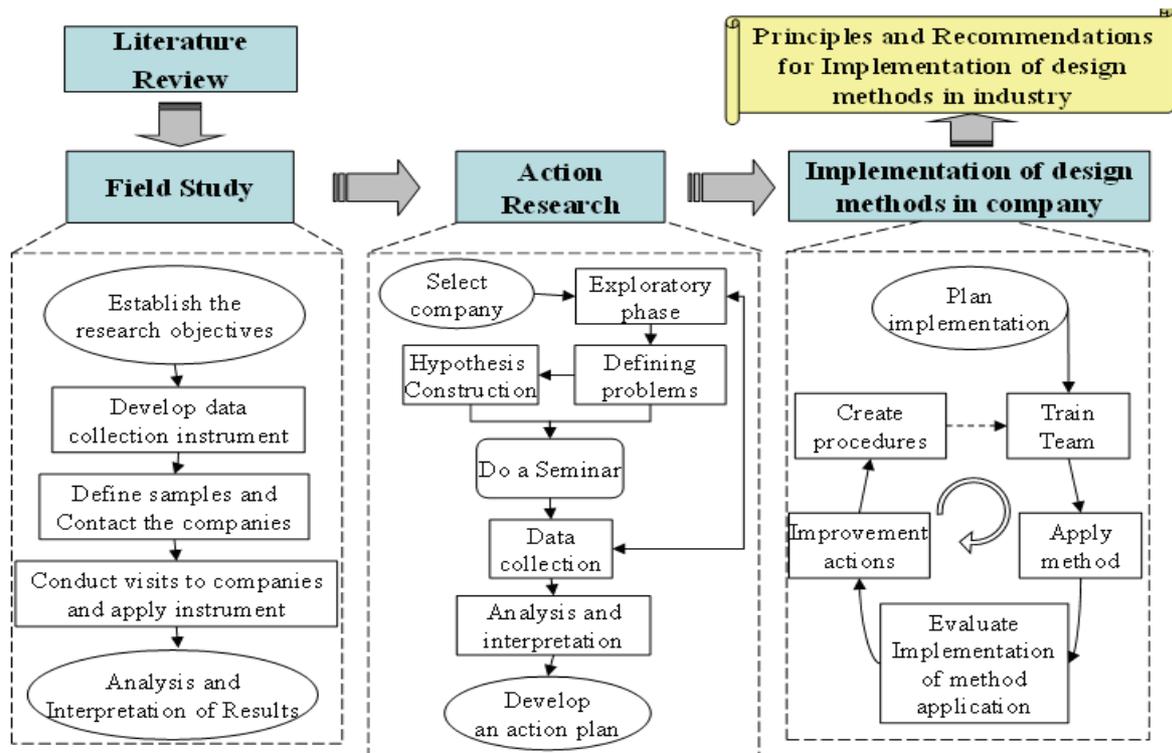


Figure 1. Methodological research procedures.

The conduction of the field study was based on the steps proposed by Miguel et al. (2012) and aimed to investigate generic aspects related to the problems of implementing design methods in PDP companies. The action research is a type of social research with empirical basis that is designed and carried out in close association with an action or resolution of a collective problem in which researchers and participants representative of the situation or the issue, are involved in a cooperative or participatory manner (Thiollent, 2000).

Results and discussion

Field Study

The field study target was composed of large and medium-size Brazilian companies, located in the State of Santa Catarina, with experience in the Brazilian and international markets, and activities related to industries in the metal-mechanic, electrical materials and plastic products sectors. The number of companies with availability to participate were eight companies (due to the exploratory nature of the research) and this study consisted of visits to the premises of the companies, analysis of documents and a questionnaire applied through interviews with those responsible for product development. Data was summarized and grouped based on the following aspects.

Company's general characteristics

The following characteristics were obtained from the companies that participated in the field study:

- **Size of the companies:** according to Brasil (2006) and Sebrae (Serviço Brasileiro de Apoio as Micros e Pequenas Empresas, 2015) criteria, 63% of enterprises were large and 37% medium-sized.

