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**Development of a monitoring method as a support
tool for design management in the Product
Lifecycle Management (PLM) context**

GRADUATION MANUSCRIPT PRESENTED AS PARTIAL REQUIREMENT TO OBTAIN THE

Master of Science in Engineering

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Abstract

In the New Product Development (NPD) process, measuring the contribution of the design stages has become a subject of interest in the recent literature, due to the noticeable benefits of good design in Value Added products. Nevertheless, the subject is difficult due to the high level of uncertainty, complexity and fragmented nature of the design process, that hinder decision making in product development. Current research is fragmented and focuses on measuring and monitoring specific activities of the design process. However, to support design credibility in organizational environments, the contribution made by design, needs to be measured and analyzed as a whole. Design activities are often accountable for establishing a significant amount of the expenses in product development, being critical to downstream activities where late decision making can cause delays and rework cycles. Additionally, the benefits of good design are not easy to visualize due to the intangible nature of design efforts and the long time frame needed for result appraisal. This problem make design departments vulnerable to constant budget reduction. Most of the existent efforts and mechanisms available to measure and monitor the design process, are used to control time and budget but not the design itself. This project compiles a research work that includes the creation and application of a monitoring method as a support tool to assist design management efforts in measuring and improving design activities within organizational environments. The aim of the research is to find insights regarding the monitoring and measuring activity, from a designer point of view, and to propose a method to accelerate information search and processing. The monitoring method correlates three dimensions: i) Design Indicators , ii) Design Activities and iii) Best Practices, in order to simplify and assist the selection of essential information needed for decision making in design. A repository of Design indicators was created, as a foundation to simplify the process of indicator creation, selection and implementation, through their correlation with Activities and Best practices. The logic behind this correlation is established by means of a vector that determines their coherence using attributes embedded in each dimension. In addition to the description of the proposed method, an applied case study comprising a design project, supported by software tools for Product Lifecycle Management (PLM), shows an approximation of the implementation of the method and the benefits it offer, in terms of acceleration of information capture, processing and display, in order to support decision making in Design Management (DM).

Keywords: Design Management, Monitoring, Indicators, Product Design, Product Lifecycle Management, Decision Making, Control, Measurement, Performance

Personal publications

During the development of this research project, some of the results were submitted to international peer review processes and published. These articles were published in:

Book Chapters:

- Carolina Marroquín, Melisa Gaviria and Ricardo Mejía Gutiérrez. Considerations in Product Design Through PLM Technologies. in Product Lifecycle Management for Digital Transformation of Industries, ISBN: 978-3-319-54659-9 (IFIP International Federation for Information Processing ISSN: 1868-4238). Harik, R., Rivest, L., Bernard, A., Eynard, B., Bouras, A. (Eds.), Springer-Verlag (2017). Lugar: South Carolina, USA. DOI: 10.1007/978-3-319-54660-5-4
- Product Lifecycle Management for Digital Transformation of Industries, ISBN: 978-3-319-54659-9 (IFIP International Federation for Information Processing ISSN: 1868-4238).
- R. Mejía-Gutiérrez, C. Marroquín, and J.D. Giraldo-Gomez. A Knowledge Management Approach through Product Lifecycle Management Implementation: An Industrial Case Study. In Product Lifecycle Management for Society, ISBN: 978-3-642-41500-5 (IFIP Advances in Information and Communication Technology, ISSN: 1868-4238). A. Bernard, L. Rivest, and D. Dutta (Eds.), Springer-Verlag (2013). Lugar: Nantes-Francia. Vol. IFIP AICT 409. pp. 277-286. DOI: 10.1007/978-3-642-41501-2-28
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- 17th International congress on Project Management and Engineering (AEIPRO 13). Logrono, Spain. July 17-19 (2013)
- Carolina Marroquín, Melisa Gaviria. Ricardo Mejía-Gutiérrez. Ergonomic Considerations in Product Design Through PLM Technologies. In Proceedings of the 13th IFIP International Conference on Product Lifecycle Management (PLM 16). Columbia, South Carolina, USA. 10 - 13 July (2016)
- 13th IFIP International Conference on Product Lifecycle Management (PLM 16). Columbia, South Carolina, USA. 10 - 13 July (2016)

- R. Mejía-Gutiérrez, C. Marroquín, and J.D. Giraldo-Gomez. A Knowledge Management Approach through Product Lifecycle Management Implementation: An Industrial Case Study. In proceedings of the IFIP WG5.1 10th International conference on Product Lifecycle Management (PLM 13). Nantes, France. July 08-10 (2013)
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Glossary

Action Research (AR): Cyclic research methodology used in highly complex social context, that seeks to understand phenomena in real case scenarios through action, theory construction and reflection. It generates recommendations in the way of rules, procedures or practices.

Aras innovator (AI): Open source PLM software from Aras Corporation.

Architecture, Engineering and construction industry (AEC): Sector that provides the services on the architectural design, engineering design and facility construction.

Balance Score Card (BSC): Strategic management system used to keep track of the execution of activities in the value chain of an organization.

Best Practices (BP): methods, techniques and strategies that have proven successful in industrial applications.

Design activity: Actions taken to create artifacts. An artifact is considered as any artificial human creation that improves well-being.

Design Management (DM): Discipline in charge of coordinating all resources necessary to carry design abstract problems to concrete successful solutions Best (2006).

Fuzzy Front End (FFE): Activities developed prior to a product development process.

Key performance indicators (KPI): An key performance indicator is a relationships between two or more data that carry a logical connection and provide information over critical aspects of an organization (Beltran, 1999). These data are qualitative or quantitative variables that pinpoint targets related to objectives and provide an overview of the changes in a system.

New product development (NPD): Process that encompasses design and management efforts, to shape a new product or service that meets the organization and the client requirements from idea to launch.

Product Lifecycle Management (PLM): "PLM is a strategy developed to manage the product life cycle, through the management of intellectual capital that is generated around it, in the extended enterprise, by integrating people, processes and resources supported by an organizational culture that can be supported on a technological platform" Ruiz Arenas et al. (2012).

Research and Development (R&D): Systematic approach undertaken by organizations to dis-

cover solutions to problems through research and consequent development of new products, services or knowledge that generate competitive advantage for organizations.

Total Quality Management (TQM): Management philosophy that seeks to integrate all organizational functions (marketing, finance, design, engineering, and production, customer service, etc.) to meet organizational objectives by constantly improving functional processes, products and services.

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Chapter 1

Introduction

1.1 Background

Design management seeks to find a balance between external and internal influencing factors in a competitive business environment that embrace design activities as drivers for improved performance (Lockwood, 2007; Walsh et al., 1988). Design properly managed results in products and services of value and enhanced capabilities that might lead to competitive advantages (Geraghty, 2008). Therefore, organizations with ongoing design strategies understand this discipline as a valuable organizational asset (De Mozota, 2003).

A design activity is a broad term with several descriptions and uses, usually linked to the very definition of design. In the context of this research project, a design activity will be, as described by Liu and Liu (2001) an action in a cognitive process towards a clear design goal. Therefore, design activity requires the capacity of setting clear goals and visions to create artificial entities through task (Alexiou et al., 2009). This complex group of task varies according to the industry, knowledge field or society in which are executed (Cooper and Press, 1995). However, the literature establishes that there are enough similarities in the cognitive process carried during design activity regardless of the professional fields connected to design (Liu and Liu, 2001) to facilitate management. Hence, when subscribed inside the design management field the design activity becomes part of a formal program to implement across an organization (De Mozota, 2003) to manage all design resources associated with design activity inside an organizational environment.

Design deals with long term goals derived from a global design program coordinated and communicated through operational, organizational and strategic levels of the organization, which means is a core activity in which all knowledge fields and all organizational areas participate. To develop credibility in the design activity, the design manager allocates and develops resources, creates information networks in addition to planning and deploying strategies, guided by the interests of the company.

These efforts make explicit the organization know-how and transform the mindset of the organization around design (De Mozota, 2003; Best, 2006).

The managerial spectrum provides concepts and methods derived from behavioral, decisional, systemic, situational, and operational theories used to enhance design intuitive, investigative and experimental management model (De Mozota, 2003). Thus decisions are often confronted within qualitative and quantitative parameters (Van Aken, 2005), usually inherent in both design and managerial cognitive convergence structure (De Mozota, 2003). Both Management and design activities imply a decision-making process triggered by human beliefs and desires. Despite this, decisions are rational when a human not only does act under beliefs and desires but also when he does it over clearly establish goals (Peterson, 2009). However, before having a clear goal the problem or situation at hand needs to be understood. This requires a complete identification, formalization, and visualization of the problem (Peterson, 2009). Only by understanding the relevant entities present in a problem a decision-making process can be carried out. Entities are carriers of information that provide enough evidence to make decisions and manage uncertainty (Peterson, 2009; Krishnan and Ulrich, 2001). In the design activity, decisions are present in all levels of design management and all stages of design processes (Roozenburg and Eekels, 1995; Krishnan and Ulrich, 2001; Dubberly, 2004). In fact, according to Krishnan and Ulrich (2001) despite the differences in the design process found in companies, taking design as a core business process, decisions remain consistent in a certain level of abstraction.

Design managers require a strong vision and reliable information for decision-making. Nevertheless, business processes often provide large amounts of information that needs to be properly organized and understood to become valuable for decision making (Edmunds and Morris, 2000). In some cases, the information associated with standardized design processes is found explicit in information technology platforms, particularly in those used exclusively to manage product life-cycle. The purpose of Product Life-cycle Management (PLM) technologies is to offer managerial tools to product development process backed by an extensive organizational strategy that allows industries to align their intellectual capital to create products more efficiently, integrating the complex dynamics around product development (Jun et al., 2007). The prevalence of intellectual capital in PLM suggests its direct link with knowledge management capabilities (Gecevska et al., 2010; Raza et al., 2011) as it captures data, provides order to create information and allows the use of specific information to create and diffuse knowledge linked to product development (Briggs, 2006). PLM excels when it comes to delivering information, the technology enables the display of summarized information for analysis. Consequently, it comes down to the proper configuration of the software to ensure the capture and display of information for decision-making.

In an effort to track the consistency of the design strategies and the design activity results, some mechanisms are taken from other disciplines such as management and production. Total Quality Management (TQM) methods offer a performance measurement in scientific, managerial and human

dimensions and evaluate the objectives against the results of the process (De Mozota, 2003). Large evaluations are suggested by auditing tools to question the coherency between systems, strategies, and practices used by a company although, these audits are usually carried out in a partial way and require wide time frames (De Mozota, 2003; Cooper and Press, 1995; Best, 2006). Gantt charts and stage gate processes are usually deployed to visualize process roadmaps and project developments (Council, 2007). Benchmarking methods have been used to recognize best practices for business improvement (Bhutta and Huq, 1999). Also, the use of strategic methods such as the Balance Score Card (BSC) are currently under exploration as an alternative for measuring in a holistic way the design activity (Westcott et al., 2013).

The control mechanisms are based on measuring systems. Measures are the link between strategies and actions (Sinclair and Zairi, 1995), design leading companies in developed economies show a growing interest in measuring design contribution to organizations (Lockwood, 2007; Best et al., 2010). However, best practice studies exhibit little use of indicators in the design context (Cooper et al., 2004), to gauge the benefits resulting from design enhancement, it's necessary to measure design work to support decisions based on evidence rather than conjecture and faith (Lockwood, 2007). Some efforts have been made to measure design (Lockwood, 2007; Viladàs, 2011; Westcott et al., 2013). Nevertheless measuring requires a formalized design process and working methods so knowledge and valuable lessons can be captured and shared within the organization to improve overall procedures (Council, 2007; Bhutta and Huq, 1999) but no methodology has been embraced by the industry yet (Jozaisse, 2011; Best, 2006).

1.2 Research problem

Design managers face the complex activity of determining wherever design activity is ill-structured (Krishnan and Ulrich, 2001) and define points of intervention to improve the outcomes of the overall design program instated in a company. Unfortunately, the literature evidence shows that current design management action plans are often no actionable given the misalignment presented between any design endeavor and the capacities of organizations. There is often fragmented design information that causes a disconnection between performance and bottom line design results (Lettice et al., 2006)Luttikhuis et al. (2015). Several problems are associated with the difficulty to achieve successful improvements into design activity.

When making decisions, design managers face the challenge of ensuring alignment and positive results for every stakeholder expectations according to business demands. However, managing such interest requires communication across all personal linked to the design process, despite the different knowledge fields. Information is often misinterpreted and unclear, which prevents successful or on time decisions. Consequently, adapting design to the changing environment of a company requires

only a few information (Kandemir and Acur, 2012) to achieve successful outcomes and avoid risks such as failure to launch, re-processing, delays and elevated costs.

Decisions in the design field come from complex parameters both quantitative and qualitative. Moreover, design variables are often disruptive (Van Aken, 2005) and commonly affected both by internal and external factors. A holistic view of design seeks to control these relevant factors on every level of design management and ensure that design activity is not an isolated effort from the business direction (Clevenger and Haymaker, 2011). However, managing design information requires expertise and time to convey dispersed data during design activity, in addition to the synthesis process and the efforts to represent and share the information in order to transform it into know-how for practical use. Additionally, design outcomes are usually available in the long term, this restriction difficult decision making in the short term; thus, being proactive while managing design rather than reactive, requires information beyond product results and customer satisfaction (Dávila, 1999).

The purpose of this project is to elaborate on the information requirements necessary to create a monitoring method to support decision making in design management in several management levels.

1.3 Research question

The previous overview presents the gaps and challenges found in design management decision-making, the availability of information and the difficulties of a successful intervention of design activity. Given these findings, the research question of this project associates to the relevant information used for design management planning and its availability. Therefore to establish a clear research direction, this project will elaborate on the following research question.

- How to provide adequate information to assist design managers in their decision making process towards design process improvement?

To answer this question it's necessary to understand the design management activity and the design processes to identify relevant information that relates to the state of the design activity. Furthermore, questions about the issues faced by design managers, their information needs and their decision making process as well as control mechanisms.

Assuming that a design activity occurs under a process or project, the activities and their structure provide information and evidence that supports which decisions and plans to execute. Quantifying and evaluating these activities might result in an overview of the state of design activity and a starting point for decision making.

The first question derived in several secondary research inquiries:

- Which information is significant enough to drive intervention of the design activity?

- What are the difficulties associated with design measuring for engineers and designers?
- What kind of information of the design process seems to be of relevance for monitoring strategies?

The research project presents two research cycles explained in this document in section 1.7 and attempts to elaborate on the previous questions.

1.4 Research justification

Given that design management activities rely on design evidence to transform or improve the design strategy of a company, the comprehension of the entire design management system provides support to (i) ensure the effectiveness of the design process and activities despite product final result, (ii) create awareness of the benefits of design activity in all its dimensions, (iii) increase proactive decision making due to simplified information visualization in real time, (iv) visualize in short lapses the design efforts and the direction they are taking, (v) accelerate decision making due to selection of relevant information for visualization, (vi) facilitate the coordination activities of the design manager by providing a monitoring strategy to guide the decisions, (vi) Define actionable plans for design improvements, and (vii) Support design decision in robust strategies and information technologies such as PLM.

Establishing control inside a design process provides structure to the design strategy and reduces the time spend on information selection and processing and decision making

1.5 Objectives

1.5.1 General objective

The overall objective of this research is to develop a design management monitoring method by correlating design indicators, activities and best practices to increase design management decision-making processes agility and scope.

1.5.2 Specific objectives

To accomplish the desired outcome, the present research concerns specifically with

- Analyze design management models, activities, indicators and decision-making processes. Based on studies reported by other authors in the fields of product development, design management, design performance, design evaluation, to understand the variables and needs present on design management.

- Gather insights regarding design measuring, evaluation and improvement from a previously conducted case study to provide initial inputs for a monitoring method.
- Analyze design measuring, through the application of an indicator creation methodology in an explorative case study to understand decision making in design based on indicators.
- Identify design dimensions and variables needed for design monitoring and improvement through the analysis of design activities, indicators, and best practices present in the analyzed literature and cases to lay a foundation for a design monitoring method.
- Relate design variables through identification of common properties and variables to construct a design management monitoring method.
- Implement the proposed method in a explorative pilot project to evaluate its effectiveness and get feedback for further improvement of the proposal.

1.6 Research Scope

The research project delivers a descriptive model to monitor design and a structured method for its application. It also delivers a report with the development of the theory behind the model and the results of (1) the literature research (2) the findings of an explorative case study to underline monitoring needs in the design context and (3) the results of the implementation of the method in a case study and (4) an approximation to the configuration of the method in a PLM software.

The method simplifies the identification and selection of activities, indicators and best practices for monitoring, its main application is to assist novice design managers. When used in mature design managers environments its a consulting tool to add value to current established processes in small scale.

Given the nature of the research the project will include only a case study due to the time necessary to plan, implement and obtain results in design projects. Hence, the indicators use in the application case relate to short term measurements.

The PLM configuration would be explored as part of each chapter of the project but it will not be fully used in the research cases. The creation of a final structure to implement the method in the software will evolve during the research, but due to the complexity of the software programming the project will focus primarily on developing the method rather than automating it in the software.

1.7 Research Approach

The current research project was executed under an Action Research (AR) approach. To do so, several considerations were taken into account to select such an approach:

- The nature of the problem undertaken subscribes into a social situation in a real context.
- The researcher is not an isolated participant of the situation; in fact, the problem linked to the project requires high levels of participation and co-creation
- The research question is still too open. Thusly the iterative nature of the approach allows the evolution and refinement of the research questions as an action is taking place. The flexibility of the approach seeks to evolve and create new knowledge around a situation. It also provides a research focus to generate theories from the practice.
- The problem comprises complex elements with several uncontrollable variables
- The time assigned to the overall project and the context of application are both factors that difficult the planning and execution of case studies.

Action research is an appropriate research approach when the situation undertaken by the research project is closely attached to a specific context and requires the development of concrete knowledge Bell (2014) through the active participation of the researcher Dick (2003); McNiff (2016). The sole purpose of this approach is to understand and analyze the interaction of components of complex systems Dick (2003) to generate recommendations in the way of rules, procedures or practices Denscombe (2002) towards improved performance.

This approach works in social situations where the understanding of the problem is scarce and the research questions are still open Dick (2003). Due to its flexible configuration adjustments regarding the research question, hypothesis and overall design of the research evolve as the understanding of the situation grows.

Given its applied nature AR develops into iterative cycles executed within the natural learning cycles commonly embraced by practitioners Dick (2003). Therefore, each cycle contains four stages (plan, act, observe and reflect) Kemmis et al. (2004). This setup combines action and research to achieve a balance between understanding through action and theory construction through reflection Dick (2003). In addition, the cyclic nature of AR provides a feedback loop for theory refinement Bell (2014) as shown in figure 1.1.

The current project comprises two research cycles, both structured to tackle the considerations shown on the right column of the figure1.1. The first research cycle was an explorative case study in which two of the secondary research question were answered, the case study comprises a design project

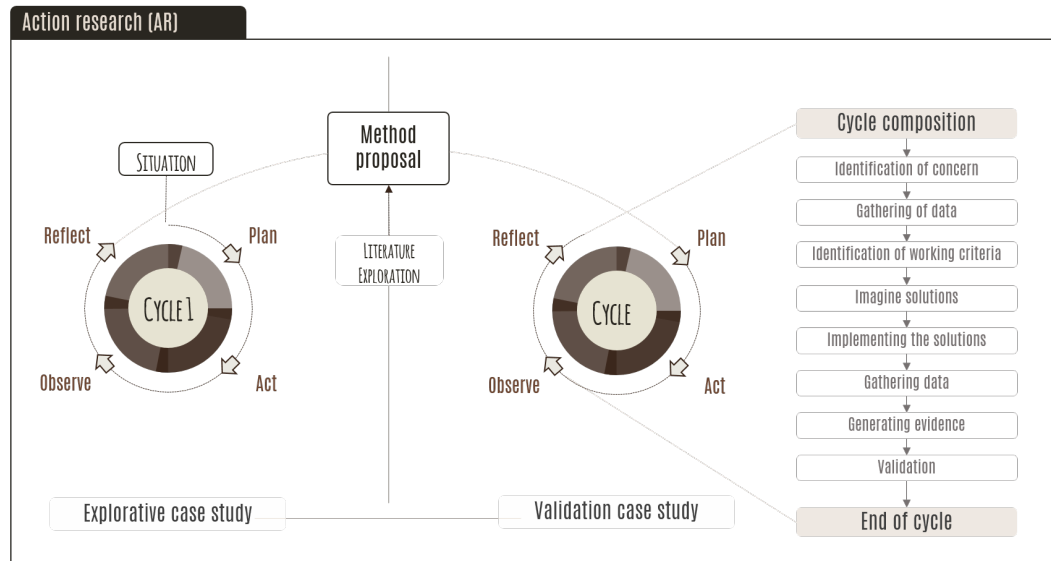


Figure 1.1: Research methodology

in which a novel design methodology was applied. The aim of the project was the creation and use of indicators to improve the said methodology. The results of the first research cycle were the insights necessary to create a monitoring method implemented on the second research cycle in which a case study involving five companies, students and professors of the product design engineering bachelor program of EAFIT university join strengths to work on a design project that sought to develop novel approaches towards solving the companies design concerns for the future, the application of the method was monitored and the benefits of the method were analyzed.