- **Industrial activity:** there were identified four company industrial activities, where 71% of companies were represented by the metal-mechanical sector, 14% electrical equipment, 14% white goods and 14% plastic products.

- **Certifications held by the companies:** it was identified that all companies have ISO 9001 (Associação Brasileira de Normas Técnicas, 2008) certification, 75% have ISO14001 (Associação Brasileira de Normas Técnicas, 2004) certification, 38% have OHSAS (Occupational Health and Safety Assessment Series, 2007) and about 38% have international product certifications, e.g. (American Society of Mechanical Engineers [ASME], 2010; Comunidade Européia, 2008 and Instituto Argentino de Normalización y Certificación [IRAM], 2008).

Product Development area characteristics

- Educational attainment of professionals: the predominant educational attainment of professionals who develop products is an undergraduate degree (100% of the professionals). Professionals with Undergraduate degree were represented for 63% and master degree was represented for 50%. The study did not identify professionals with PhD degree.

- Project Types usually developed: According to the model of Condoor, Shankar, Brock, Burger and Jansson (1992), 88% of companies execute Development Projects (few new concepts and high complexity in its configuration) and 75% execute Redesign Projects (few new concepts and low complexity for configuration change). The Original Projects (high level of new concepts and high complexity in its configuration) and Adaptive Projects (high level of new concepts and low complexity in its configuration) are executed by only 25% of the companies.

Therefore, it is clear that most of the surveyed companies develop projects with few new concepts.

PDP characteristics

It consisted in identifying the main PDP phases at each company and the difficulties during the execution of PDP activities, as presented in Table 1.

Summarizing the information reported in the research, the main difficulties and/or barriers faced by companies during the PDP activities are:

- Clear definition of customer needs and product project specifications;

- Difficulties in the product development management, especially regarding the planning of the project;

- High number of errors and/or number of design changes, mainly due to the lack of product validation.

Usability and implementation of design methods by companies

The design methods most used by the companies were: CAD systems, brainstorming, and prototyping. The least used methods were: morphological matrix, functional analysis, DOE, EVA, QFD and FMEA.

Another fact identified in the companies were the 'reasons for implementing the methods'. Among them stood out:

- Improve quality control in products (100% of companies researched);

- Reduce failures or increase reliability in products (75% of companies researched);

Table 1. Analysis of the performance of PDP activities of companies.

PDP activities common in companies	COMPANIES							
	1	2	3	4	5	6	7	8
Product Request Defining needs								
Analysis of product viability								
Product Project Planning								
Product design (conceptions, drawings, etc)								
Prototype development and testing								
Supplier Development								
Product Validation								
It has experience Partial execution Difficulties in PDP								

- Reduce development time (38% of companies researched);

- Reduce development costs (25% of companies researched).

Regarding the 'main difficulties in the implementation of design methods', the professionals indicated the following difficulties:

- Short time available for team to learn the design method (100% of companies researched);

- Difficulties in selecting the appropriate method (63% of companies researched);

- Human and cultural barriers in the company (50% of companies researched);

- Difficulties in learning the design methods in potential (38% of companies researched).

Action research

For the action research, a large manufacturing company from the metal-mechanic sector was selected, named in the study in order to preserve its identity, as Action Research Company (represented by the letters ARC). According to the methodological procedure, the action research was outlined through the execution of activities with the results shown in Table 2.

Scalice (2006), with details of the activities' levels from the Informational Design, Conceptual Design and Detailed Design phases.

The identification of improvement areas was made by a comparative assessment of the ARC's PDP and the PDP reference model of Rozenfeld, Forcellini, Amaral, Toledo, Silva, Alliprandini and

the evaluation method and the results at the ARC are shown in Figure 2.

If an activity does not apply to the company's current PDP, this activity was identified with the code NA (not applicable).

Based on the PDP evaluation results of the ARC shown in Figure 2, it is clear that there are 3 activities of the PDP reference model that the company does not develop, even as they are needed. These deficiencies are aligned to the problems identified in the company during the exploratory phase (ID 3 of Table 2).

As illustrated in Figure 3, many methods can support every activity considered critical in the company's PDP. Thus, to select exactly the design method, it was taken into consideration the expertise of the researcher in the methods for each activity, since he would be responsible for implementation. It was also found that some of the activities considered critical and as high priority for improvement, could be solved with the implementation of only one design method. For example, activities 1.4 and 1.5 can be supported by the QFD method.

Therefore, regarding the critical activities prioritized by the professionals, the expertise of the researcher on some of the design methods inherent to such activities and the fact that some design methods provide better results than a PDP activity, it was decided that QFD (Quality Function Deployment) and FMEA (Failure Mode and Effects Analysis) should be implemented in the action research company.

Table 2. Procedures and results of action research in the company.

ID	Activity	Investigative Techniques	Results
1	Select company	Intentionality: company's availability, permission, sponsorship and intent.	Large manufacturing company from metal-mechanic sector, located in the northern State of Santa Catarina.
2	Exploratory phase	Questionnaires and interviews with professionals from the product development area and other company departments	A) Company departments B) Project sector and its team C) PDP - phases and activities D) Design methods used.
3	Defining problems	Identify opportunities for improvement	A) Reduce re-work during PDP. B) Reduce the number of changes in the products due to failures. C) To develop the PDP steps in a systematic and formalized way.
4	Hypothesis Formulation	Qualitative hypothesis, according to Gil (2002) and should offer solutions to the problems.	The implementation of design methods in the company is a prerequisite to remedy the problems identified in the PDP.
5	Perform a Seminar	Meeting with researcher and members of the company involved in the research, via reports and presentation.	Report of goals, methodology, deadline, design, problems and hypothesis highlighted.
6	Data collection	PDP analysis and monitoring. Detailed analysis of documents.	Evaluation Matrix of the PDP development level of the company, as shown in Figure 10.
7	Analysis and interpretation	According to criteria for interpreting PDP evaluation, as shown in Table 5.	List of appropriate methods for use in the company, according to the opportunities for improvement, shown in Figure 2.
8	Develop an action plan	Implementation plan of methods selected.	Implementation plan of the design methods in the company.
9	Show the results	Meeting with researcher and members of the company involved in the research by reports and presentation.	Results and benefits obtained with the execution of action plan. In this company, the study shows the results of the implantation of QFD and FMEA method, as shown in the Figure 3.