Action research is also accompanied by exploratory studies to 1) narrow the literature relevant for study 2) dissect the main studies to understand the efforts and gaps found in the topic 3) generate possible research questions, and 4) reinforce the research question with further exploration of literature cases. Continuous exploration provides inputs for every research cycle. The structure of the cycles is set as suggested by Whyte (1991).

The research cycles were supported on structured case studies. A case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real world context Yin (2013). Case study approach works for exploratory, descriptive and explanatory research in which a how or why research question is worked upon. Such is the case of the research question at hand which subscribes under a social sciences phenomenon inside a complex context, thereby real observation of the said case provides new approaches for the problems of the particular context. The research is of qualitative nature. Therefore, the case study works to 1) construct the first inquiry 2) understand the difficulties associated with the inquiry and, 3) apply a new methodical proposition into a real scenario for further improvement.

1.8 Thesis organization

This research work has been structured into 6 chapters (see fig 1.2). The current chapter presents an overview of the research foundation, objectives, scope, and methodology. Chapter 2 provides a review of the literature of relevant background topics for the project, and the insights gathered from a real case that became the driver of the research and presents the theoretical framework for the research. Chapter 3 contains the first AR cycle making use of an exploratory case study. Chapter 4 shows the development of a model and the proposal of a method for monitoring design. Chapter 5 shows the implementation of the method in a case study and its results. Finally, Chapter 6 presents the conclusions from the research project and the future work associated with it.

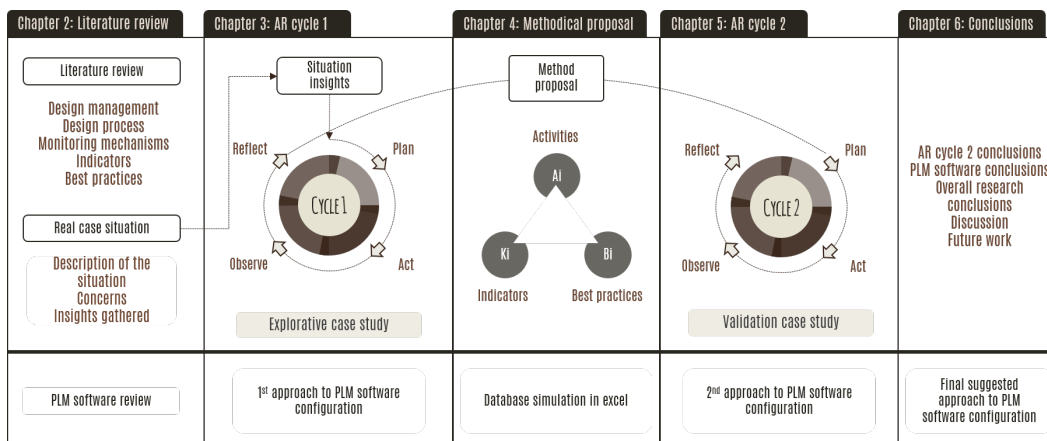


Figure 1.2: Thesis structure

Chapter 2

Literature review

2.1 Design activity

For the current research project, design activity purpose is to create artifacts. An artifact is considered as any artificial human creation that improves well-being. In that sense design is the transformation of existing conditions into preferred ones (Simon, 1969), for instance design is an activity that adapts to changing environments and evolves in time. Design today creates not only tangible products but complete systems that carry promises and brand identities. Design creates expanded products that are complemented with services, networks, interfaces, social benefits, initiatives and underlying symbolism and significance (Krippendorff, 2011). Today, design is holistic.

In developed countries design is considered a valuable asset to open new markets capable of setting differentiating factors from competitors, launching successful products, securing market position and adding value to the company brand (Council, 2007). Design is seen as an innovation catalyst.

However, design problems prove to be a challenge for any organization, given the natural characteristics of design problems. The literature has been extensive when treating the so-called wicked problems (Buchanan, 1992; Rittel and Webber, 1973) that made any design endeavor unique and complex. Design is wicked because it depends on the integration of many factors, so problems have no clear formulation. In that sense, it depends on the experience and information package of the individuals resolving the problem, the context in which is subscribed and the external restrictions set upon the project. Each problem is unique and so is each solution. There is always room for improvement and the only reason to stop the endeavor is because external factors provoke it, such as budget or time (Rittel and Webber, 1973). In addition, the solution is evaluated under subjective parameters and upon the impact made on people.

Thereupon designers face the challenge of providing solutions for people they do not know, in markets they do not understand, under tight economic, environmental and social constraints and

expectations they cannot visualize, inside multidisciplinary environments. Design managers deal with the challenge of coordinating all resources necessary to carry design abstract problems to concrete successful solutions (Best, 2006; De Mozota, 2003).

2.2 Design management

Design management is a process that allows to communicate, manage and control all design activities through strategies that capture the identity and values of the organization into the products they create and transmit those values into the final clients and users (Best, 2006). The aim is to assign the creative assets available to generate competitive advantages that made companies sustainable (Geraghty, 2008). and provide alignment between brand identity, product and services vectors (Cooper et al., 2013; Xenia, 2010).

The management models combined with the design approaches seek to gather sufficient capabilities supported in methods, tools and skills to improve the innovation process and promote the relationship between creative and business partners (De Mozota, 2003).

According to De Mozota (2003) Design management focuses on several fronts.

- Manage the strategy: Requires to identify the opportunities, create the implementation plans and search and develop the skills to execute the plans successfully.
- Manage the design process: Requires to create a structure for design and develop the assets and human resources around a culture of creativity and team synergy.
- Manage the new business models: Used to generate new business opportunities through the application of idea enrichment, continuous improvement, prototyping and user research to create value through design
- Manage service design: To satisfy the users, clients and suppliers with a systematic management approach that not only involves the product and brand promises but the experiences they share while interacting with any part of the organization.
- Manage organization identity and brand: where all design decisions consider the brand as a main axis to determine the design and development of products and services.

Thereby, design management evaluates the context, assigns resources and generates feedback to improve the processes.

The benefits perceived by the implementation of design management as an organizational asset derive from the value that adds the design to the practice in product innovation regarding aesthetics, functionality, profit and differentiation (Cooper et al., 2013).

In the organizational context design can be found in different levels of application, for instance, design can be approached as a strategy, as a functional area, as a project or as a technical activity that is absent from the management level (De Mozota, 2003). According to the level in which design is established it is the range of empowerment that has a design manager. Hence, when design is in the highest level (strategic) the main axis of innovation is based on Design Activities and the contribution is not only on the technical design but in the development of design teams, the identification of opportunities and businesses, among others previously mentioned. According to the application level is the control exercised by the design manager, in the operative level (project management), in the tactical level (functional management or process level), and finally in the strategic level (mission of the organization). Further detail on the characteristics of levels are shown in figure 2.1.

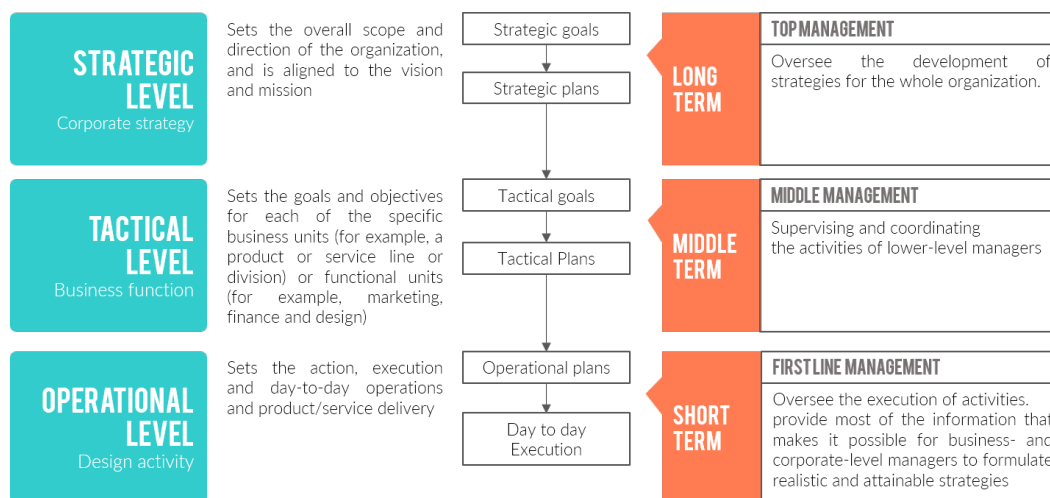


Figure 2.1: Management levels adapted from Cooper and Press (1995); Mintzberg et al. (1997)

Under these levels the necessary factors to ensure good design focus on three different fronts where (i) planning is necessary to set the objectives and activities of design to align the organization, (ii) the design process is central to establish the innovation programs and the design politics of the company, and (iii) the resources are divided to ensure the adequacy of the infrastructure to promote the creative thinking, develop the design teams and generate design projects.

According to De mezota De Mozota (2003) the design, as a process, tries to balance 4 different fundamental characteristics:

- Creativity: the processes of creation
- Complexity: Decisions based on a great amount of parameters and variables
- Compromise: Balancing contradictions found between parameters and prioritizing such parameters according to restrictions and interest

- Choices: Selection between several solution in all product stages.

The design manager deals with this characteristics making use of several management concepts as shown in figure 2.2.

DESIGN CONCEPTS	MANAGEMENT CONCEPTS
DESIGN IS A PROBLEM-SOLVING ACTIVITY.	<i>Process. Problem solving.</i>
DESIGN IS A CREATIVE ACTIVITY.	<i>Management of ideas. Innovation.</i>
DESIGN IS A SYSTEMIC ACTIVITY.	<i>Business systems. Information.</i>
DESIGN IS AN ACTIVITY OF COORDINATION.	<i>Communication. Structure.</i>
DESIGN IS A CULTURAL AND ARTISTIC ACTIVITY.	<i>Consumer preferences. Organizational culture. Identity.</i>

Figure 2.2: Management concepts in design from De Mozota (2003)

With such concepts the design management focuses on two perspectives: Managerial and strategic (see figure 2.3).

Design management approach	The objective of design management	Its application to quality management
The managerial approach to design management	Enhance design with managerial methods	Contribution of "qualityicians" to designers and design managers
	<ul style="list-style-type: none"> • design and organizational performance • design/brand, identity, strategy • general management and design management methods 	Data on design's impact on "zero defects"
		Test of quality perceived
The strategic approach to design management	Improve management with design knowledge	Contribution of designers to "qualityicians"
	Theories of form; design principles	Rethinking processes
	Creativity and idea management	Shared vision, continuous improvement

Figure 2.3: Perspectives of design management taken from De Mozota (2003)

The design decision are taken with the help of such sources of management. The current project focuses on a strategic perspective with emphasis on operational and tactical levels given that design

in most of the organizations belonging to the local context manage design in the inferior levels and have yet to reach a strategical approach. Therefore the method has a greater application ranges and as a consequence the possibility of greater impact and further escalation into the strategic level in posterior years

Design efforts deliver return of investment on a three year average or 15 months after the product launch, with an average period of fifteen months (Walsh, 1995; Potter et al., 1991). This situation difficults the measurement of design in the short term given that financial measures are available after measuring the sales, the price (Sentance and Clarke, 1997; Press, 1995), or perceived value (De Mozota, 2003). Changes in the design structure become a result of this measures which means decisions are made mainly in the long term and are of reactive nature.

2.3 Design innovation processes

Design is a process of goal directed reasoning (Roozenburg and Eekels, 1995). Design is at the base a process in which analysis and synthesis take place and were choices are made to decide properties and behavior of new systems (Van Aken, 2005; Simon, 1995).

Design processes are organized in stages and sequences of activities executed by people. But, unlike other processes, design its not a linear process but an iterative one with improvement cycles to arrive at a satisfactory solution for all stakeholders in a time constrain. Much has been discussed about the different configurations of design process, but given the ill-define nature of design problems there is no process formula that can be applied to all design situations (Rittel and Webber, 1973; Buchanan, 1992). However some relevant approaches have been made and therefore have been further studied for this research project in hopes of understanding a general structure, since design managers intervene the design process for improvement. Every time a new improvement is made to design, the design manager is changing the human systems related to it (Van Aken, 2005). Therefore, organizational change takes place and constrains such as culture, budget, and development time, need adaptation.

The literature regarding innovation design process structure is extensive. The product development processes are detailed in several studies resulting in diverse models of the product development process. In this research project, two stages of the innovation design process are of interest. The first is known as the Fuzzy Fron End (FFE) process. The second, is known as the New Product Development (NPD) process. Although in industrial applications the design processes are often unique, most of them comprise similar structures and general activities (Clarkson and Eckert, 2010) as shown in figure 2.4.

The preliminary stage is called by some authors as Fuzzy Front End (FFE) and formalized in a variety of models with their activities (Koen et al., 2001). Others provide a pre-planning stage in the new product development process and set design activities to detail the endeavor prior to development.

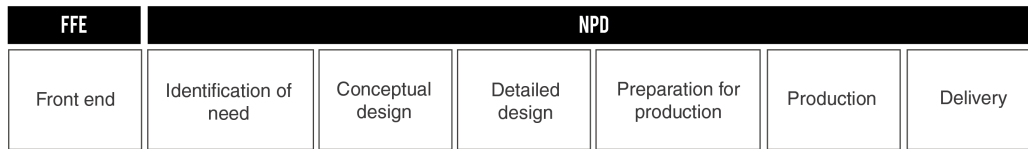


Figure 2.4: Design process general stages

Once a clear direction is defined, the second process, known as New Product Development NPD is set into motion and both, design and management efforts, began to shape a new product that meets the organization and the client requirements from idea to launch.

Given that the validation case study (section 5), takes place in a FFE project, further detail is explained about this process in the subsection below.

2.3.1 Front End of Innovation

Fuzzy Front End (FFE) is the name given to the activities developed prior to any product development process. For many years the NPD was the focus of many studies, however, since innovation has revolutionized the industry, the FFE has been determined as a great area of weakness in the innovation process (Koen et al., 2001).

Several studies encompassed the importance of the definition of this stage inside organizations and suggest the need of managing it in a structured way (Smith et al., 1999; Khurana and Rosenthal, 1997), since it defines the future competitive scenario of organizations (Cooper and Kleinsemidt, 1995; Khurana and Rosenthal, 1998).

The term Fuzzy Front End was first used by Smith and Reinertsen (1998), and several authors follow this denomination. Khurana and Rosenthal (1997) suggest the use of Front End and remove the fuzzy as they were suggesting a structured approach to reduce the uncertainty. Koen Koen et al. (2001) used the label Front End of Innovation to name his model and correlate tools, methods and activities used at the beginning of the innovation process.

Setting FFE as an organizational process is necessary to make the first stage of the innovation process effective for corporate interest, it is also a possible approach (Smith et al., 1999). FFE in the corporate environment seeks to (1) maintain a sustainable flow of ideas, (2) Create idea storage mechanisms without killing creativeness, (3) structure trial and error, the idea is to fail fast, i.e discard ideas that do not fit the company current expectations (Smith et al., 1999), (4) Deliver a complete information package with elaborated business opportunities to support decision making, (4) reduce risk by making quality decisions about what should be send for development and, (5) create fast cycles to make the process valuable for the company competitiveness.

A fair balance between a structured but open approach is necessary to ensure a successful FFE

process, one that can be managed and improved consciously. Given the creative nature of the first stage of the process, an open creative loop must be open and only a recollection mechanism should be put in place (Boeddrich, 2004). However, a Design Manager requires not only the ideas but information structure to decide wherever a radical approach or an incremental approach is more convenient according to the organization's current expectations and strategic goals (Boeddrich, 2004). Therefore, idea selection based on specific rules can be used in the stages of FFE (Geschka and Schwarz-Geschka, 2000). This mixed approach encourages creativity and structured ideas selection, reducing uncertainty and resulting in valuable inputs for informed decision making.

2.4 Design decisions

Decision making can be defined as the cognitive process related to the selection between several alternatives (Peterson, 2009). For Kandemir and Acur (2012) the strategic decision making is supported on three main elements:

- **Rationality:** Is the systematic analysis made by the decision maker, based on reliable evidence around the problem.
- **Behavior:** It addresses the balance between interest and influences made by external and internal stakeholders immersed in the problem.
- **Intuition:** Relies on the experience, judgment and instinct of the person making the decision.

According to Roozenburg and Eekels (1995) Decisions comprise four main characteristics: (i) who is entitled to make the decision, (ii) the quantitative or qualitative criteria established to evaluate which alternative to choose, (iii) the indicators related to those criteria that provide the values for evaluation, and (iv) the importance of the criteria. These characteristics combined with a clear goal made the decision rational (Peterson, 2009).

The decision is constituted by relevant entities and information regarding the decision to take. Hence, before making a decision, a clarification, formalization and visualization of the problem is necessary to understand the actions and the expected results (Peterson, 2009). Making a decision is also a structured process in which several steps and activities should take place to support the final decision. According to Litvaj and Stancekova (2015) the decision making process comprises five steps shown in figure 2.5.

Decision making is constrained by the capacity to process large amounts of information from different sources (Roozenburg and Eekels, 1995). The alternatives should be evaluated separately to gather a final summary of values that result in the best decision. Each evaluation needs elements or criteria used to weight the alternatives under the same conditions. Hence, a criteria is a requirement or demand

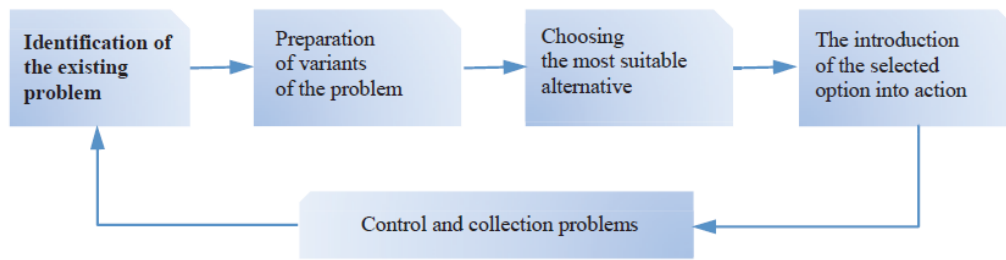


Figure 2.5: Decision making process Litvaj and Stancekova (2015)

that constraints the decision. The way in which the decision process is structured and supported by methods, tools and means for data representation makes the criteria usable for decision making.

In the product planning a set of decision ensure that the company pursues the right markets and products in alignment with the strategic objectives (Kandemir and Acur, 2012). Hence, in the practice all design process stages are trajectories of decision taken under the direction of the previously formulated strategies (De Mozota, 2003)). The decision are based on the understanding of the processes and the capture and processing of data into information to support decision making (Council, 2007). The design manager defines the procedures and methods that strengthen the performance of the design activity. Since new product development is assumed usually by multidisciplinary teams, subsets of decision are assigned to work teams with common criteria and value scales defined in procedures, this division increases the fragmentation of sources of information to get a general picture of the state of design in all levels (Krishnan and Ulrich, 2001; Luttkhuis et al., 2015).

However the ill-defined nature of design problems generate high levels of uncertainty when making decisions, to deal with such situation, uncertainty in design is managed through the information processing (Thompson, 1967; Galbraith, 1977). When studying the literature on product development evidence shows that every organization manages design according to their specific needs (Krishnan and Ulrich, 2001) However, what is decided in the different levels of design, seems to be fairly consistent. Hence, a generalization of decisions (Krishnan and Ulrich, 2001) and practices is possible (Kandemir and Acur, 2012). Although most design managers gather information from multiple sources, when it comes to making decisions only a few data are relevant (Kandemir and Acur, 2012).

Research has shown that managers are surrounded by disturbing amounts of data and information on their daily basis (Gunnlaugsdottir, 2003). Most of their work is related to the search of information to fulfill their jobs (Braganza, 2004). To understand the difference between information, data and knowledge this project will focus on the definition suggested by Braganza (2004) and Davenport et al. (2001) in which the data are define as facts and observations derived from information. Information are facts and observations made in context that enable work practice and are constituted by data elements, as well as knowledge that is information processed to make decisions and transformed in

knowledge in which people base their actions and results. Figure 2.6 shows the hierarchy of knowledge in a bottom up and top down approach.