What?		Matrix for evaluation of development level of the PDP activities of company.					OBS . N ^o																																																																
Where?	In the product development area and other departments involved in the company's PDP.	<table border="1"> <tr> <th colspan="5">Evaluation</th> </tr> <tr> <td>0%</td> <td>25%</td> <td>50%</td> <td>75%</td> <td>100%</td> </tr> <tr> <td></td> <td></td> <td>X</td> <td></td> <td></td> </tr> <tr> <td>X</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>X</td> <td>X</td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td>X</td> <td></td> </tr> <tr> <td></td> <td></td> <td>X</td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td>X</td> </tr> <tr> <td></td> <td></td> <td></td> <td>X</td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td>X</td> </tr> <tr> <td>X</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td>X</td> </tr> <tr> <td></td> <td></td> <td></td> <td>X</td> <td></td> </tr> </table>						Evaluation					0%	25%	50%	75%	100%			X			X					X	X							X				X							X				X						X	X									X				X
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Who?	Researchers, managers, coordinators and members of the PD area.																																																																						
How?	With the Action Research, questioning and monitoring the practical execution of the company's PDP activities.																																																																						
When?	In the data collection phase of action research.																																																																						
Why?	Identification of improvement needs in the PDP by selection of design methods required by the company's PDP.																																																																						
Question:	How is the company executing this activity in developing their products:? Or, What are the results achieved by the company in this activity?																																																																						
PDP model and Activities (adapted from Rozenfeld <i>et al.</i> , 2006)																																																																							
1 - Informational Project	1.1 Update the Informacional project plan			X																																																																			
	1... ..																																																																						
	1.4 Identify the requirements of product customers. R: customer requirements.	X																																																																					
	1.5 Define product requirements. R: product requirements.	X																																																																					
	1.6 Define Product Specifications. R: Product Specifications.		X																																																																				
1.7 Monitor the economic viability				X																																																																			
2 - Conceptual Project	2.1 Update the Conceptual project plan			X																																																																			
	2... ..																																																																						
	2.4 Develop alternative solutions for the product. R: Project or solution alternatives.		X																																																																				
	2... ..																																																																						
	2.7 Define ergonomics and esthetics of the product. R: Conceptions for the product			X																																																																			
2.8 Define suppliers and co-development partnerships. R: suppliers and qualified co-development partnerships				X																																																																			
3 - Detailed Project	3.1 Update the Detailed project plan			X																																																																			
	3.2 Create and refine systems, components, documents and settings. R: Specifications for systems and components; final drawings with tolerances; product structure; process plans; working prototype.				X																																																																		
	3... ..																																																																						
	3.8 Optimize product and process. R: specifications of the systems and components (optimized); final drawings with tolerances (optimized); product structure (optimized); process plans (optimized).	X																																																																					
	3.9 Create Product support material. R: product operations manual; Training material; Product discontinuation manual.				X																																																																		
	3.10 Designing packaging. R: packing design.				X																																																																		
OBS: When the activity of the PDP reference model does not apply to the company, fill in the "Note" field NA (not applicable)																																																																							

Figure 2. Evaluation form of the company's PDP development level.

PDP model and Activities (adapted from Rozenfeld et al., 2006)			Result Evaluation	Methods suggested to PDP
1 - Informational Project	1.1	Update the project plan <i>Activities that needs improvement</i>	50%	Best project management practices, techniques, financial analysis, PERT charts (Project Evaluation Technique) EDT (Project Breakdown Structure), Breakdown Structure), Checklist, evaluation of specialists, SWOT
	1.2	...		
	1.4	Identify the requirements of product customers. R: customer requirements.	0%	Structured questionnaire; interviews; check list; brainstorming; affinity diagram; QFD (Quality Function Deployment); Mudge diagram; clinical assessment (focus group); Product benchmarking.
	1.5	Define product requirements. R: product requirements.	0%	Matrix attributes; check list; QFD (quality function deployment); parametric analysis; Mudge diagram; brainstorming.
	1.6	Define Product Specifications. R: Product Specifications.	25%	Matrix attributes; check list; QFD (quality function deployment); parametric analysis; Mudge diagram; brainstorming.
	1.7	Monitor the economic viability	75%	Technical and financial analysis procedures.
	2 - Conceptual Project	2.1	Update the Conceptual project plan	50%
2.2	
2.4		Develop alternative solutions for the product.	25%	Morphological matrix, brainstorming
2.7		Define ergonomics and esthetics of the product.	50%	Benchmarking, cognitive ergonomics analysis and physical
2.8		Define suppliers and co-development partnerships.	75%	Analysis of suppliers and supply chain
3 - Detailed Project	3.1	Update the Detailed project plan	50%	Same à 1.1
	3.2	Create and refine documents and <i>Activities that needs improvement</i>	75%	Classification, identification and coding, project standardization, specification of tolerance, GD & T calculation methods and standards, CSM Systems, CAD / CAE / CAM / CAO, PDM / EDM, PLM.
	3.3
	3.8	Optimize product and process.	0%	CAT, DFA, FMEA, DfX Methods
	3.9	Create Product support material	75%	Electronic editing systems, films, virtual reality, others.
	3.10	Packaging design	75%	Logistics analysis, design to packaging and transportation.

Figure 3. Identification of design methods appropriate to the PDP situation.

Implementation and application of Design Methods in the Action Research Company

Procedures and implementation activities in the methods of the action research company were based on the PDCA continuous improvement cycle (Plan, Do, Control, Action), as shown in Figure 4.

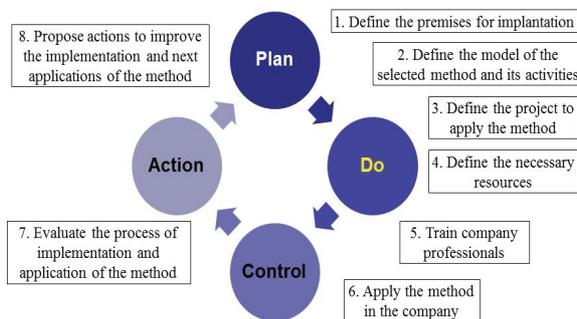


Figure 4. Generic stages of implementation of design methods at ARC.

The QFD method and FMEA method were applied to the same product project due to the availability of projects in the company. These

methods were applied to a Development Project and encompassed all PDP phases and activities.

The positive effects on the project with the implementation of these methods are presented as results, where it provided improvements in PDP and products. The specific information of the product where the methods have been applied will not be presented because they belong to the strategic planning of the action research company.

Validating the importance of applying QFD in the company was proceeded by the risk level assessment of project requirements, obtained with the application of QFD, as they received inadequate priorities by the designers if the QFD method was not applied. The risks were divided into three levels: high risk, medium risk and low risk. The selection of this evaluation criterion was based on the consequences of inadequate prioritization, as for example, increasing the number of changes in the product project, or increasing the number of changes during product use by customers (Table 2, ID 3). Altogether, there were 84 design requirements evaluated.

The main results obtained in evaluating the application of QFD in the ARC project show that 50.6% of project requirements had high risk of being inappropriately prioritized if the QFD method was not applied to this product project. In other words, there was a greater probability of product changes and customer dissatisfaction during the product project. Only 25.3% of project requirements had low risk of being inappropriately prioritized if the QFD method was not applied in this product project. The project team also mentioned in the evaluation that the process of getting the design requirements was a complicated and obscure activity in the company's product projects. Using the QFD method, that definition had become clearer, facilitating the development of a second project. Based on this importance, and as a result of the company's PDP deficiencies, such evaluation has helped in the implementation process, showing the importance of proper selection of the design method for the company.

The validation of the importance of applying FMEA in the company proceeded with the analysis of product failure rate. For this analysis, information was collected by the Customer Service Department, related to product failures in the field where FMEA was applied and the failures of a similar product, but without the application of FMEA, as shown in Figure 5.

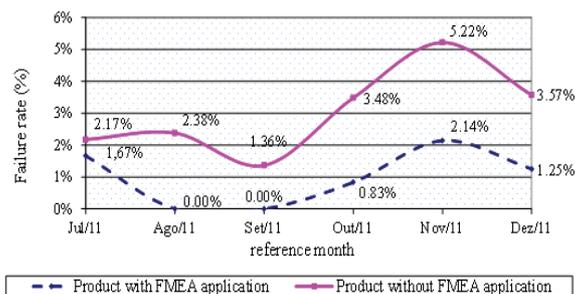


Figure 5. Impact on the failure rate of the company's products with and without FMEA application.

It can be seen on Figure 5 that the product failure rate when the FMEA method was applied was lower (mean = 0.98%) than the failure rate of a similar product without the use of that method (mean = 3.03%). After the evaluation, the project team realized the fundamental importance of implementing FMEA in the company's product projects, validating the method selection and implementation process.