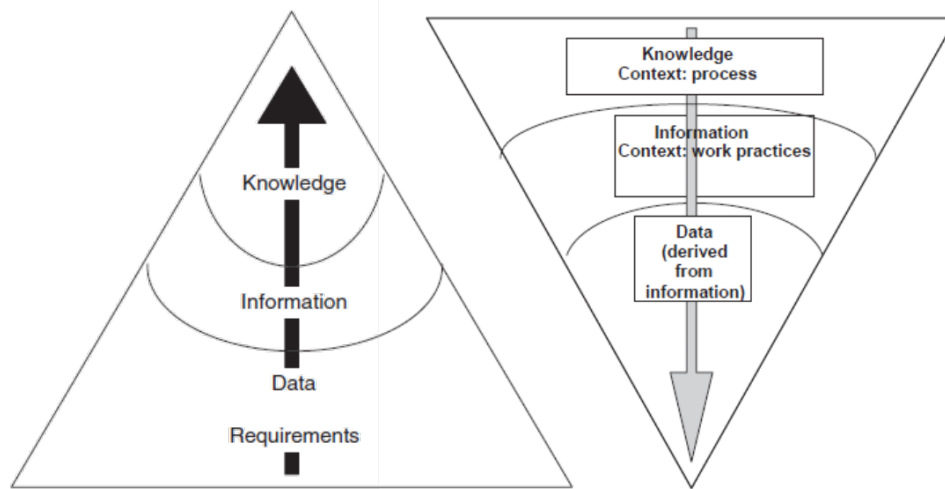


Figure 2.6: Knowledge management hierarchy Braganza (2004)

Knowledge management for instance can be defined as the creation of conditions necessary to capture, maintain, storage and use the intellectual capital of a company (Litvaj and Stancekova, 2015). In the design process capitalizing knowledge for decision making is a strategy to improve future developments (Chandrasegaran et al., 2013).

The top down hierarchy model suggested by Braganza (Braganza, 2004) shows a causality between the data, information and knowledge that shows the source of decisions. In design, explicit information and knowledge come from fragmented sources, due to the high complexity of the developments, the different parties involved, the stake-holders with interest and influence over the design and the stages it goes through. Consequently visualizing the decisions and their consequences is a difficult task (Luttikhuis et al., 2015). Under this outlook, capturing data and information becomes essential for most design managers. However, capturing the information requires a planned structure for information management supported on technological aids (Chandrasegaran et al., 2013), a combined effort between automatization and user intervention is necessary to capture, share and maintain information integrity. Each stage in design, generates different kind of knowledge represented in different forms from graphical to algorithmic that ultimately create a model of information (Chandrasegaran et al., 2013). Relevant information is usually unstructured, undocumented, and shared through channels without any protocol (Luttikhuis et al., 2015). The lack of tools to structure and interpret an amount of information, in an organized manner, hinder the visualization of the state of design and difficult the decision making process. The delays in opportune intervention of design manager generates corrections that can cause budget overrun in subsequent stages (Chandrasegaran et al., 2013).

The design manager spends time searching in the abundant pools of information for concise bits for decision making. The task is highly inefficient and involves constant search, correction and iteration processes (Luttikhuis et al., 2015). Moreover, decisions in design create a predecessor relationship, which means all decisions are dependent of each other. The errors might escalate in the overall processes without control. Research shows that decision made in the early stages of design are accountable for the 75 % of the manufacturing costs (Chandrasegaran et al., 2013), which means decisions can snowball into all product life-cycle stages and impact the financial state of an organization on the long run.

To align decisions and generate opportune communication of design state the relevant information should be extracted in an agile manner, making use of appropriate mechanisms of calculation (indicators) (Luttikhuis et al., 2015), this decreases the constant efforts spend in creating communication protocols, search and iterations processes

2.5 Design monitoring and control

Control is defined as the group of criteria policies and procedures established to standardize operations and facilitate the measuring of performance that ultimately guides the achievement of objectives inside organizations (Davila, 2000). A control management system seeks to reduce the uncertainty which means closing the gap between the amount of information required to perform a task and the information already available in the organization to achieve it (Galbraith, 1977; Davenport et al., 2001). In this sense control systems are based upon a clear management of knowledge and drive organizational learning and improvement. Control systems use monitoring mechanisms to capture snapshots of the state of a process. While monitoring focuses on capturing, control focuses on decisions and exerting influence on the system based on the information delivered by constant monitoring.

The literature regarding the implementation of control systems in design is scarce, most of the developments focus on the broader scale of an R&D department, however several researchers have express the need to implement control systems in design to reduce the high levels of uncertainty and focus on providing scope and timely response to support decision making (Abernethy and Brownell, 1997; Birnberg, 1988; Akhilesh, 2014). The benefits of this approach seek to reduce delays and information inconsistency (i.e technological uncertainty in NPD can cause delays up to a 58 % in a design project (Davila, 2000)).

Currently the majority of control mechanisms in the New Product Development (NPD) process are related to time management (Davenport et al., 2001) supported on project management methods. Financial control is not necessarily addressed in a large extent, due to the long term results of product development. The indicators associated to finance are used to display the commitment of an organization to their R&D departments (Davila, 2000), given that financial control only works in processes

with low uncertainty (Abernethy and Brownell, 1997; Perrow and Perrow, 1970). Hence, most control efforts are based on non-finance indicators to broaden the view for decision making, that occurs at the end of each stage of the design processes (Davenport et al., 2001).

Design requires a thoughtful control of design work consistency and alignment with the strategy formulation. In this sense, in the practice, the design manager becomes a internal consultant that establishes control mechanisms creating relationships between design activity, strategy, identity and culture (De Mozota, 2003). An additional difficulty is that control in design has proven to be a controversial subject in research due to the creative nature of the design processes. Some researches have come to the conclusion that innovative behavior does not necessarily increase with a loosen management control in comparison to innovative behavior under strict control. Thusly, a control mechanism in design requires a balance between control and freedom, flexibility and precision, individual effort and team effort (Davila, 2000)

The control strategies and mechanisms depend on the tools used in design that provide criteria for evaluation of the contributions made through design. Research shows that there is a strong relationship between the performance of an organization and design management (Walsh et al., 1988; Dávila, 1999). However, if the design activity wants to gauge its contributions, then it must use a language that the top of the organization can understand. This approach is achieved through the use of indicators (De Mozota, 2003; Lockwood, 2007).

Design leaders struggle to make tangible the value of design, as consequence the budget assigned to design is usually the first to get cut (Jozaisse, 2011). The barriers to measure design are well studied in the literature:

First, historically design has resist quantification arguing that it diminishes the creative perspective (Lockwood, 2007). Second, when design is established as a functional area it is usual to find measures in terms of marketing and production, but not on design itself (von Stamm, 2013). Similar behavior is noticed in the management of design as projects, where indicators are related only with project management approaches Third since design its an activity with long term result, the benefits are only tangible after at least three years after product launch, the control is usually based on reactive measures usually related to finance dimensions (De Mozota, 2003).

Measuring performance of design has been a key research topic in accounting, business and engineering performance measuring systems that strive to provide "a set of mechanisms and processes used by an organization to identify key objectives and support the implementation of actions, plans, measurements and control rewarding and learning" (Ferreira and Otley, 2009).

The idea is to look beyond the numbers into the objectives. There is a causality effect that allows to trace objectives and targets from the measurements (Mrazek et al., 2011). To achieve proactive management it is not enough to have the measures that show the consequences of the efforts after the implementation, but to be able to act over the causes of misalignment's (Dávila, 1999). Therefore a

cause-effect relationship connects actions to results (Mrazek et al., 2011) for decisions making.

A measurement processes derives from product development activities in order to provide support for decision making (Lettice et al., 2006; Mrazek et al., 2011). It also aligns the distributed stakeholders and design parameters used in successful developments in both project and programme level efforts (Griffin and Page, 1996). It also provides insights into the weaknesses and improvement opportunities, therefore allocation of resources can be made constantly and successful product developments can be repeated (Mrazek et al., 2011; Griffin and Page, 1996). Measuring Systems increase the reliability on strategic decisions and enables ways to save costs, reduce product life cycle and reduce time in decision making (Mrazek et al., 2011).

Indicators should come during the processes in a dynamic way. However, capturing such extensive amount of data to feed the indicators is difficult due to the concentration of indicators in different levels of product development (Lettice et al., 2006). Isolated efforts are common, but organizations have struggle to give a holistic approach to measuring design (Clevenger and Haymaker, 2011). Most developments have been made at the project level given that design usually happens at this level borrowing strategies for control and monitoring from project management fields in which time, scope and budget are primary sources of measurements (Gries and Restrepo, 2011). However design perspectives tent to get unaccounted due to their intangible characteristics (Viladàs, 2011).

Several control mechanisms are suggested to measure design, from the managerial perspective design can be measured using Total Quality Management (TQM) approaches, from the strategic perspective the Balance Score Card (BSC) has been addressed in design as an ongoing project in developed countries (Westcott et al., 2013). Performance measuring systems are also created as independent efforts. Hence, companies like Philips and procter & gamble have created their corresponding methodologies (De Mozota, 2003; Jozaïsse, 2011), with satisfactory outcomes (Mrazek et al., 2011). The literature is extensive in the suggestion of design measuring criteria, project measurement indicators and overall performance indicators. Other robust control mechanisms are the evaluation tools such auditing, diagnostic and maturity evaluation methods. However, there is no methodology yet that has been adopted by the industry in a large scale (Jozaïsse, 2011).

Given the importance of measures in design control, a systematic search was developed in order to find methods, tools, frameworks and methodologies regarding metrics, indicators, performance measures and value measurements on design reported in the literature. Several search equations made with specific key words were used in academic databases such as Scopus, Google Scholar, Science direct and Emerald, to gather documents in journals, conference proceedings and thesis. The search derive on 678 documents, 64 related to the strict topic of measurement and indicators (see table 2.1)

38 indicators are related to isolated proposal of indicators to solve a particular issue during design, 11 relate to methods, tools or frameworks to measure design and 17 show an array of studies on measurement in design, the remaining two are books addressing indicator theory. The methods found

Table 2.1: State of the art main sources

#	Author	Name
1	Henri J. Thevenot, Fabrice Alizon, Timothy W. Simpson, and Steven B. Shooter	An Index-based Method to Manage the Tradeoff between Diversity and Commonality during Product Family Design
2	Brent A. Nelson and Jeannette Yen	Refined metrics for measuring ideation effectiveness
3	Anna Wingkvist , Morgan Ericsson, Rüdiger Lincke and Welf Löwe	Metrics-Based Approach to Technical Documentation Quality
4	Benjamin Kloss-Grote and Michael A. Moss	How to measure the effectiveness of risk management in engineering design projects
5	Mustafa Batuhan Ayhana,b, Ercan Öztemela,b, Mehmet Emin Aydinb and Yong Yueb	A quantitative approach for measuring process innovation: a case study in a manufacturing company
6	Sarah K. Oman , Irem Y. Tumer , Kris Wood, Carolyn Seepersad	A comparison of creativity and innovation metrics and sample validation through in-class design projects
7	Y. Borgianni, G. Cascini and F. Rotini	A proposal of metrics to assess the creativity of designed services
8	Maí C.R. de Vasconcelos, Denis T. Franco, Lirida A.B. Naviner, Jean-François Naviner	Relevant metrics for evaluation of concurrent error detection schemes
9	Marco Alemanni a, Grimaldi Alessia , Stefano Tornincasa , Enrico Vezzetti ,	Key performance indicators for PLM benefits evaluation: The Alcatel Alenia Space case study
10	J.-D. Caprace , P. Rigo	A real-time assessment of the ship design complexity
11	Yuanyuan Yin	Development of a design performance measurement matrix for improving collaborative design during a design process
12	Mustafa M. Rashid Hossam Ismail	Generic tool for measuring the reliability of product development processes
13	DANE	Guía para Diseño, Construcción e Interpretación de Indicadores
14	Helmi BenRejeb, LaureMorel-Guimaraes, Vincent Boly , N'Doli Guillaume,Assie' lou	Measuring innovation best practices: Improvement of an innovation index integrating threshold and synergy effects
15	Caroline M. Clevenger and John Haymaker	Metrics to assess design guidance
16	C. D. W. Lomas, J. Wilkinson, P.G. Maropoulos, P. C. Matthews	Measuring design process agility for the single company product development process
17	Bruno Gries, John Restrepo	KPI measurement in engineering design – a case study
18	Abbie Griffin	Metrics for measuring product development lifecycle
19	Fiona Lettice Norman, Roth Ingo Forstenlechner	Measuring knowledge in the new product development process
20	H. Driva, K.S. Pawar, U. Menon	Measuring product development performance in manufacturing organizations
21	Xènia Viladàs	Measuring Design's Contribution to Business Success: A Three-Tier Approach
22	Deborah Mrazek, Sam Lucente, Katherine Wakid, Steve Sato, Conrad Wai, Adam Menter, and Philip Hartley	The Holy Grail of Design Measurement
23	Jeanne Rae	What Is the Real Value of Design?
24	Jesus Mauricio Beltran Jaramillo	Indicadores de gestion: herramientas para lograr la competitividad
25	Matthias Kreimeyer, Carsten König and Thomas Braun	Structural metrics to asses processes
26	Michael Westcott, Steve Sato, Deb Mrazek, Rob Wallace, Surya Vanka, Carole Bilson, Dianne Hardin	A Design Measurement and Management Model
27	Griffin, Abbie, and Albert L. Page.	"PDMA success measurement project: recommended measures for product development success and failure."
28	Yang Xu , Alain Bernard	Quantifying the value of knowledge within the context of product development
29	Raquel Arévalo Tomé, Begoña Urgal, María A. Quintás	A proposal for measuring the innovation performance: an application in Spanish innovative firms
30	Marco de Haas" and Ad Kleingeld	Multilevel design of performance measurement systems: enhancing strategic dialogue throughout the organization
31	Kerssens-van Drongelen, Inge, Bill Nixon, and Alan Pearson	Performance measurement in industrial R&D
32	Søren Petersen and Peter L. Phillips	Inspiring Design—Informed by Metrics

are depicted in table 2.2.

In design processes, non-financial measures are more important than the final financial outcomes. This perspectives is supported in the premise that all design (non financial) efforts are impacting the final financial success and, since design outcome is usually on the long term, the finances are merely the consequences of a great design job (Davila, 2000). Methods such as the Balance Score Card seek a balance between financial and non-financial indicators.

Most methods are based on the use of Key Performance Indicators (KPI). An indicator is a relationships between two or more data that carry a logical connection and provide information over critical aspects of an organization (Beltran, 1999). These data are qualitative or quantitative variables that pinpoint targets related to objectives and provide an overview of the changes in a process or system (Domínguez, 1998). They are management tools (Bissay et al., 2008) to verify cause-effect relationships between the inputs of the process and its outcomes (Beltran, 1999). When compare with a reference point, it signals a deviation or an accomplishment of results. Hence, an indicator shows the effectiveness of a processes or system (Alemanni et al., 2008). A KPI is an indicator connected with and internal or external objective (Alemanni et al., 2008).

KPIs are useful to rationalize, monitor and coordinate decisions (Gries and Restrepo, 2011) and are more essential than other indicators due to their attachment to critical success factors surrounding the organizational objectives (Gries and Restrepo, 2011) to constantly improve the quality of the design function (Viladàs, 2011).

The KPIs must have a balance between financial and non-financial metrics, require a protocol for constant measurement, should be encouraged by the top management of the organization, must identify and motivate the actions require from the staff for improvement (Davila, 2000)

Design control is related to several critical aspects of design in which all sorts of difficulties arise. After a revision of the literature on this regard six cluster problem divisions were identified and are shown in figure 2.7.

Each figure presents clustering groups in which difficulties have been identify. The groups are explained as follows.

1. Quantifying the value of design with indicators: Since design activity is so complex and intangible quantifying the results is also a difficulty's task, a design manager measures the progress in all levels from the first line operation to the strategical top. Measuring then, is a matter of formulating the right indicators that deliver valuable information of the state of design. The selection and implementation of the indicators is a managerial task in which the design manager measures the innovation environment, the design awareness, the alignment between operation and strategy, the final results of product in terms of satisfaction, finance and processes among other issues over which decisions are made.

and retrieval. Hence, a design manager may be interest in more visual, simple and general information than a first line design leader who seeks for more detail in the data and requires links and connections with the database to guide the technical design. The background of the users might be also connected to the preferred communication media. This is closely related with the ways in which design knowledge is represented whereas graphic, symbolic, virtual, linguistic or algorithmic (Chandrasegaran et al., 2013). The way in which the information is perceived determines part of the decision making process.

6. Scenarios: It is related to the context and the moment in which the decisions are taken. The scenario is related to the time frame available to the user to present results or take decisions. Therefore the short, middle or long term information associates directly with the scenario that is taking place in the users mind. Secondly, it is also the user needs that dictate if this scenery needs reactive or proactive decision making. Reactive decisions are made after the events take place, it trust in historical information, whereas proactive decisions are made in real time context with information up to date. The scenario is also related to the information management capacities and systems, real time information requires technological approaches to information capture, storage and sharing. The time frame of the information is not only fed by the user need to deliver a decision in constraint time frame but also the availability if the information in the time frame.

All points present a commonality related to the processing of information into indicators under the user interest and specific time frames. For this project the focus would be made in the development of measures, since it is the starting point of any control mechanism. The other difficulties could be further explored on other research projects.

Figure 2.8 shows the final critical points selected for the research. The measuring time, the user interest and the information relevance are the main difficulties tackle by the proposed method.

KPI data can be obtain in a simplify manner through the implementation of Information Technologies (IT), that ensure consistency of information of the design activity. However, according to Gries, several considerations should be taken into account when using IT systems (Gries and Restrepo, 2011): (i) centralize the sources of the information in a main environment to avoid outdated and missing data, (ii) IT technologies provide the data but do not necessarily provide the interpretation of such data and do not prioritize among possible measurements, an strategy needs to be created to sort the data into valuable information and only a few information must be selected as key performance indicators, and (3) without solving the last two data could be incomplete.

In addition to the literature findings the problem at hand appear also in a previous experience within the structuration of a design process in an Architecture, Engineering and Construction (AEC) company (Mejía-Gutiérrez et al., 2013). The lack of known mechanism to measure the success of the

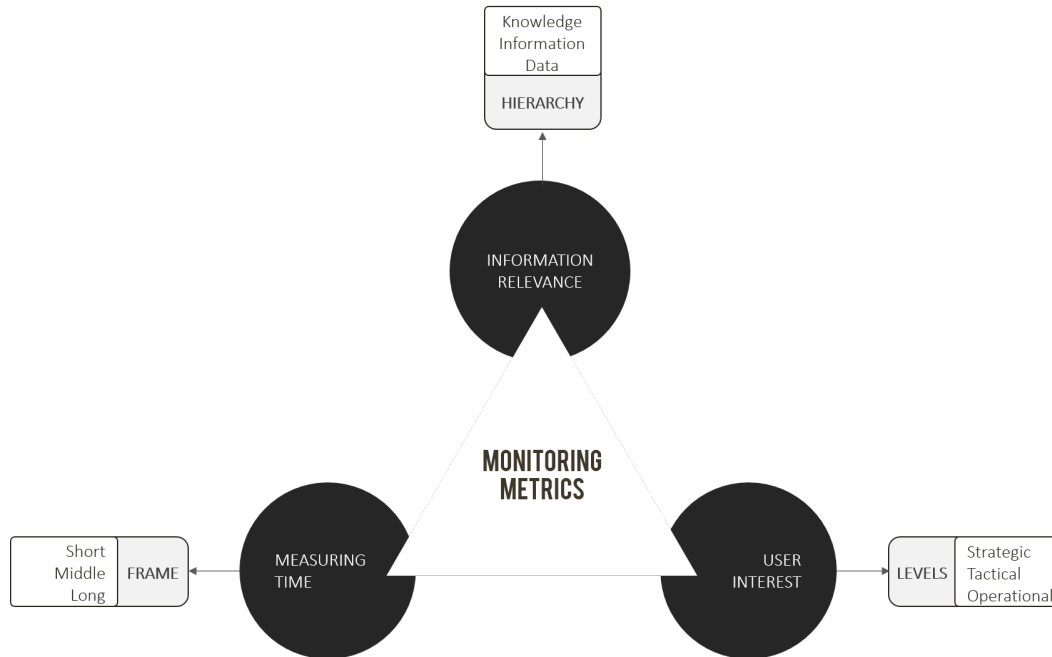


Figure 2.8: Monitoring measures critical factors

implementation arose a new set of needs.

Measuring in the short term the success of the strategy was a challenge for the team. During the course of the project, several indicators were set based on the objectives. However, the indicators to measure the strategy in pilot project of the company was not as easy to pinpoint. The situation demanded for the external team to propose some approaches for measurement.

Although the research team in the case found means to measure the progress, the lack of guidance made the measuring task difficult to repeat without the external help of experts. The time frame set for creating the measuring system and its deployment leave no time to train the R&D members on such tasks. The articulation of the measure in an advance IT system was also tackled and in the current project the approach to a Product Life-cycle Management (PLM) software will be explored to create a Central environment for knowledge management.

In essence, when it comes down to monitoring design activity, the lack of agile tools to assist the design manager in the construction of a control strategy that delivers results in the short, medium and long term, increases the working hours used to gather and processing disperse information, elevates costs in product development due to decision-making delays as well as corrections, and influences budget reduction for design activities due to the unknown contribution made by design investments and efforts.

2.6 Product Lifecycle Management

Given the dynamics of globalization, industries around the world face constant changing market demands. Those require innovation and product development competencies in order to satisfy more complex user needs. As a result, companies struggle to convey strategies to create competitive advantages that secure sustainability. Product Lifecycle Management (PLM) is a strategy (Stark, 2015; Grieves, 2006; Saaksvuori and Immonen, 2008), that allows industries to align their intellectual capital in order to create products more efficiently, integrating collaborative work (Danesi et al., 2008), concurrent engineering, process management and project management methods to support the product development decision making process ensuring benefits related to accelerated product development, change management, traceability, extended enterprise involvement and knowledge management capabilities (Danesi et al., 2008; Ameri and Dutta, 2005). The solutions accomplished with the implementation of PLM resources and the integrated capabilities it offers, as a strategy, have the potential to transform in competitive advantages(Liao et al., 2015; Demoly et al., 2013).

PLM strategies accompanied by information technology tools and systems offer support not only to product development but to the entire product lifecycle, integrating the complex dynamics around product development in a collaborative, centralized environment (Jun et al., 2007). This holistic approach aligns the efforts made around product development in strategic, tactical and operational levels and integrates the stakeholder network (Stark, 2015). Given the capabilities of this strategy the industry has received it with high expectations, particularly by the automotive and aerospace industry (Marchetta et al., 2011; Lee et al., 2008; Schuh et al., 2008; Mejía-Gutiérrez et al., 2013).

PLM vendors offer variety of solutions, but the implementation of such a solution transcends the configuration of and IT tool. In order to successfully introduce PLM some key points should be considered (i) envision PLM implementation as a complex initiative that may require the transformation of culture and working methods, (ii) PLM software license acquisition (iii) adequacy of technological infrastructure, (iv) having a capable IT support to configure and update the software and (v) ensure the correct articulation of current working methods and PLM strategy benefits.

The present research project uses Aras Innovator (AI) from Aras Corporation as the selected PLM software¹, due to the open source benefits derive from it; including free license and open source code for software configuration (ArasCorp, 2012). In addition, previous research project have been developed with AI PLM software with the research group, increases reliability and problem solving around the software usage and the PLM strategy deployment (Mejía-Gutiérrez et al., 2013; Marroquín et al., 2016). Therefore workflow, project and module configuration among other specialized arrangements are adaptable to the unique design management requests of the project. AI characterizes for its flexible application, in small periods of time, unlike some other PLM tools that require direct assistance and

¹<http://www.aras.com/>

support from vendors.

PLM solutions come organized as a series of specialized pre-configured modules. When a company acquires the software, a process of adaption must take place in order to load the product lifecycle used in the organization, under PLM strategy conditions. Some modules are part of the standard use of PLM such as:

- Portfolio/Project module: manages the product development program and keeps the project instantiation. It also gathers the client's configuration. The module provides traceability to all activities and advancements made during a project execution.
- Workflow: This instantiation executes the processes defined for each phase it keeps record of all decision and time execution of the process. The workflow automates tasks and assigns the revision of activities.
- Document management: It stores all data generated through the life cycle of the product. IT manages the change protocols for each document and keeps the updated information to display creating compliance and solid evidence of change. In addition reduces search time and information missing

In addition to the basic modules, PLM solutions contain a dashboard module. Following the other basic modules the dashboard application can be configured to customer needs, but with a new level of difficulty, given that it capitalizes the data from other modules and process it into quantitative data thought graphic representations.

AI dashboard module operates connecting data from different items. These items require a special implementation and programming. The content depends on the unique needs of each implementation although some default indicators come with the software. However to make use of the module, one has to use all software modules as they come, given that the indicators are connected to the data pulled by all default configuration. For personalized use, the indicators require special programming methods.

Table 2.2: Measurement methods and methodologies

AUTHOR	NAME	PROPOSAL	FOCUS	AIM	WHAT IS INTENDED	TECHNIQUE
Caroline M. Clevenger and John Haymaker	Metrics to assess design guidance	Set of metrics	Synthesize a set of metrics to consistently measure all dimensions of design process.			
Bruno Gries1, John Restrepo	KPI measurement in engineering design – a case study	Set of indicators for engineer design projects	Standard Key Performance Indicators (KPIs) for project management are appropriate for measuring and monitoring Engineering Design processes	Which KPIs can be used and how they need to be changed to fit specific Engineering design projects	30 KPIs were perfected and customized according to the organizational needs of the company under study.	Case study
Fiona Lettice Norman Roth Ingo Forstenlechner	Measuring knowledge in the new product development process	A cubic tool separated by dimensions in which several literature metrics are display	A literature review enabled 200 product development measures to be compiled	Ability to improve measurement and management of their NPD process	How they perceived their performance for the measurement dimension of the cube. They were able to start considering the issues surrounding. Away from the financial oriented measures. The companies were then able to tailor the measures and make them specific to their product development context.	Survey (130 companies)
H. Drival, K.S. Pawar1,*, U. Menon	Measuring product development performance in manufacturing organizations		Methodology to guide managers in the use of performance measures			
Xènia Viladàs	Measuring Design's Contribution to Business Success: A Three-Tier Approach	Control tools to value design according to user needs, before, during and after a design project.	System that provides a complete information scheme about the value of design.	The needs of the user, in design measurement terms, are related to the decisions companies make during a design project and may vary depending on the design awareness of each firm.	Do companies really need to measure design?	Survey (on going)
Deborah Mrazek, Sam Lucente, Katherine Wakid, Steve Sato, Conrad Wai, Adam Menter, and Philip Hartley	The Holy Grail of Design Measurement	Each cell of the D3 Matrix represents a strategic design goal that can be pursued on a project.	Measuring design's impact on business. The focus is the goals not in the metrics	HP development and implementation	Alignment between goals and design to made value of design contribution more explicit	Case study
Jesus Mauricio Beltran Jaramillo	Indicadores de gestion: herramientas	Creation of key performance indicators, using a	Methodology to crate management indicators			Cases studies

Chapter 3

Action Research cycle 1:

Explorative case with on-the-go indicator definition

After having analyzed the state of the art with systematic literature research and analysis, this cycle focuses on the following research questions.

- What are the difficulties associated with design measuring for engineers and designers?
- What kind of information of the design process seems to be of relevance for monitoring strategies?

A design project provides the environment to gain a deeper understanding of the problem. The designers were asked to apply an existent indicator creation methodology proposed by Beltran (1999). Although the project had an ergonomics focus, the nature of design projects reveals that, even when their aim may vary, the management decisions are very much alike (Krishnan and Ulrich, 2001). Under this premise, the focus of this action research cycle is on the indicators created, selected and measured by designers.

3.1 Objectives

Identify difficulties associated with the creation and selection of design indicators to monitor a design project, implementing an indicator methodology to define insights for the creation of a design monitoring method.

The nature of the project leaned on finding ways to improve the novel design methodology by implementing it in a project. The participants of the case had no prior experience measuring design.

Hence, their insights provide the foundation for improvements from a much richer novice perspective. To achieve the general objective this research cycle proposes an approach to tackle several points

- Select a indicator methodology for implementation.
- Capture the difficulties present in the deployment of the methodology through observation
- Define new insights for application in a design monitoring method
- Find requirements for further implementation in a PLM software

3.2 Project description

The project was an initiative created within our research group to implement an Ergonomic Oriented Design Methodology (EODM) proposed by Hoyos-Ruiz et al. (2015).

The research group has applied the EODM in the local market for specialized consultancy in redesign cases such as the improvement of working spaces for the musicians of a symphonic orchestra and the development of a product for an appliances manufacturer. The methodology comprised ideation to conceptual design stages.

The complexity of the EODM demands a complete focus on the coordination operative task such as verification of the information updates, constant meetings to solve questions over the Design Activities, assigned time to verify deliverables and a dedicated time to gather and analyze the results from each stage, leaving little time to create and implement proactive improvement strategies, that ensure successful outcomes during the course of the project (Marroquín et al., 2016). However, the purpose of the implementation is the improvement of the methodology and therefore thoughtful monitoring is fundamental to support decision making.

The project had two aims as a priority (i) redesign a small appliance for a local industry under strict considerations of physical and cognitive ergonomics design (ii) find criteria and indicators to measure the success of the methodology applied and the improvements necessary to create a consolidated version of it. A team of eight engineers took the project distributed as shown in figure 3.1. In this case, the creation and application of design indicators were the responsibility of the coordination team.

- Project: Implementation and monitoring of a design ergonomic methodology
- Client: Appliance manufacturer with high recognition in the country.
- Total participants: 9
- The design team: Six design students in the last semester of the product design engineer program at EAFIT University¹.

¹<http://www.eafit.edu.co/>

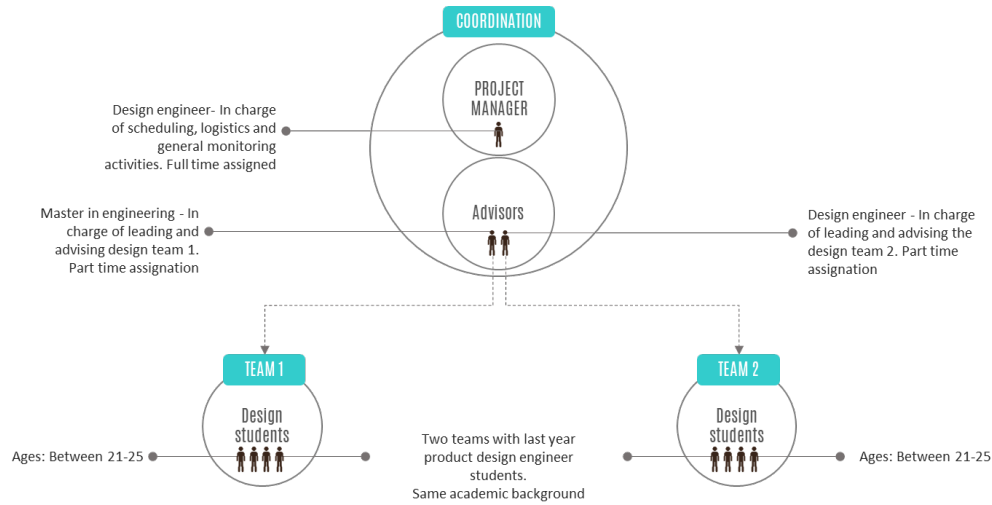


Figure 3.1: Team description

- The coordination team: Three professional product design engineers with a minimum of a year of experience in the fields of design and research. One with a master in engineering and two in current master studies.

The EODM was structured as a Stage Gate process in which each phase and stage tackles an objective. The complete process is divided into two phases and a total of six stages, as shown in figure 3.2



Figure 3.2: EODM project schedule

3.3 Action research cycle stages

To tackle the project from a research approach the four stages of action research were set as shown on table 3.1

Table 3.1: Action Research plan

Research cycle 1: explorative case			
Objective	Identify difficulties in the creation and use of metrics to improve a design process		
Duration	5 months		
Data sources	Project files Observations		
Stages of Action Research (AR)			
Planning	Acting	Observing	Reflecting
Identify a methodology for the creation of measures	Implement the methodology to measure the project under execution	Gather files with evidence of the evolution of the application of the methodology. Gather observations regarding difficulties and suggestions of the coordination team	Find clear insights to create a method to support decision making through metrics

3.3.1 Planning

To set appropriate indicators for the project, the coordination team created a project schedule to study and apply a chosen methodology suggested by Beltran (1999) for indicator generation, that includes nine stages to create and implement indicators. The chosen indicator methodology to create indicators was structured as shown in figure 3.3.

The methodology was selected due to its focus. The author gave a descriptive model comprising the steps towards indicator creation. This approach differs from other methods listed on table 2.2, in which the indicator creation was addressed as a secondary step with little detail in a broader model for measuring. Robust measuring methods provide tips to generate the indicators without giving any other instruction on their composition and how to create them.

3.3.2 Acting

Three months prior to the project execution, the coordination team began planning the schedule and setting the necessary logistics for the project contacting the company, defining the participants, gathering digital and physical workbooks of the design methodology, planning the methodology in

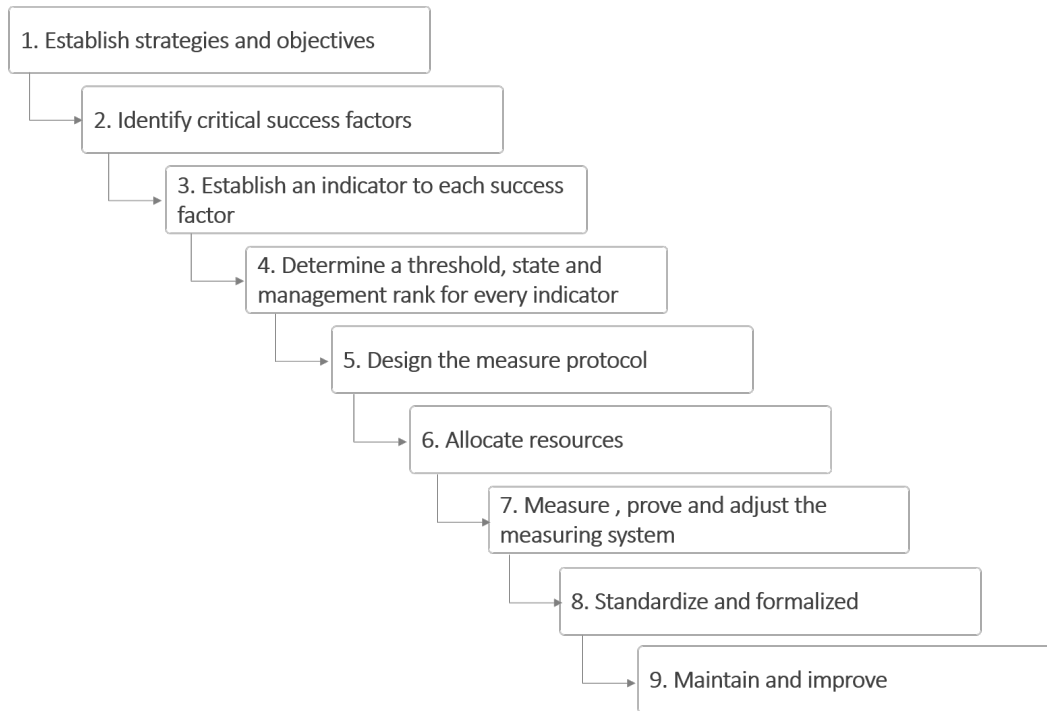


Figure 3.3: KPI methodology structure by Beltran (1999)

a schedule, setting delivery dates and final presentation with the clients. A first meeting sought to socialize the methodology only with the coordination team to (i) gather the expectations regarding the use of the methodology, (ii) explain the methodology step by step and, (iii) establish the schedule for indicator creation. To gather the data and information around the indicators, the team established a file storage mechanism.

The aim was to prove the effectiveness of the EODM methodology. Therefore the team wanted to measure:

- Ergonomic threat reduction in the final design concepts
- Validation of the methodology structure. Detection of strengths and opportunities for improvement, so the methodology can evolve.
- Management efforts, to combine a strong methodological approach with project follow-ups

In addition, the coordination team expected a thoughtful guidance, given the little knowledge they had on the indicator creation area. Therefore, the team arranged weekly meetings to follow-up the development of the indicators as shown in fig 3.4

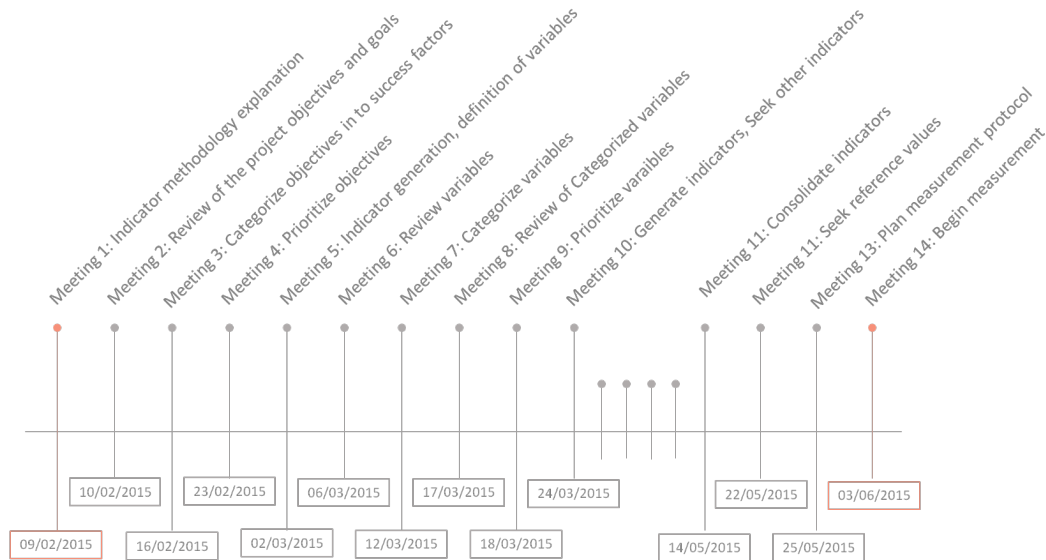


Figure 3.4: meeting arrangements

3.3.3 Observing

Three different moments of observations were established: (i) the first meeting in which the methodology for indicator creation was explained, (ii) the weekly meetings and (iii) the results of the project.

Several questions emerge during the first meeting that made evident the lack of previous knowledge in the matter. Annotations were made on each step of the methodology and organized as shown in 3.5

During the meetings, the observations regarding the execution were registered and tackled. The results were consolidated as additional observations. The annotations were finally gathered in a canvas to identify common difficulties and patterns as shown in figure 3.6.

A clustering activity was carried out in order to synthesize the observations in categories according to commonalities (figure 3.7). The final analysis reveal 11 related issues to tackle.

1. Vocabulary definitions: The terms associated with the creation are uncommon for the designers, therefore, multiple definitions had to be studied and clarified before the team was able to address the terms with confidence. Some terms are more abstract than others, such as 'success factor'.
2. Complexity: The perception the designers had about an indicator being just a simple equation or instruction to measure were hindered with the inclusion of so many procedural steps that require deep justification and formalization of the indicator attributes. The methodology was too complex for the short time of the project, and the designer couldn't visualize the benefits of such strict definition of indicators.

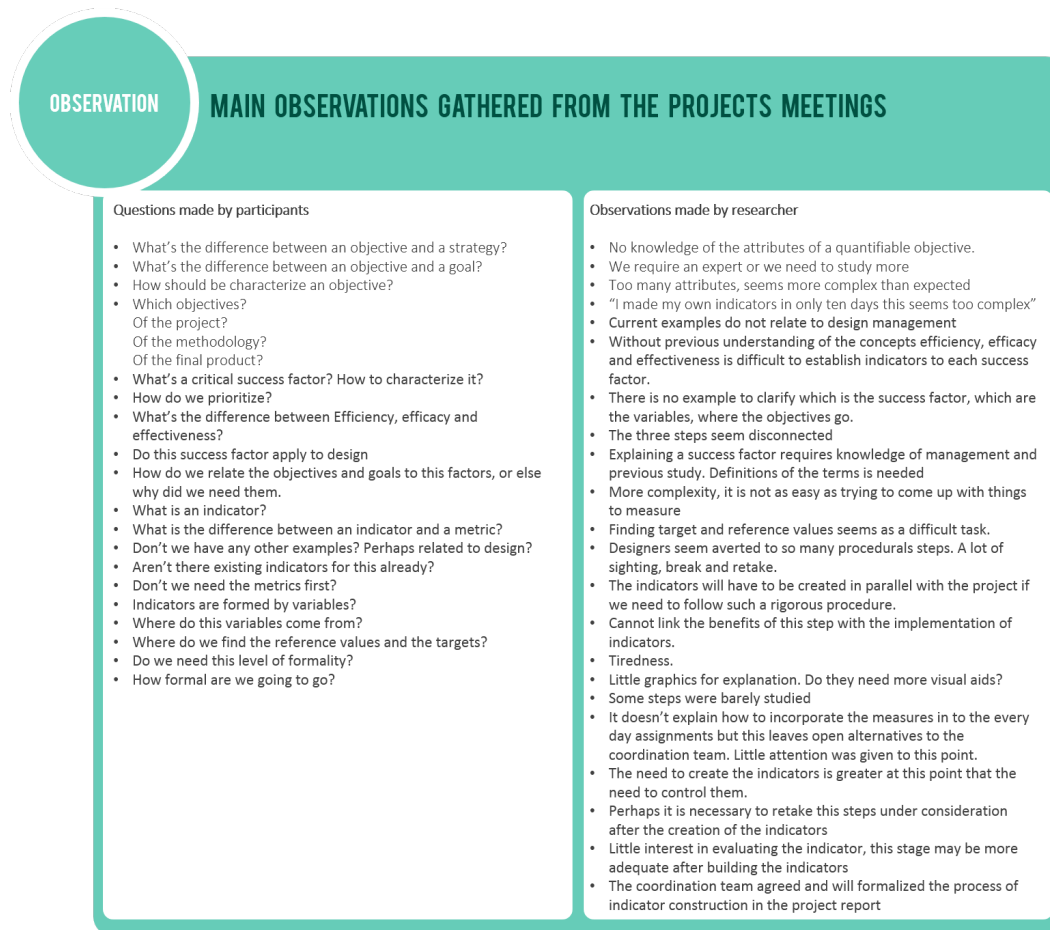


Figure 3.5: Meeting observations

3. Cognitive moments (creating vs implementing): The methodology could be divided in two stages. The first focused on creation and the second on the implementation of the indicators. This was visible on the meetings were the methodology was explained, the first four steps were explained on a first meeting, however steps 5 to 9 were explained briefly in posterior meetings. Since the methodology is not divided in such a way the final steps were not as deeply addressed as the first. Hence two main moments are necessary to implement all steps successfully, two separate meetings one to guide the creation and one to guide the implementation.
4. Time: The overall project took twelve months, five of them were spent in the creation of the indicators and seven were used for implementation of the indicators, measurement, analysis and final consolidation of the results. During the project four steps of the methodology overlap. Therefore some indicators were implemented without being completely formalized with the measuring protocol, reference values, threshold among other attributes. The steps that include measuring protocol and the allocation of results had little time assigned for understanding and