Principles and recommendations for implementation of design methods in companies

Principles and Recommendations (P&R) were generated from the results of implementing the

methodological procedures of this research, in other words, in the field study, action research and implementation of QFD and FMEA methods in the company (items 3.1, 3.2 and 3.3). These P&R were designated as 'a set of systematic character propositions, used to guide the implementation of design methods in the industry'. The 'Principles' were classified according to the aspects presented in Figure 6 and are supported by activities presented below as 'Recommendations'.

Selection of appropriate method for implementation in the company's PDP: principle of systemic analysis and principle of adoption of a reference model.

Recommendations for the 'Principle of systemic analysis', which aims to explore the company's PDP:

- To analyze the knowledge and information about the current PDP practiced by the company;
- Collect the improvement needs in the PDP;
- Search sponsorship of the company's leaders to improve team's confidence;
- Define a company agent to explore the PDP because it facilitates the identification of routine problems in the company's PDP;
- Analyze all company departments involved in the PDP, to identify problems with its scope;
- Publish information and results to stakeholders, to provide more value to the implementation process.

Recommendations for the 'Principle of adoption of a reference model', which aims to assess the company's PDP:

- Evaluating the company's PDP through the matrix of the level of development of the company's PDP activities, as shown on the example model in the item 4.2 in Figure 5;
- Based on the evaluation, identify the most suitable design method to implement, as shown on the example model in item 4.2 in Figure 6;
- Consider the interests and preferences of company professionals because it helps in decision making, encourages team participation and increases support from management.

Implementation planning

Recommendations for the 'Principle of preliminary planning' and 'Principle of implementation sponsor' that aim to set the premises for implementing the method:

- To guide managers and project coordinators about the role and the importance of the selected method;
- Consider the execution activities of the method in product project planning.

Recommendations for the 'Principle of affinity context', which aims to define a model of the method and its main activities:

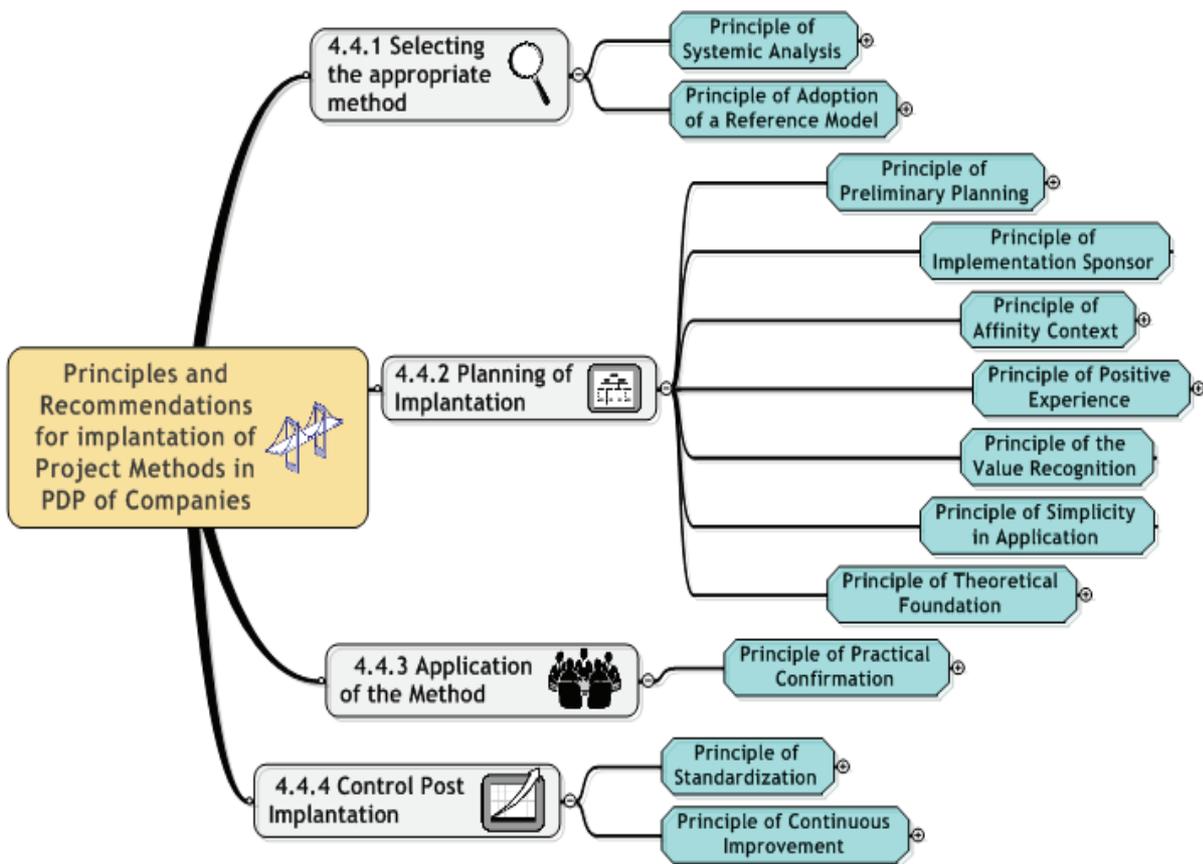


Figure 6. Principles groups for implantation of design methods in companies PDP.

- Adapt the selected method (phases and activities) to actual PDP improvement needs of the company;
- Define clearly the purpose, inputs and outputs of each activity method.

Recommendations for the Principle of Positive Experience, Principle of Value Recognition and Principle of Simplicity in Application, intended to define the project where the method will be applied:

- The project should require the execution of the PDP activities that are being improved with the use of the method, to facilitate the perception of the results in the project;
- Apply the method, first, to low-complexity projects because it reduces the risk of inefficient applications.

Recommendations for the 'Principle of theoretical foundation', which aims to define the resources required for application:

- define human resources (staff and coordinator) and financial resources required for the implementation of the selected method for the company;

- Train the team responsible for implementation regarding the execution procedures of the selected method for the company.

Method application

Recommendations for the 'Principle of practical confirmation', which aims to execute the procedures of the method that will be implemented:

- Set a team leader to manage the resources and deadlines, to identify and to correct errors and conceptually support the team on specific activities from the method;
- Make it clear to those responsible for the application of the method the inputs, procedures and outputs of each stage of the method;
- The team responsible for the implantation of the method should be aware of the importance of the method for the company, committed to outline activities, meet deadlines, and expected results.

Control post implantation

Recommendations for the 'Principle of standardization', which intends to define procedures for applying the method:

- Create a standardized procedure for future applications of the method in the company based on the procedures used in the implementation process. A process becomes standardized after successful applications;

- Perform additional and continuous training of professionals in the company about current concepts of the method, to develop the team's expertise.

Recommendations for the 'Principle of continuous improvement', which aims to establish control measures for the implementation:

- Establish control measures of the activities stipulated in the method to monitor progress and avoid mistakes during execution;

- Conduct regular meetings with the team, with the participation of an expert in the method, to identify difficulties in the initial application and opportunities for improvement;

- Evaluate the team's knowledge level, seeking to share knowledge among members to facilitate future applications of the method in the company.

It is important to emphasize that the adoption of the suggested P&R depends on the suitability of their characteristics and structure of each company. Thus, the advice is for companies interested in using the methods to adapt them according to the real needs for improvement in PDP and the method to be implemented. Therefore, the understanding is that the P&R listed are an important guide to help companies to correct deficiencies in PDP by implementation of design methods.

Conclusion

According to research results, most companies and professionals in product development do not know the design methods available and their potential. The P&R were grouped into four aspects: regarding the selection of the method, planning the implementation, application and control of actions to improve the implementation.

It is expected that this study will serve as a reference for practical applications of design methods in the industry to facilitate the improvement of the company's PDP. It is recommended that the P&R are applied to other companies and by experts in other design methods, in order to validate and complement them.

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