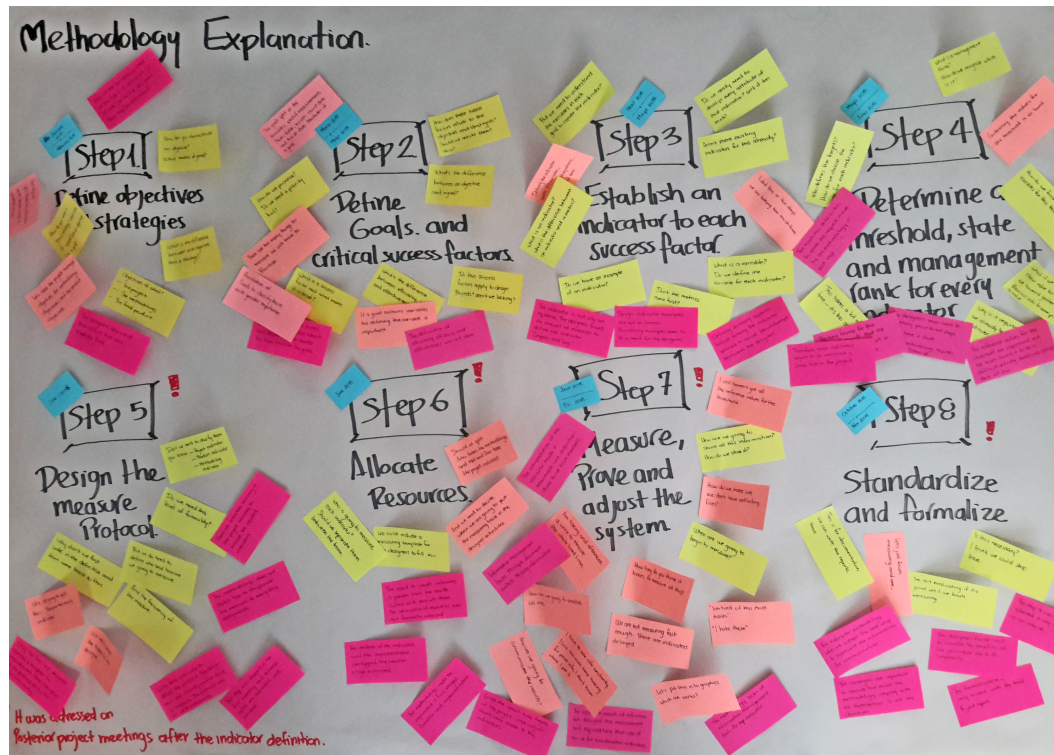


Figure 3.6: Observation canvas

application and it affected the measuring progressively. The lack of all measuring protocols was most evident and it contributed to the difficulties in the information management consistency in terms of disperse documents from where the measures were to be extracted. Figure 3.8 shows the time spent in each step. The longest step was related to the measuring step with 39 % of the time, followed by step two in which the success factors were defined and also the goals for the objectives with 17 % of the project time.

5. Who?: Depending on the responsibilities of a role, the person shows more inclination to measure one or other indicator. The management rank is directly link to this interest.
6. Prioritize: The team found too many available indicators to measure. The team began to characterize each of them but soon realized it took an elevated amount of time to formalize and measure all indicators. Therefore, an evaluation of those indicators with easier implementation in terms of time and effort was made to prioritize the indicators with more value. This step was an addition to the methodology.
7. Information management: The constant search for information to define the indicators delayed the measurement. In addition, the methodology lacks of recommendations in regards to information capture, storage and classification. The team created a repository on the cloud. However



Figure 3.7: Clustering

several documents were conflicting copies and went outdated. There was no clear control of last versions and some of the information went missing after the project ended. The formalization and standardization step was not executed and only a final report was presented with no recommendations for improvement due to lack of time.

8. Tools and strategies: The methodology gave a brief explanation of the steps but did not provided strategies or tools to support the development. Therefore, several ideas came from the team such as: (i) the use of a priority tool to select indicators, (ii) the divisions of the assignments and measurement tasks, and (iii) The creation of measuring templates to gather the data necessary to calculate the indicators as shown in the example in figure 3.9 with an ergonomic template used by designers to evaluate the product results and provided specific data for ergonomic indicators. The indicators were divided in three groups according to their focus. The first group was related to the EODM evaluation, to understand how efficient was the methodology. The second group was related to the project management indicators regarding time, scope and resources. The third group was related to the products resulting from the project and the compliance with the requirements set during the design processes.
9. Communication: This difficulty presented in the final stages of the project when beyond the measures the designer needs to represents the results and share them with the design team. The

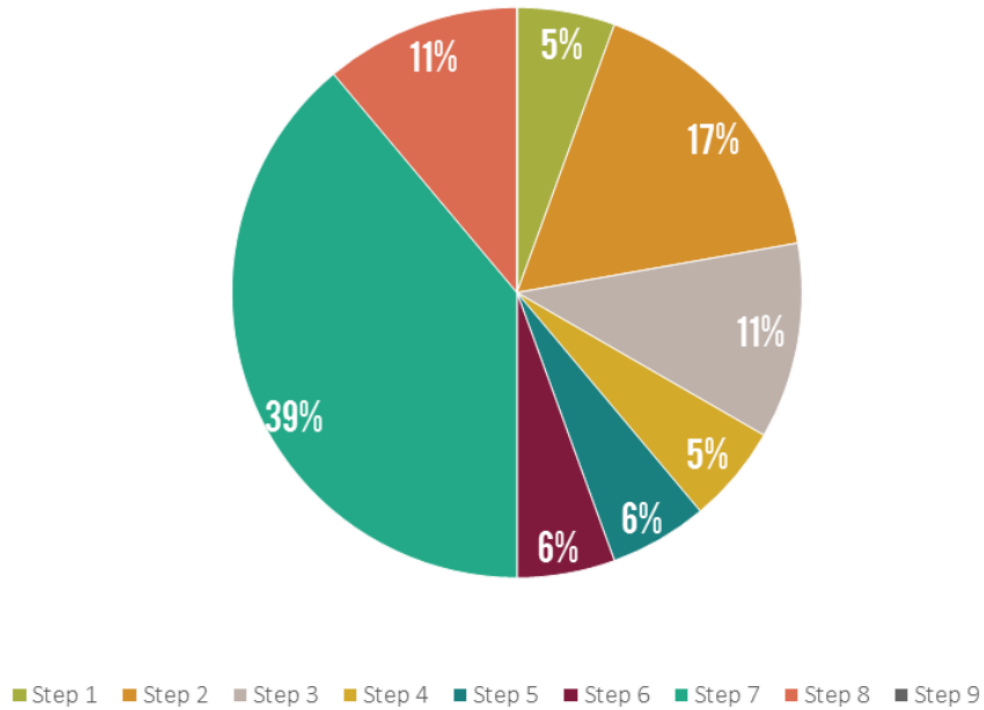


Figure 3.8: Time distribution during the implementation of the indicator methodology

methodology chosen for application had no guidelines on this matter. A set of graphics were created under the judgment of the designer. The list of available graphic possibilities is long and each works better depending on the magnitude of the information, the detail and other features. Some authors such as Few (2006), offer direction in regards of graphic representation. There is also an additional situation regarding the interpretation of the indicator, the description and reference value was fundamental to offer a homogenized point of view about what is being measure and why.

10. Reference values: Closely linked to the communication issues, is the one resulting from the establishment of thresholds and reference values that give meaning to the indicators by offering a comparative reference. However, the reference value is also difficult to extract form historical or current information. There is also little knowledge about the benefits of having a well defined measuring reference. It only becomes important after the team starts to analyze indicators and tries to make sense of them. The reference values and the current values give traceability, and provide an overview of the story of the project.
11. Examples: During project execution the team try to migrate to existing indicators. Visualizing existing design indicators gave them a more accurate sense of what they were trying to do and

Listado de especificaciones	Pregunta que se le realizará al usuario sobre las acciones que realiza durante la actividad - lo que se observe debe reflejar el cumplimiento o no de la especificación	Análisis de la percepción de cada diseñador al observar la situación de uso del producto				COMPARACIÓN ESTADO INICIAL Y FINAL CON RESPECTO A LAS ESPECIFICACIONES			
		PROPUESTA FINAL		PROPUESTA INICIAL		La propuesta final mejoró o empeoró frente al inicial		Cuanto mejoró o empeoró %	
		Comparación Rango de valor	Nivel de cumplimiento de la especificación y rango a medir	Comparación Rango de valor	Nivel de cumplimiento de la especificación y rango a medir	Señala con una X la respuesta			
1 El agarre del producto es cómodo y no genera sobre esfuerzos en la manipulación del producto.	¿Cómo transportaría usted este producto de un lugar a otro?	Ángulo de agarre: Flexión muñeca menor a 30 grados	20 grados	Señala con una X la respuesta 0 1 2 3 4 5 Indicador de cumplimiento de especificación y comparación de rango de valor	Sin agarres definidos (es este caso no cumple con la especificación)	Señala con una X la respuesta 0 1 2 3 4 5 Indicador de cumplimiento de especificación y comparación de rango de valor	X		5:100% 4:80% 3:60% 2:40% 1:20% 0:0%
2									
3									
4									
5									
6									
Etc...									

FORMATO 1. PERCEPCIÓN DISEÑADORES

Figure 3.9: Ergonomic measuring template

achieve. However, design indicators are context related and difficult to find.

The project resulted in eight objectives with a total of 18 strategies and 74 possible goals, the final selection went from 241 indicators to 40 by means of the implementation of a priority tool. 98 % of the chosen Design Indicators were given a reference value and a threshold, however only 26 were completely define and the remaining 13 had the source of the value identified but were still undefined in terms of measurement frequency, and reference values. Only three measuring templates to gather information were implemented. Finally all indicators were measured successfully.

3.3.4 Reflecting

The previous groups of difficulties and opportunities were summarize in 11 design insights to support the development of a new approach towards design monitoring.

- Insight 1: Provide examples and references of existing indicators associated with design process, projects, products and management from reliable sources. Organize a reference repository.
- Insight 2: Support the method with state of the art information management tools and applied best practices to reduce search time and information inconsistency.
- Insight 3: Address the representation of the information, including topics such as dashboard design, visual perception tips and graphic types and tools.
- Insight 4: Provide examples of successful strategies used in design searching in reliable sources.
- Insight 5: Synthesize to the minimum amount of steps and address how they relate with one another. List the benefits of addressing each step.

- Insight 6: Separate the creative moment and the implementation moment with clear suggestions on how to approach each.
- Insight 7: Find a way to sort the indicators that are essential for the project circumstances, before entering into details.
- Insight 8: Divide the indicators according to management interest. In this way only a few users would be responsible of handling moderated loads of information.
- Insight 9: Sort by time frame, not all indicators can be measured in the given time, use those that fulfill the time demands.
- Insight 10: Reduce time spent on both, creation and implementation stages.
- Insight 11: Manage a good set of descriptions for all terms in a easy to understand vocabulary.

Finally five main contributors to indicators definition were identified from the clustering analysis. These were: activities, strategies, users, time, and objectives.

3.4 Approach to indicator implementation on a PLM software

Several created indicators were selected for deployment on a PLM software based on the default functionalities of the AI software. In this case project management and information management tools are already available in the system and require little configuration. Therefore, the indicators with some connection to this functionalities were sort out for further analysis of the necessary requirements to measure them in the software.

23 indicators were selected and analyzed to determine wherever they were viable for measurement according to the requirements of time and knowledge. Each indicator was characterized according to the information entries needed, the complexity of the calculation process and the expected outcome (see table 3.2).

Table 3.2: Indicators for PLM

Item	Equation	Input data		Process	Output data
		Input Document	Aras usage	Calculation mode	Calculated indicator
1	% objective accomplished	1. Methodology guide	The objectives are loaded in to AI manually and correlated with the Project schedule to extract the data	1. Manual. Assigns a percentage of completion according to deliverable quality	% of completion of objectives
2	(Deliverable to date/Deliverables panned for the date)*100	1. Design brief	2. The scope and deliverables are assigned in the Project Schedule and the milestones are used to verify completion	1. Manual. Assigns a percentage of completion according to each design specification , 2. Automated: AI completes the deliverables achieved making use of the Project Schedule milestones	% of completed scope

From those 23, only five were chose for implementation in the PLM software. The main criterion to chose them was the complexity of the calculation process, some indicators came from information entries that could be automated with the current configuration of the software, whereas others require an in depth configuration. Given that the team seek to explore the automation of indicators, only five were finally chosen (see table 3.3).

Table 3.3: Final indicators for PLM

Indicator	Item	Equation	Input		Process	Output	
			Document	Aras	Calculation mode	Indicator calculated	
Executed activities	7	$(\text{Executed activities})/(\text{planned activities}) * 100$	Default dashboard. Synthesize in a report (i) executed activities, (ii) pendant activities and, (iii) delay activities				% executed activities % pendant activities % delay activities
Phase deviation	9	$(\text{Effective execution time per phase})/(\text{Planned time of execution per phase}) - 1$	Methodologic al guide	1. Project Schedule	1. Automated based on the milestones of the Project Schedule	% Schedule deviation per phase	
Deliverable completion	11	$(\text{Effective days for delivery})/(\text{planned days for delivery})$	Methodologic al guide	1. Project Schedule	1. Automated based on the milestones of the Project Schedule	% of deliverables on time	

AI PLM software is configure over items. An item is an entity (object) that can be manage in the software. All existing objects in AI are items. Hence, when trying to configure a new indicator in the software a series of items must be created.

The item is populated with properties (attributes) which are the data necessary for processing (see figure 3.10). Thereby, each indicator requires:

1. The creation or identification of the item type attached to it, to generate the attributes that will become the source of data when processing information.
2. Establish if the attributes created deliver all the data necessary to calculate the indicator.
3. Establish how to relate the variables to ensure the expected outcomes (indicators). Define where would the calculation take place in a dashboard or a report
4. Define a method or tool of representation that simplifies the understanding of the indicator in a manageable way.

Besides exploring the creation of items to support indicators, the dashboard functionalities were also assessed. AI has a default dashboard functionality, in order to understand how this work, a trace of the chain of items related to it was executed. Hence, creating a dashboard is complex, this

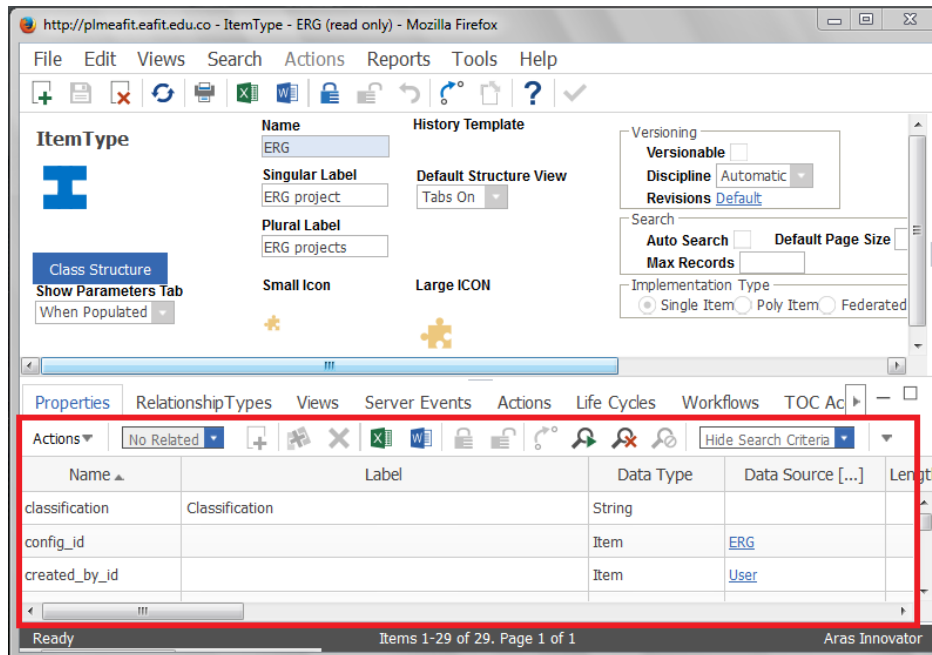


Figure 3.10: Item type overview in AI PLM software

functionality connects with six items, so it can show graphics of the indicators. The configuration requires programming using methods or queries to call for the data of the items.

In this explorative case, the team only manage to asses the requirements necessary to deploy indicators in the PLM software, further explorations in section 5.3 will seek to assist the complete method in PLM.

Chapter 4

A monitoring method proposal

The insights gather from the previous case provided a set of requirements to propose a method to monitor design. Figure 4.1 shows the definitive criticalities in design monitoring.

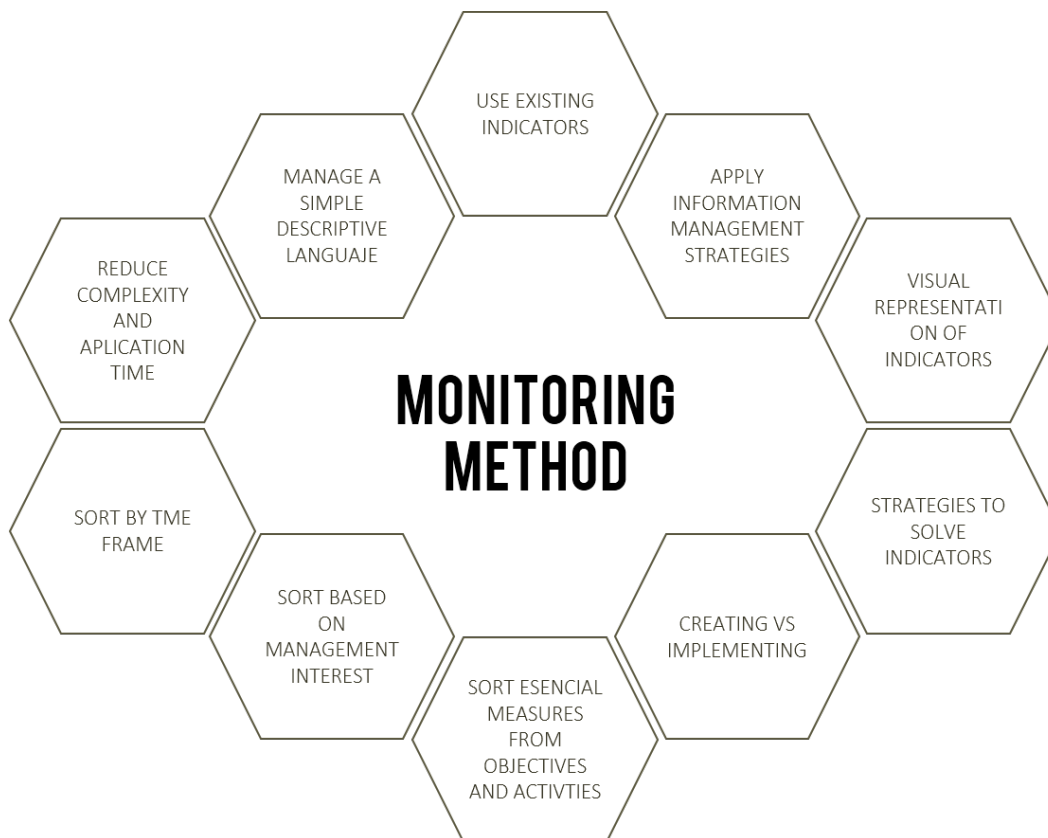


Figure 4.1: Method requirements

The method was then build using several theoretical foundations (1) knowledge hierarchy model, (2) design innovation process models reported in design literature, (3) Design Activities, Design Indi-

cators and Design Best Practices extracted from the literature and, (4) Dashboard design theory (see figure 4.2).

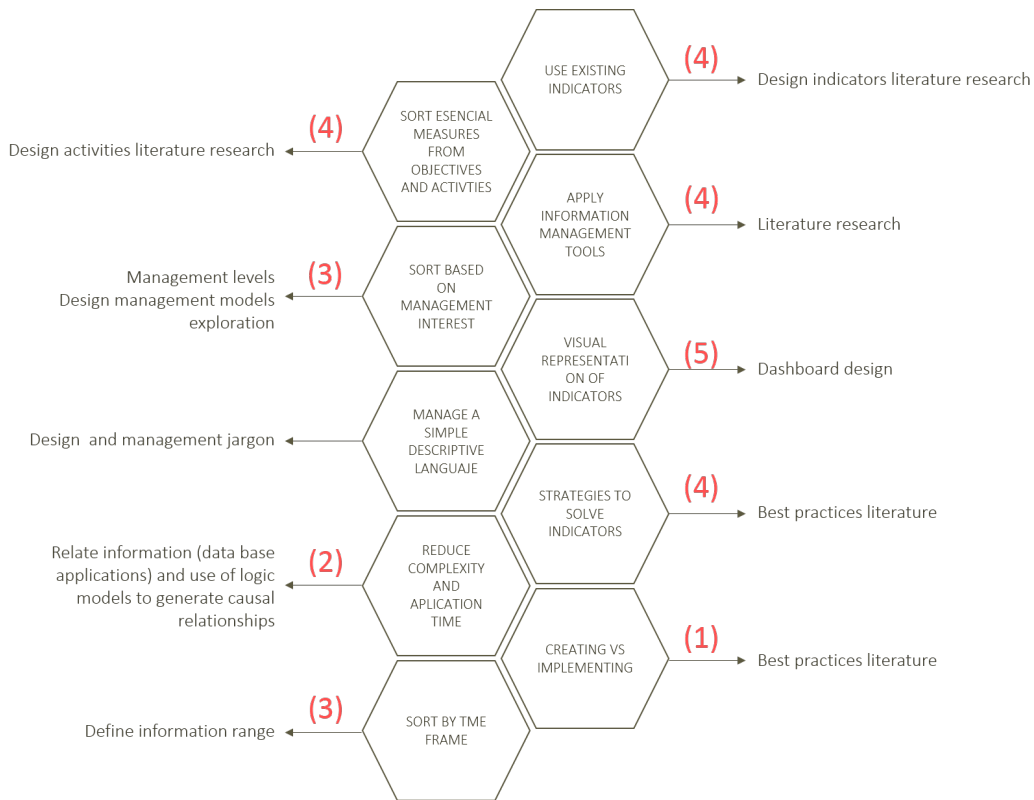


Figure 4.2: Theoretical framework

The proposed method allows the design manager to understand three main dimensions associated with improvement.

- The Design Activities present on the design innovation process
- The Design Indicators available in the literature associated with design
- The Design Best Practices gathered from literature.

Design decisions require processed information to reduce uncertainty. The purpose of the method is to assist design process monitoring and alignment. It suggests Design Activities necessary to undertake new directions and provide adequate Design Indicators to control the design activity in three management levels (strategic, tactical and operational).

The result is an applicability vector that correlates Design Activities, with Design Indicators and best practices to provide information useful to suggest improvements by allowing a logical connection between actions (Activities), consequences (Indicators) and expectations (Best Practices) (Kellogg, 2004). The relations between the dimensions results in to a basic model of the method 4.3.

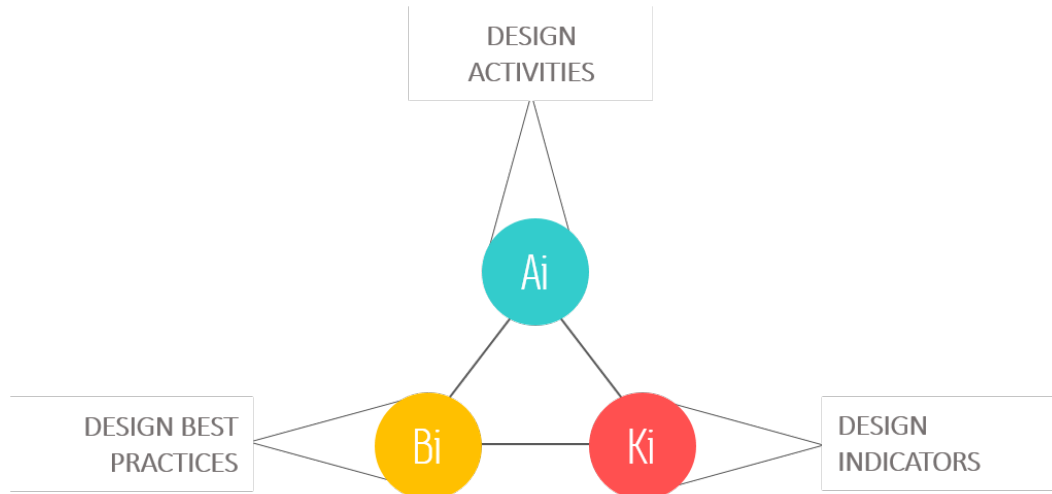


Figure 4.3: Indicator method model proposed

The dimensions will be called vectors and were labeled as follows:

A_i = Design Activities used in design processes and projects (i.e idea generation, concept definition, etc.)

B_s = Design Best Practices are methods and strategies used in design management that have proven successful in industrial applications

K_j = Design Indicators, are metrics related to design, extracted from the literature.

This chapter will elaborate on each component and the final model that encompasses all three vectors to provide a method for design monitoring in real time for a close loop improvement of design. Each vector will be further characterized in the sections bellow.

4.1 The Design Activities

Monitoring requires continuous measurement of outcomes by extracting relevant data and comparing it against strategies. The Design Activities are a major factor over which a monitoring strategy is based upon.

The Design Activities may vary accordingly to several internal and external aspects related to an organization (Best, 2006). Deciding which Design Activities to carry out in a project, process or company depends, on the product and service portfolio, the strategy, the objectives and the overall capacities of the enterprise. However, According to Clarkson and Eckert (2010) most design innovation processes comprise similar structures and general activities separated in seven stages as shown in figure 2.4.

Under this premise the structure of Design Activities works as a the bottom level from which

design is controlled and works as starting point to monitor and evaluate design through suggested design measures.

An activity is a component of the work performed during a process or project (Guide, 2004). Activities are related to business entities, that is to say any existent object tangible or intangible that is susceptible of management. This entity is formed by attributes that represent a property of interest (Elmasri, 2008).

The attributes of the Design Activities are characterized based on project and Business Process Management (BPM) theories. Since Design Activities may be subscribed inside a design project or a design process it is important to note the difference between them.

- Design activities in a process: Are directly associated with the functional operations of an organization and therefore require an operational management or business management lead. A group of these activities derive in an organizational process that can be use permanently without modifications. The outcomes of the Design Activities are expected to be always the same which means tools, methods and techniques for activity executions are standardize and so are the procedures of execution and the assigned resources. A process might be launch as many times as necessary to achieve the same results in similar estimated times. Processes activities may come across projects, usually to support schedule activities that require common business operations.
- Design Activities in a project: A group of Design Activities results in a project schedule. Projects are temporal efforts pursued to create a unique result. Hence, they are not repeatable and the outcomes vary according to project restrictions such as time, budget, scope, quality and resources. Design Activities are carefully sequenced with a mandatory duration in order to ensure a delivery deadline. Each project is unique and requires different sequences of Design Activities defined by a project or director manager.

Each vector is composed with entities and attributes. The attributes of each Design Activity are shown in figure 4.4, this overview provide the first fundamentals for posterior relation with the other two vectors (Design Indicators and Design Best Practices). The definition of each attribute is taken from the. Project Management Institute (PMI)(Guide, 2004).

A Design Activity is constituted by the following attributes.

- Design Activity code: A number or name convention that identified the activity. The code filters the activities according to a characteristic and provide order to the work units.
- Tools, methods and techniques: systematic procedures used to achieve a result, a product or a service, techniques may employ different tools.

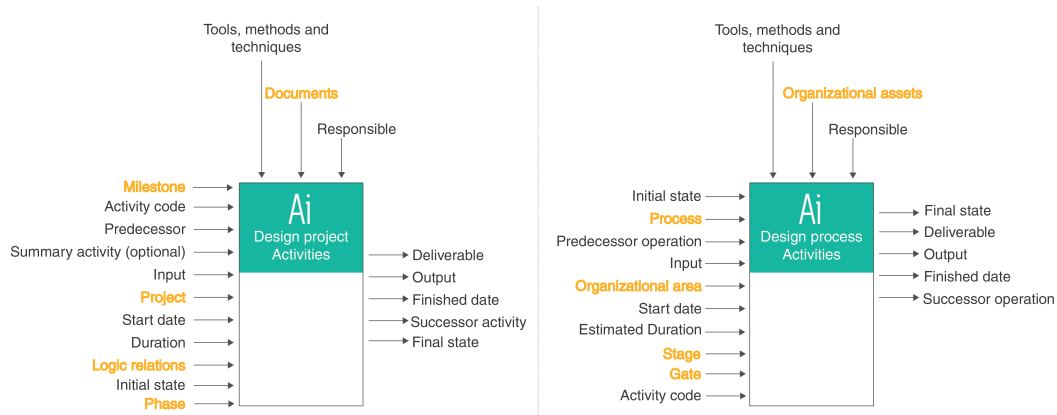


Figure 4.4: Design Activity attributes

- Predecessor: Prior Design Activities that provide inputs necessary to execute the current activity. Activities determine when the logic successor may begin or end.
- Successor: Design Activity that follows after the predecessor. They are sequenced with logic relations.
- Phase: A group of Design Activities logically related that are associated to a deliverable. Main divisions that group several Design Activities and provide a gate or a milestone established to control the developments in a regular mandatory basis.
- Summary activities: A Design Activity that groups several schedule activities.
- Input: information or tangible assets necessary to develop any activity. Any element internal or external required for a process execution. It can be a result of a predecessor.
- Output: Results (Contain consequences i.e. revised processes. It also contains documents) obtained from the execution of the Design Activity, tangible products or intangibles such as services. The output might be necessary for a successor activity.
- Milestone: A significant event in a project that has no duration.
- Gate: Represents a point to determine whereas the process or project is under the expectations or if it presents failures.
- Deliverable: the expected result, product or service expected from an activity. It can also be related to an external result requested for submission to revision and approval.
- Initial state/ final state: It provides information about the moment in which an activity is still under work or approved.

- Start date /finish date: in projects, the finish date represent the moment of delivery. Any delays may represent elevated cost and legal complications. In design projects the duration varies according to the scope. In design related business processes the dates work more as an estimate, processes may be launch with the same configuration multiple times and therefore the time may vary but only in small intervals.

The attributes of the Design Activities are also main variables when a value is attached to them. The variables allow the relationship of the activities with Design Indicators and Design Best Practices by separating them in categories according to the entity in which they operate (e.i. the Design Activity "concept testing" operates over the entity "Concept").

All Design Activities are susceptible of evaluation, but not all provide essential Design Indicators for decision making. Therefore, each Design Activities was matched only with the Design Indicators and Design Best Practices from the literature, since these have been applied in industries with frequency and success.

Looking at the maturity of the design in an organization two conditions may need a different approach according to the Design Activity selection.

- Condition 1: A strong Design Activity structure exist and the design manager seeks to control the existing process with Design Indicators, as well as visualize the Design Best Practices impacted by the process. In this case, the design manager may suggest changes in the Design Activities based on measurements and experiences, but also requires new Design Indicators to control the changes.
- Condition 2: A new design department is being structured. Hence, the design process may be setup from scratch or with little knowledge from the design participants.

A repository of Design Activities for the method results from the revision of the different existing models of the innovation design process. Generally the models are found with an emphasis whereas on FFE or NPD. Therefore the models were analyzed separately.

Design Activities from nine models of the FFE were summarized. After classifying the models by author, stages and Design Activities. On the other hand the classification of NPD Design Activities was based on ten detailed models of the NPD. The initial study comprehend 45 models, however the detail found in most of them was superficial. The ten models selected for further study showed high detail on the execution, methods and procedures to follow up.

The studied models display similar Design Activities, for instance, Idea related activities appears 41 times, followed by the Concept (37) Product (31) and Project (16) activities. Furthermore, the actions related to the FFE showed a preference for Study and Analysis (16 times), Evaluation and

Assessment (14), Generation and Creation (12), and Planning (8). The actions show the tendency of the fuzzy front end towards research, analysis and evaluation prior to planning.

Consequently, the actions related to the NPD show a preference for development procedures (20 times), only exceeded for the evaluation and assessment actions with 21 appearances. Diversity of testing actions (18) followed. The actions show the tendency of the NPD towards development, evaluation and product testing.

The exploration deliver a final repository of 391 Design Activities available for selection (see Appendix C). Each design process may be unique, but this summary provides a starting point to enhance the process with new Design Activities already proven under research, industrial or academic application.

4.2 The Design Indicators (Kj)

It happens, industries set up to measure things that sometimes are not possible within the working methods established in the organization (Siemens, 2009). Particularly in young R&D departments, that develop innovation and design projects. In addition design is a long-term intangible activity and measuring intangibles and non-financial performance is still a challenge in most organizations (Lockwood, 2007). According to Kaplan and Norton (1996) 35 % of an organization generated value comes from non-financial factors . Design activity is even more challenging to control and measure given the iterative nature of the design processes and the long term oriented results. Two things may happen: (1) organizations do know they need to measure certain things to prove an alignment with the company objectives but do not have the actual activities and strategies to do so, due to the lack of sources of data to measure the indicator (2) What organizations measure does not provide value or direction. Hence it is possible to start with an indicator and associate this with activities and Design Best Practices to provide context towards where the organization will go. The Best Practice works as an insight for organizational strategy.

The literature does provide a series of tested indicators for overall design process. Gathering Design indicators stated in the literature to provide a solid starting point for formulation is valuable to guide a design manager. Information attributes, goal attributes and indicator attributes (seen in Beltran (1999)), support the definition of indicator attributes as shown in figure 4.5.

A Design Indicator is constituted by the following attributes.

- Name: A label used to identify the indicator. It allows to differentiate between indicators. The name must be concise, easy to understand and should associate the goal to which it is attached.
- Stage/phase: The indicator is associated with a process or a phase of a project.
- Input value per variable: The factors associated by the indicator are numerical inputs.

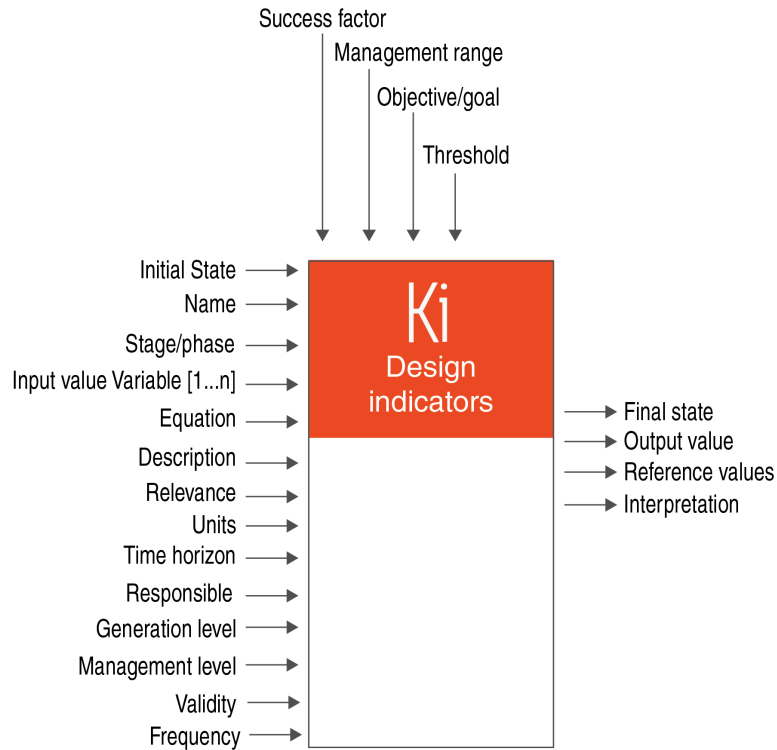


Figure 4.5: Indicator attributes

- Output value: The expected result value, is often known as threshold.
- Equation: When the indicator is quantitative the mathematical calculation and the factors use in the equation are necessary.
- Units: Represent the way in which the results of the equations are represented. The units are related to the factors of measurement.
- Description: The indicator should have a clear definition of the factors and the relationship documented. The descriptions provides interpretations details to ensure proper understanding of the given information.
- Relevance: the importance of the information if provided for the situation at hand.
- Threshold: The reference value expected to be achieved and maintain.
- Horizon: The expected time in which to achieve the threshold value.
- Origin: External sources or internal sources.

- Management range: The interval of values the indicator can take. Variables do not always behave in the same manner and the value may vary, therefore a range of acceptable expected values should be assigned.
- Frequency: For the recollection of data, the frequency derives from the relevance of the indicator and the distribution through the validity period of the indicator.
- Validity: The period of time in which the indicator is expected to last.
- Management level: The level in which the indicator is used (Strategic, tactical or operational).
- Generation level: The level in which the data to generate the indicator is obtain.

Usually indicators are created from the top of the management level to the bottom (Beltran, 1999), whereas information is gathered from the bottom to the top. In this case the Design Indicators are created bottom up using causal relationships between activities and results.

Design Indicators are classified according to the stage of the Innovation Design Process (FFE and NPD), some work in both stages. The variables are the means to relate the indicator with Design Indicators and Design Best Practices. The collection of existent Design Indicators of the literature is shown in Appendix B.

The 212 extracted indicators were summarized and classified accordingly to:

- The design innovation process stage whereas FFE or NPD.
- The time frame in which the indicator can be measured
- The management level most appropriated for each indicator

The selection was made according to published literature on design, R&D and project indicators. A total of nine authors were chosen as source of Design Indicators due to their re-known reputation in the fields of Design management and their through exploration of Design indicators used in industrial applications.

4.3 The Design Best Practices (Bs)

The literature has studied the Design Best Practices used by industries to manage design processes. Although not all practices apply to all Design Activities mostly because they are context embedded (Cooper et al., 2004). There are several general practices that might relate to specific Design Activities and should be available for consideration whenever a design manager chooses to perform these Design Activities to reinforce design.

Best Practices are statements that gather significant methods, procedures or techniques that have been proved successfully in the industry (Kahn, 2012). They are also strategies that have worked in a specific knowledge field (Kellogg, 2004). Figure 4.6 shows the properties associated with best practices.

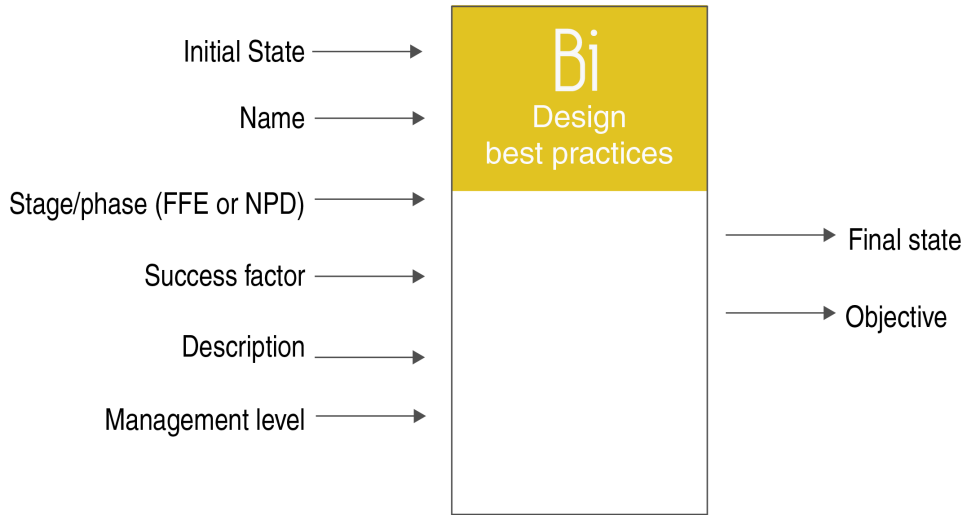


Figure 4.6: Design Best Practices attributes

Best practices drive big changes in organizations given the strategic level in which they operate and the overview they offer about the big picture that the company is aiming.

A Design Best Practice is constituted by the following attributes.

- State: It provides information about current use or misuse of the best practice.
- Name: A label assigned to identify the best practice. It allows to differentiate between best practices.
- Code: A number or name convention that identifies the Design Best Practice. The code filters the best practices according to a certain properties
- Stage/phase: The best practice aims to a stage of the innovation process or a phase of a project
- Management level: The level in which the best practice provides the most information. Strategic, tactical or operational
- Objective: The Design Best Practices is a general strategy and can be synthesized into one or several objectives for implementation.

Selecting a Design Best Practices might cause a chain of Design Activities to become necessary to achieve it. The method should provide the Design Indicators related to this Design Activities and Design Best Practices.

The collection extracted from the literature gathers the Design Best Practices provided by several re-known authors in the field of design and project management. 317 best practices characterized by author, process design stage, and entity, conform the final Design Best Practice repository (see appendix A).

The Design Best Practices that appear with most frequency are related to Ideation with 42 apparitions, followed by "Process" with 32, and "team", "personnel" and "consumer", each with 20 apparitions.

4.4 Creating the relations

The attributes of each vector reveal the relationships between them as show in figure 4.7. The main relationships are made according to the attributes. These attributes will turn into variables. In this context, a variable is a property that is measurable and acquires a value given the circumstances in which it is subscribed. It can be applied to any sort of entities such as objects, people or phenomena (Hernández Sampieri et al., 2010). In this case each Design Indicator, Design Activity and Design Best Practice operates over an entity. For instance, idea generation is a Design Activity with the attributes shown in figure 4.7 the entity over which it operates is the Idea.

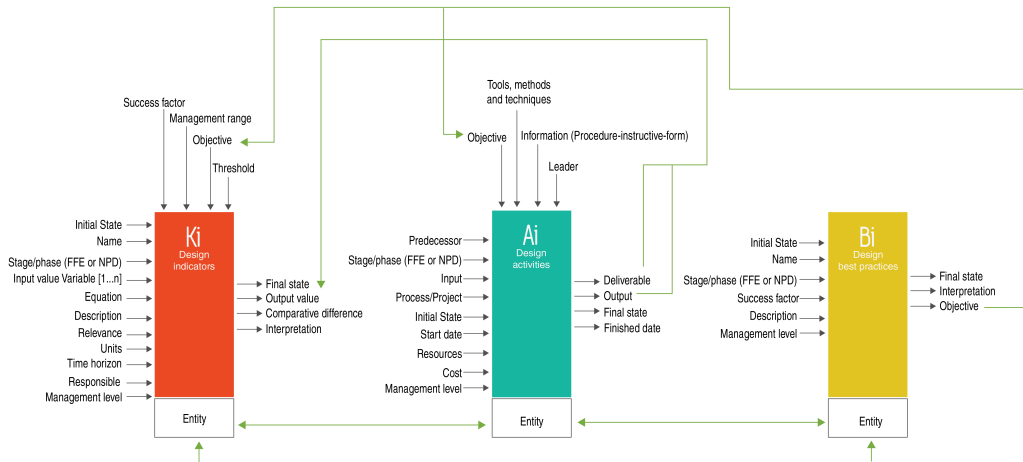


Figure 4.7: Vector connections

The green lines represent attributes that connect the three vectors and allow the creation of an applicability vector. However, the connections between different attributes surrounding the vectors (A_i , B_i , K_i) need to be addressed first, to create a relationship basis. An UML model (figure 4.8) was

detailed to deepen the management connections between vectors and their links with organizational entities.

The UML diagram shows the three main vectors in connections with several management entities all separated into classes with their corresponding attributes. In addition, the attributes that repeat in some classes can be use for association.

The share properties define the connections of the vectors. Therefore an applicability vector can be formed as follows:

Consider:

A_i = Design Activity vector

B_s = Design Best Practice vector

K_j = Design Indicator vector

Where Design activity A_i attribute conformation was defined by the following expression

$$A_i \rightarrow Stage(x), Dimension(x), Entity(x) \mapsto A_i = (S_x, D_x, E_x) \quad (4.1)$$

Design Indicator K_j attribute conformation was defined by the following expression

$$K_j \rightarrow Stage(x), Dimension(x), Entity(x), TimeFrame(x), Level(x) \mapsto K_j = (S_x, D_x, E_x, T_x, L_x) \quad (4.2)$$

Design Best Practices B_s attribute conformation was defined by the following expression

$$B_s \rightarrow Stage(x), Dimension(x), Entity(x) \mapsto B_s = (S_x, D_x, E_x) \quad (4.3)$$

The vectors share a the attributes that provide the means to relate them, an therefore assign their compatibility, this attributes are:

S_x : Is the stage of the design process whereas a FFE, NPD or DM or a combination of them.

D_x : Is the dimension associated to the design management model. During the construction of the repositories all Design activities, Design indicators and Design Vectors were categorize in 9 dimensions of a design management model suggested by Cooper and Press (1995), to identify the major area of impact inside an organization. The nine categories are (i) Strategy, (ii) Policy, (iii) Process, Programmes and procedures, (iv) People, structures, culture and climate, (v) investment and finance (vi) Training and learning (vii) Documentation and communication, (viii) Projects (ix) Rewards and evaluation.

E_x : Is the entity related to the vector. Is the object under management (e.i Idea through put rate is a Design Indicator of both FFE and NPD, the entity of this Design Indicator is the "idea")

T_x : Is the time frame in which result can be noticeable. (short, medium or long term)

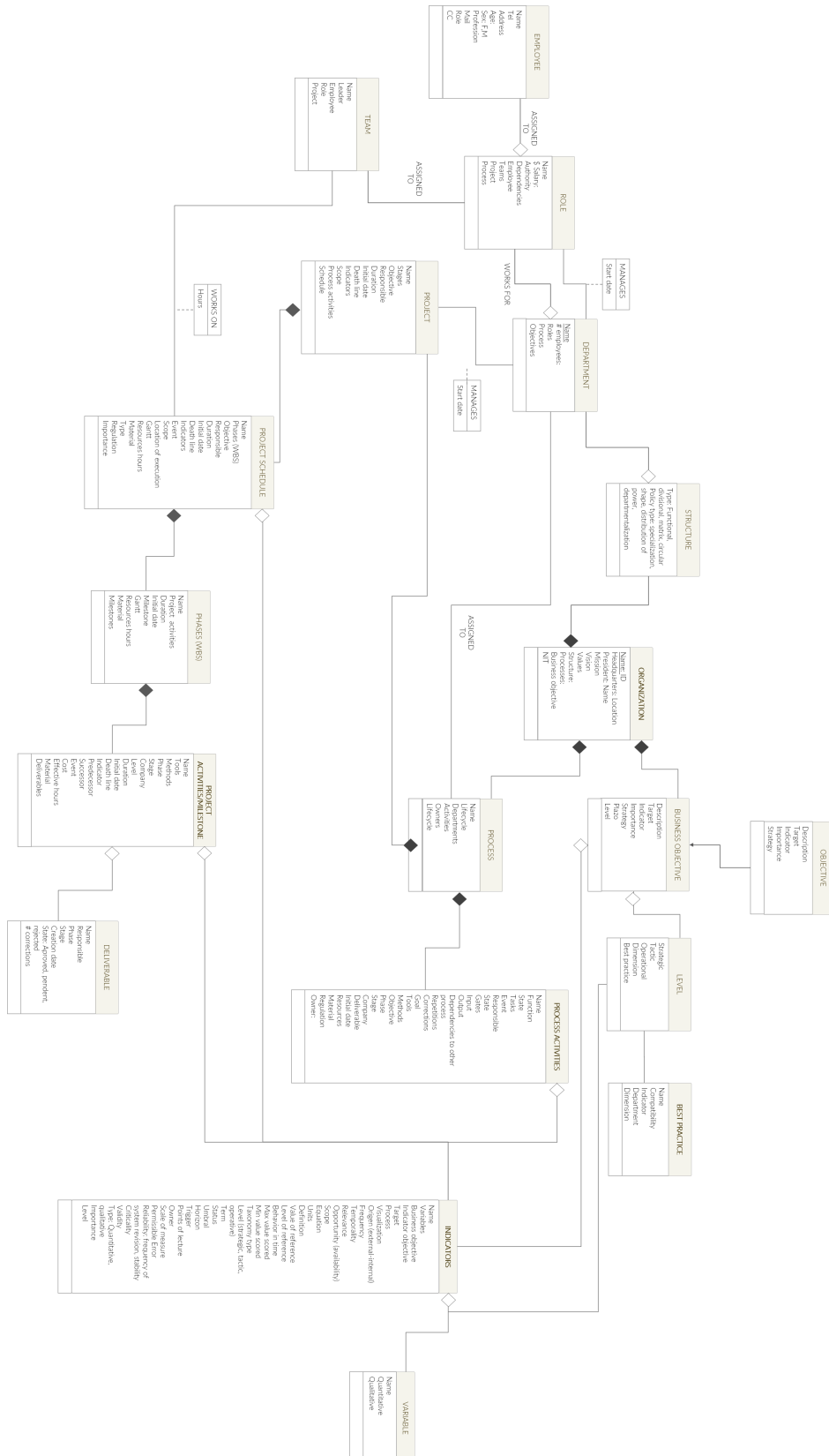


Figure 4.8: Vector UML relationship model

L_x : Is the main level of management in which the vector provides essential information (Strategical, Tactical and Operational).

Therefore:

An applicability vector describes how compatible are A_i , B_s and K_j through the following expression:

$$V_i = [A_i, B_s, K_j, C_o] \quad (4.4)$$

Where C_o : is the variable that defines if the use of a given combination of the three vectors is compatible. The value of this final element is binary, 0 when it's not compatible and 1 when it is.

The final element C_o filters those vectors that apply. Hence, the method separates the three possible vectors as starting points and define the steps, according to the chosen starting point in order to provide the final vector fit.

4.5 Method structuring

The three vectors $(A_i), (B_s), (K_j)$ are correlated to each other, the properties they share, allow the design manager to find the relationships between them, despite the initial starting point. The scheme in 4.9 shows the steps of the method. When a vector is chosen as a starting point, a path is triggered and the steps to fulfill the path are presented. Each path would be further explained in the subsections bellow.

4.5.1 Design Activity vector (Ai) path

The design manager may start in any side of the model (figure 4.3, for instance when starting at the Design Activity vector the method must be applied as shown in fig 4.10

The following steps apply for this path:

1. Select Design Activities: The method begins by selecting a structured design process within the organization. If the Design Activities are already defined, the design manager can choose from the repository those Design Activities that best fit their current design process or project. This condition may also require an evaluation of the existent processes so it can be decided wherever to discard it, improve it (by adding or removing Design Activities) or to continue with the current structure. On the other hand, when the process is unstructured, it is necessary to select the Design Activities and create a new design process or project structure for design. The selection will made the design Design Activities explicit providing the first approach to a standardized working structure for design. The selected Design Activities narrow the available Design Indicators for measurement.

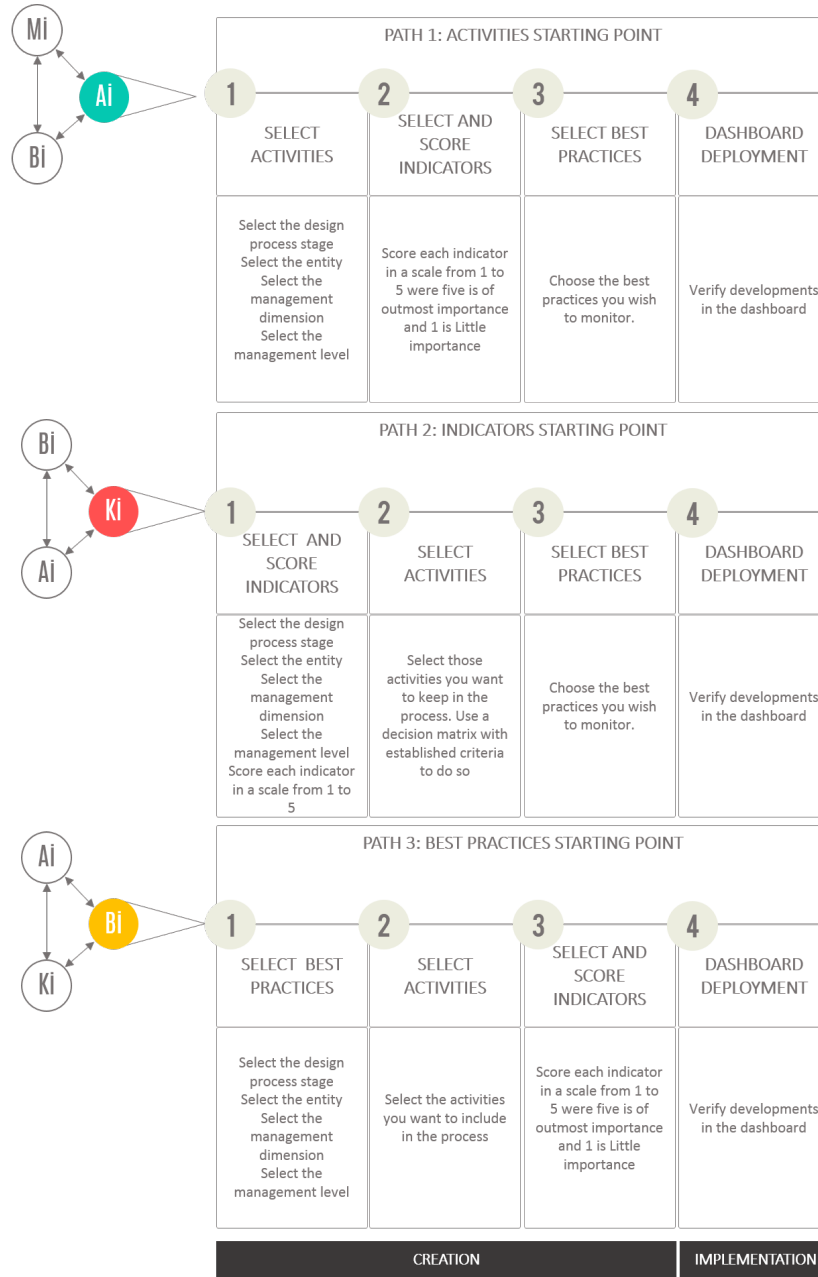


Figure 4.9: Method proposal

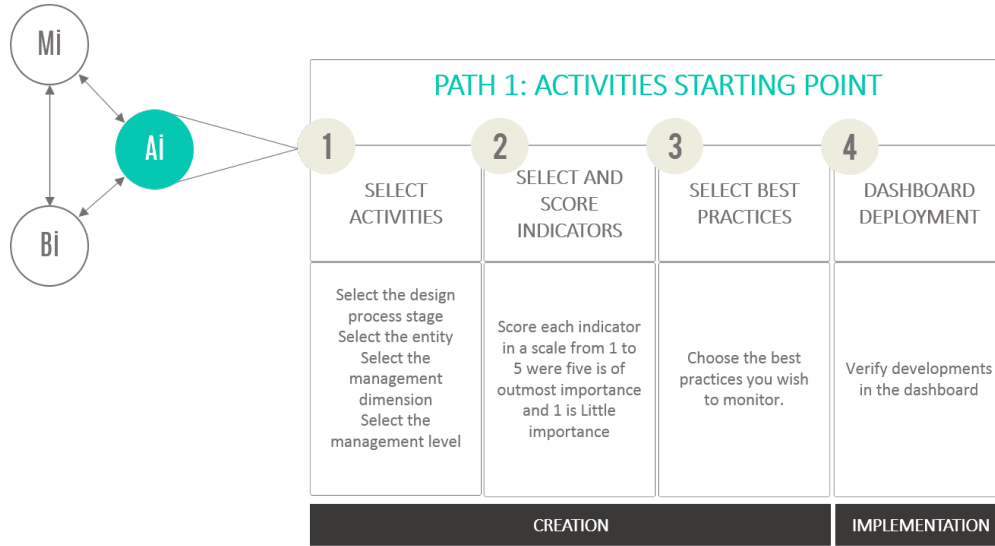


Figure 4.10: Path 1: (A_i) starting point

2. Select and score Design Indicators: If there is an existent need to implement the chosen Design Activities as soon as possible due to time constraints then the option for Design Indicators is available for selection, this will provide the means to monitor the chosen Design Activities. The design manager with his/her team should visualize and score the Design Indicators according to their needs. If the team considers the indicator is highly relevant to monitor and control the design (at least 90 %) then choose a score of five, if the indicator is relevant then the assigned score is four (70 %). If you think the indicator is necessary in certain occasions then choose a score of three (50 %) as it is not an indicator with constant relevance. A score of two (30 %) is for an indicator you find interesting or that combined with other provides interesting insights, it works as support information rather as primary information.

The following expression corresponds to the value scale for the Desing Indicator score I_s

$$Design\ Indicator\ score\ I_s = \begin{cases} 1 & \text{if } (0\% \leq I_s < 30\%) \\ 2 & \text{if } (30\% \leq I_s < 50\%) \\ 3 & \text{if } (50\% \leq I_s < 70\%) \\ 4 & \text{if } (70\% \leq I_s < 90\%) \\ 5 & \text{if } (90\% \leq I_s < 100\%) \end{cases} \quad (4.5)$$

Those Design Indicators with a score of one will be discarded as they do not provide necessary information for the current interest of the organization.

3. Select Design Best Practices: The Design Best Practices provide insights on the direction of the design process and might generate ideas to enhance the Design Activities. After the indicator

selection the team can visualize the Design Best Practices impacted and choose those to monitor closely. If a nonconformity is visualized then it might be necessary to return to the Design Best Practices side of the method for further planning.

4. Dashboard deployment: The relevance score of Design Indicators will be used to determine the best dashboard display as explained in subsection 4.5.2.

4.5.2 Design Indicator (K_j) path

There are several situations in which organizations know what they want to measure but don't have the Design Activities necessary to acquire information. The result is that they end up with an indicator that never gets measured or is measured wrong. The method provides information of the indicator when starting on the K_j side of the method 4.11.

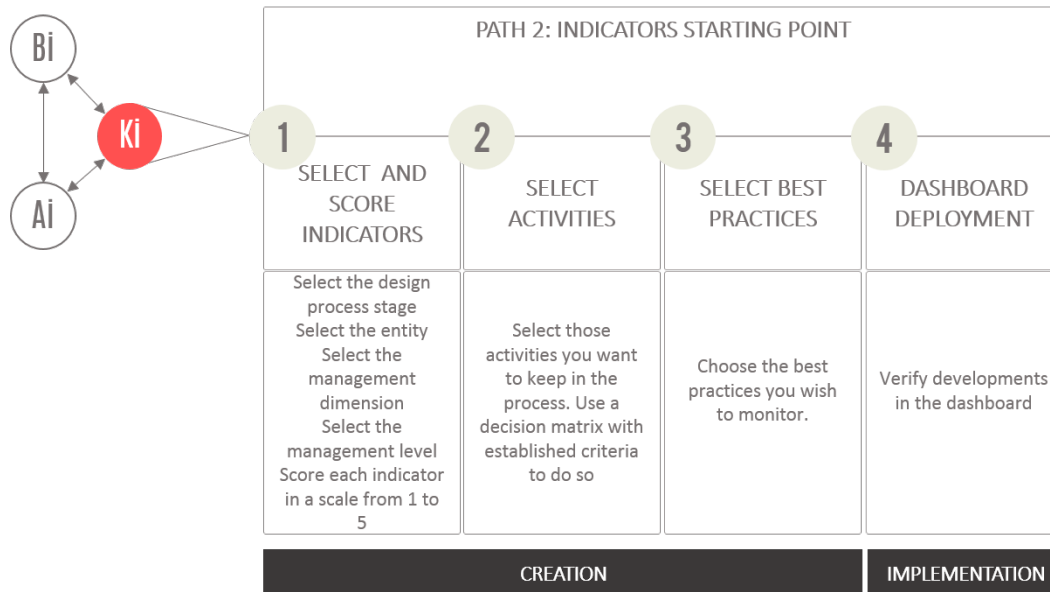


Figure 4.11: Path 2: (K_j) starting point

The purpose of the second path of the method is to provide the information gathered accordingly to the user interests and needs. The display of the information is therefore separated, making use of the three different management levels explained in figure 2.1. Each user, according to its role can be subscribed into one or more of these levels. However, one prevails over the others. Hence, if a design manager subscribes into a strategic level, but may also require to have tactical information as support. In this case the levels are describe as shown in figure 2.1.

The steps for this path are the same use in the (A_i) path, but the order changes to suit the indicator (K_j) side of the method.

1. Select and score Design Indicators
2. Select the Design Activities
3. Select the Design Best Practices
4. Dashboard deployment

Once the Design Indicators have been selected, the Design Activities associated to them can be visualized. The design manager may choose between them. The Design Best Practices to monitor appear in the database and the user may chose which ones to monitor. All the information above is sent to the dashboard for deployment.

The selection of dashboards as means to communicate results is convenient given that as Few (2006) describes it a dashboard is "a visual display of the most important information needed to achieve one or more objectives; consolidated and arranged on a single screen so the information can be monitored at a glance".

Several considerations were taken from the work of Few (2006) to ensure proper dashboard design. First and foremost, two selected parameters define the best distribution for the dashboard layout; a relevance score (Rs) and a user type (Us) embedded in each indicator. Thereby, the dashboard layout might be arranged accordingly to the scheme set in figure 4.13.

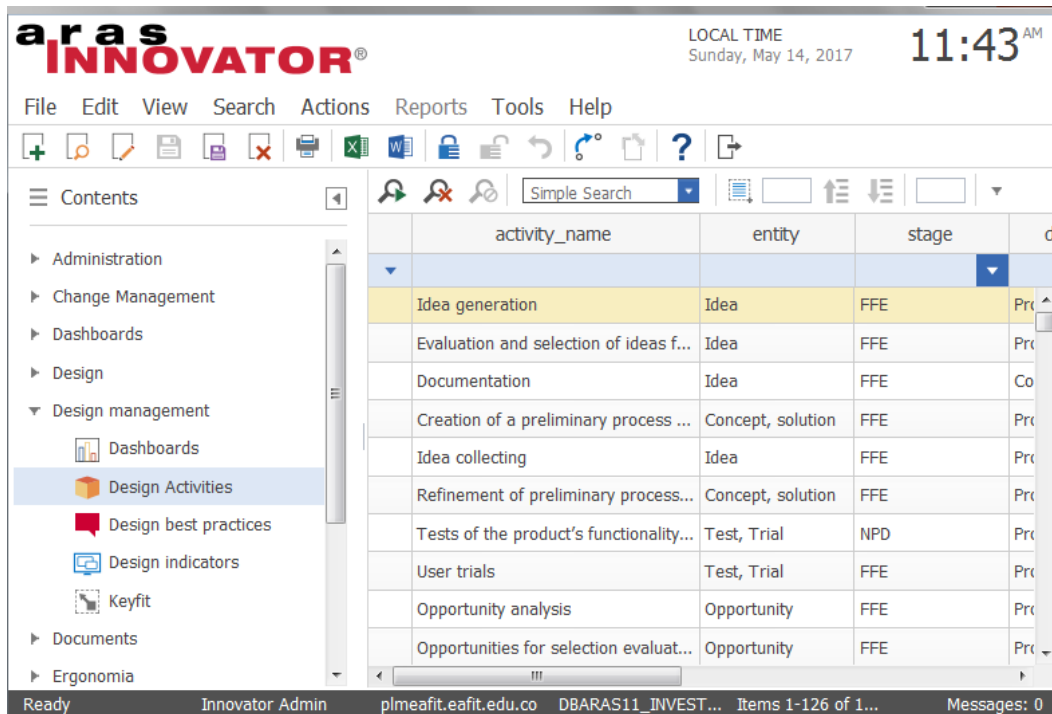


Figure 4.12: Design management module TOC

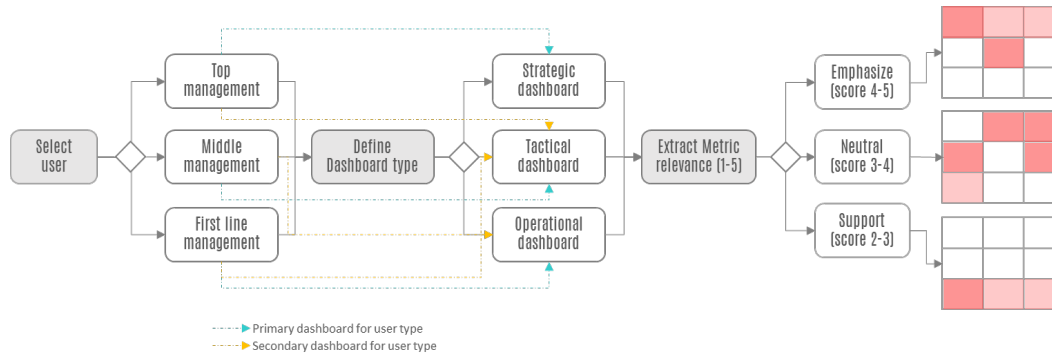


Figure 4.13: Dashboard design

The user type (Us) sets the chart as part of the operational, tactical or strategic dashboard. Moreover, each user owns a primary chart designed with the information that best suits its needs. A secondary chart may be a useful source of detail. Therefore, if middle management uses the tactical dashboard on a daily basis, when besieged with doubt the secondary chart, in this case, the operational chart might be necessary to understand, in further detail, the causes of doubt. On the other hand, the strategic chart might reflect the consequences of the mishap. The relevance (Rs) determines the order in which to locate the graphs. The greater the relevance (which means a score of 4 or 5), the better the location i.e. either center or superior left quadrants. The dashboard has capacity for at list 6 charts. Score are taken form the indicator selection and are equivalent to the dashboard as explained below:

- Highly relevant (Rs=5): Provides an extended overview of a stage in a simple way.
- Relevant (Rs=4): Provides an extended overview of important parts of a stage.
- Complementary (Rs=3): It enforces one of the relevant or highly relevant Design Indicators
- Support (Rs=2): Further knowledge, it does not say much on its own.
- Irrelevant (Rs=1): For the user or project at hand.

Once an indicator has been introduce into the repository the relevance is required. However, the indicator scores can change depending on the project and user.

4.5.3 Design Best Practice (Bs) path

The Design Best Practices approach is more top down given that his work as strategies from which objective can be set up.

The Design Best Practice path seeks to provide with insights on the strategic direction of the Design Activities. For instance if a company is focusing on providing incremental innovations it may

be shown in the best practices that the current Design Activities do not offer incremental solutions but more radical sided innovations. Therefore a correction on the Design Activities might be made.

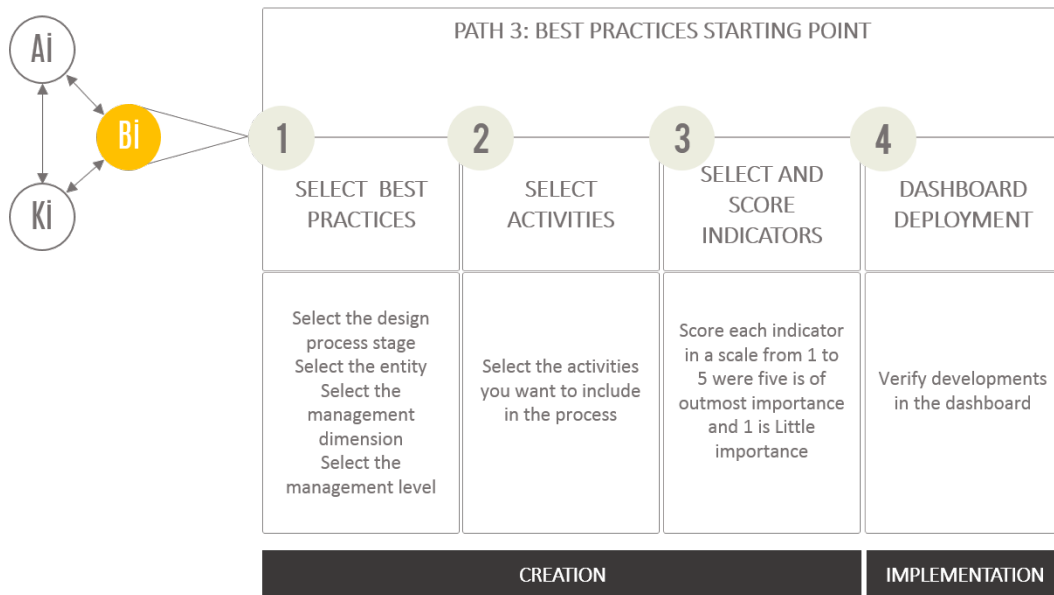


Figure 4.14: Design Best Practices (B_i) path

The Design Best Practices can be compare with the design and organizational strategy or given the case that the design strategy is none existent it can work as the first strategic approach to design. If the Design Best Practices satisfy the needs of the team, the indicator path is selected. If the Design Best Practices show many discrepancies the team might need to start on the best practice side of the framework.

A repository of 317 Design Best Practices is available to the design manager. Filtering the stage of the design process, the design dimension and the management level the compendium can be reduce to possible new approaches with their respective related Design Activities.

The steps for this path are the same use in the Design Activity (A_i) path, but the order changes to suit the Design Indicator (K_j) side of the method.

1. Select Design Best Practices
2. Select the Design Activities
3. Select and score Design Indicators
4. Dashboard deployment

The design manager might choose to pursue the Design Activities associated with the chosen for practices, hence the Design Indicators related to the Design Activities are also deploy for monitoring (see figure 4.14).

The Design Best Practices approach is more abstract in the sense that it can shift the current design process to pursue a complete different set of goals. Therefore it requires more reflection and more time for decision making, whereas the Design Activity approach is more inclined to immediate implementation.

4.6 Method implementation and testing

To reduce time and complexity the first adaptation of the method was made on a database created in Microsoft Excel for exploration. Each vector was assigned a sheet with its corresponding attributes. The filters of the software allowed the vector selection and the relations between them. For instance an example is made below with the idea related Design Activities. Let's assume that a design manager wants to include a Design Activity related to ideation into their existent FFE design process. The Design Activity path is chosen and the selection goes as follows:

In the database the attribute "stage" is selected in the first column of figure 4.15. The Design Activities are narrowed from 391 to 128 activities.

Ai	Stage	Author	Phases/Stag	Activities	Entity	Operation	Main Dimension
1	FFE	*FFE (Fuzzy Front End) PDMA p21. Kenneth B. Kahn. 2012	NA	Initial idea screening	Idea	Screening	Process, programmes and
2	FFE	FFE (Fuzzy Front End) Effective Methods, Tools,	NA	Idea generation and enrichment	Idea	Generation	Process, programmes and
3	FFE	Predevelopment activities determine product success. R	Preliminary assessment	Preliminary technical	Technical	Assessment, evaluation	Process, programmes and
4	FFE	Predevelopment activities determine product success. R	Preliminary assessment	Preliminary market assessment	Market	Assessment, evaluation	Process, programmes and
5	FFE	Predevelopment activities determine product success. R	Preliminary assessment	Preliminary evaluation	Idea	Assessment, evaluation	Process, programmes and
6	FFE	Predevelopment activities determine product success. R	Concept	Concept identification	Concept,	Identification	Process, programmes and
7	FFE	Predevelopment activities determine product success. R	Concept	Concept generation	Concept,	Generation	Process, programmes and

Figure 4.15: Design Activity path Step 1: Stage selection

The dimension of the design management is next, considering which of the nine available dimensions the ideation operates on a project or process context therefore that dimension is chosen. The database

is narrowed to 127 possibilities.

Then is time to chose the Design Activities related to the ideation itself, which means choosing the entity idea to narrow the search. The database offers 33 options. The selected Design Activity in this case is "idea generation" (see figure 4.16).

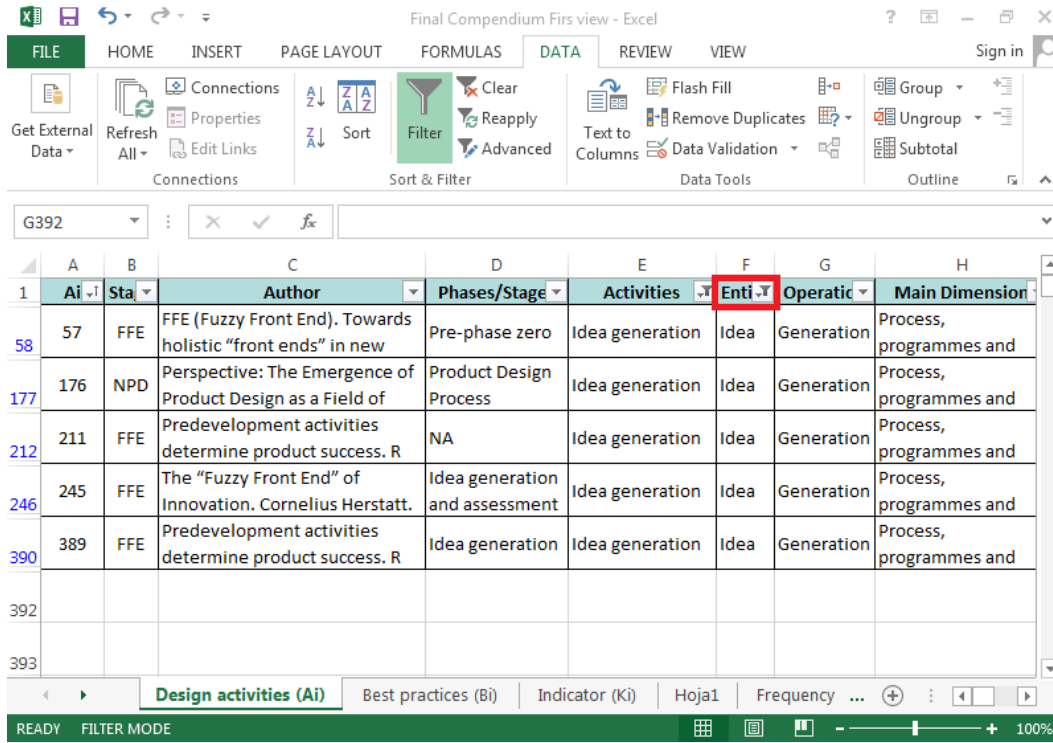


Figure 4.16: Design Activity path Step 1: Design Activity selection

The Design Indicators related to the idea generation activity are already narrowed (15 in this case), which leads to the step 2 of the method.

Select the time frame you have to present the results of the project and the level of management of the users, for instance if you are the head of design you might be more interested in those Design Indicators with a strategic approach, then choose "strategic" management level. In the case of the Design Indicators, the score in a value scale (1 to 5, where five means very relevant) in order to send the distribution to the dashboard layout.

Once the selection of Design Indicators is completed the review of the 20 available Design Best Practices to monitor, two spaces in the dashboard are available for follow up on Design Best Practices.

The excel data sheet is a mock up that shows the filters and use of information to relate several Design Activities activities, Design Indicators and Design Best Practices. The next step is to prove the efficiency of the method in a project and upload this approach into a PLM software.

Four item types were created in the PLM software, each named after its corresponding vector.

Inside the item types the attributes used in the excel data-sheet were replicated.

In addition, a module called "design management" was created and configured for accesses in the Table Of Contents (TOC) of the software (Figure 4.17). This module draws each vector item type in a group of databases.

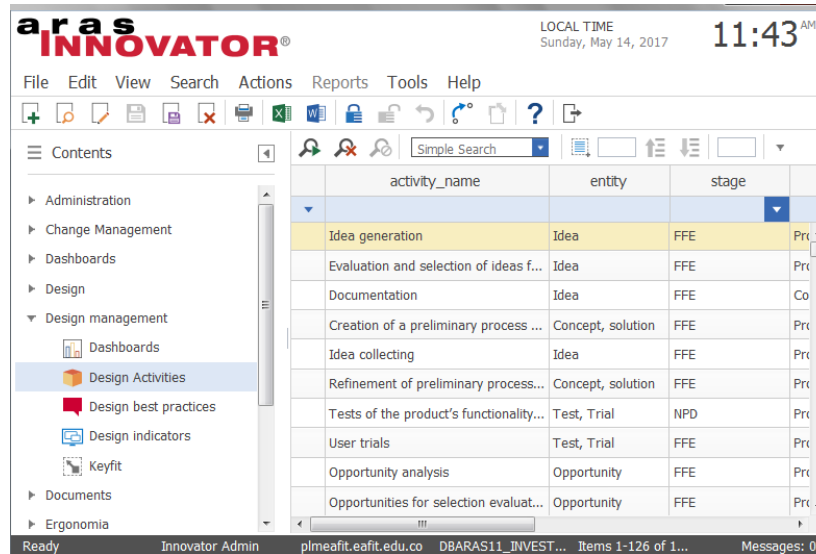


Figure 4.17: Method location in the Table Of Contents in the PLM software

Each database is design with a form to request an user to specify the attributes of each new entry (see figure 4.18). For instance, the idea generation activity creation form requires information about the attributes.

The creation of the databases takes time to fulfill. Hence, other functionalities necessary for the deployment of the method in PLM would be configure in section 5.3.

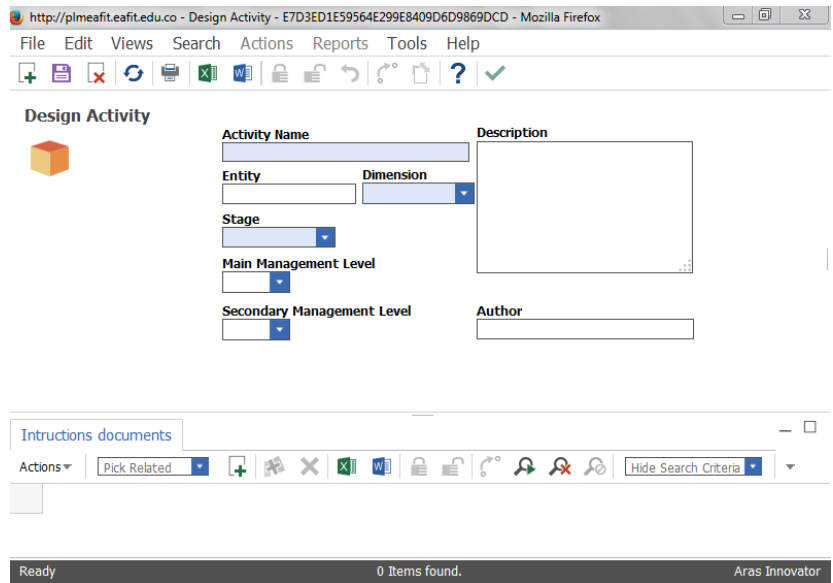


Figure 4.18: Activity form

Chapter 5

Action Research cycle 2: Validation case

This cycle will elaborate on the implementation of the method proposal in a validation case study. The focus of this cycle is to verify the effectiveness of the method in regards to indicator selection. The effectiveness is measure in terms of effort (time), options and compatibility. The validation case was performed on a real design project.

5.1 Case description

The First view project (FV) was a combined effort made by universities, industries and external advisers to offer a novel approach to the implementation of Fuzzy Front End (FFE) of innovation in local industries to provide new business opportunities in the fields of product design and service design.

The Fuzzy Front End is a stage of the innovation process uncommonly difficult to develop by organizations with traditional design and development processes. The daily routine, surrounding the organizations, leaves little time to spend in the front end of innovation. Most organizations spent their time in the present, focused on short-term result, rather than exploring the future of possibilities, particularly when the benefits are visible only for long periods of time. The inclusion of a FFE process requires interest and commitment from the top management of organizations who often misunderstand the benefits of conducting opportunity as well as idea exploration and concept definition in a systematic manner.

The creation of an atmosphere to explore the benefits and the structured approaches to FFE is a way to incorporate innovation practices into organizations in the company of experts and structured

programs to support R&D departments and engage all levels of organizations. The knowledge transfer made between organizations and universities is valuable, for both sides. The encounter novel practices and the experience from industries, provides an opportunity to understand the design mindset of the local organizations and to incorporate new methods and tools to support innovation practices.

The First view design lab environment promotes creativity, outside of constraint and boundaries of strict engineering developments. Allows the exploration of a wide range of opportunities that can dictate the industries future based on their field of knowledge and provides out of the box innovations to explore. The project environment also emphasizes on collaboration and the creation of ties between organizations.

The research at hand seeks to provide essential processed information about the performance of the FFE through the use of existent Design Indicators and Design Best Practices extracted from the literature coupled with the Design Activities planned by the First View management team. The resulting evidence supports decisions concerning the improvements of future project planning and execution.

The companies invited to the project had ties with the design engineering department of EAFIT University. Table 5.1 shows the characteristics of the companies and the emphasis of their design briefs and their size according to the SMEs regulation (Colombia, 2004).

Table 5.1: Companies profiles

COMPANY NAME	KNOWLEDGE FIELD	SIZE	PROJECT AIM
Company A	Manufacturing and commercialization of furniture: 67 years in the industry	Middle (between 50 and 200 employees)	Experiences for customer care in non-clinical spaces of health care institutions
Company B	Manufacturing and commercialization of household and industrial plastic solutions: 64 years in the industry	Middle (between 50 and 200 employees)	Promotion of environmental culture around household and institutional products.
Company C	Manufacturing and commercialization of home appliances: 75 years in the industry	Big (more than 200 employees)	Experiences around the cleansing kitchen activities.
Company D	Manufacturing and commercialization of home and construction products: 135 years in the industry	Big (more than 200 employees)	Experiences around the use of public toilet facilities.
Company E	Innovation and design studio: Branding, Design, Packaging and Business development: 11 years of experience	Micro (less than 10 employees)	Approaches towards the inclusion of creativity and innovation in teaching activities in basic and secondary education in Colombia.

The project had assigned roles of participants clarified and socialized. Table 5.2 explains the focus of every role within the project.

The project participants distributed in teams with at list two product design engineer students and

Table 5.2: Role distribution

TEAM	MEMBERS	RESPONSIBILITIES
Coordination	Management	Project schedule, budget approval, team establishment, contract development and assignment of responsibilities.
	Logistics staff	Ensures materials, resources, spaces, contacts, agendas and necessary arrangements are made to support the development of the project
	Monitoring staff	PLM software support. In addition to monitoring activities to gather information of project development and indicators
Expert advisors	International experts	Advisors in the usage of methods, tools and techniques, clarification of questions, guidance of presentation of results
	Local experts	Advisors in the usage of methods, tools and techniques, clarification of questions, guidance of presentation of results. Intermediaries between company, experts and designers
Designers	Senior designers	Company designers with experience in their respective fields
	Junior designers	Student of last semesters of product design engineering and invited researchers.

two professional designers from the participant companies. The project was accompanied by design professors of EAFIT and Delft University with experience on FFE development. The international experts carried out the distribution of the participants into ten teams, according to Myers-Briggs personality test, (figure 5.1).

The coordination team estimated a total of 200 hours of work per team in the FFE, spread in two intensive weeks of work, divided into three different stages with suggested tools for development and a detailed schedule. The coordination team planned 28 Design Activities gathered in four phases:

1. Project Kickoff: The main focus of this stage was to create an adequate environment for the first participants meeting and to give the first project schedule, the project rules and the expectations of all people involved.
2. Exploration of opportunities: It comprehends the understanding of the company cases, research Design Activities and the first encounters with users and customers. The expected result is a pool of opportunity areas and a final selection to pursue into next stage.
3. Ideation: Creative approaches take place in this stage, the coordination team set a creative experience with the alone purpose of gathering as many potential ideas as possible for selection.
4. Design vision definition: The pool of ideas selected finally is brought down to a real context, the designers develop concepts and perform several tests with end users to refine the final concept for delivery.

The coordination team, gave space to the participants to diverge and converge, several times and iterate between solutions. The project arranged a holistic experience in which the work spaces, the materials, the relaxation areas and even the food menu fall into planned schedule.

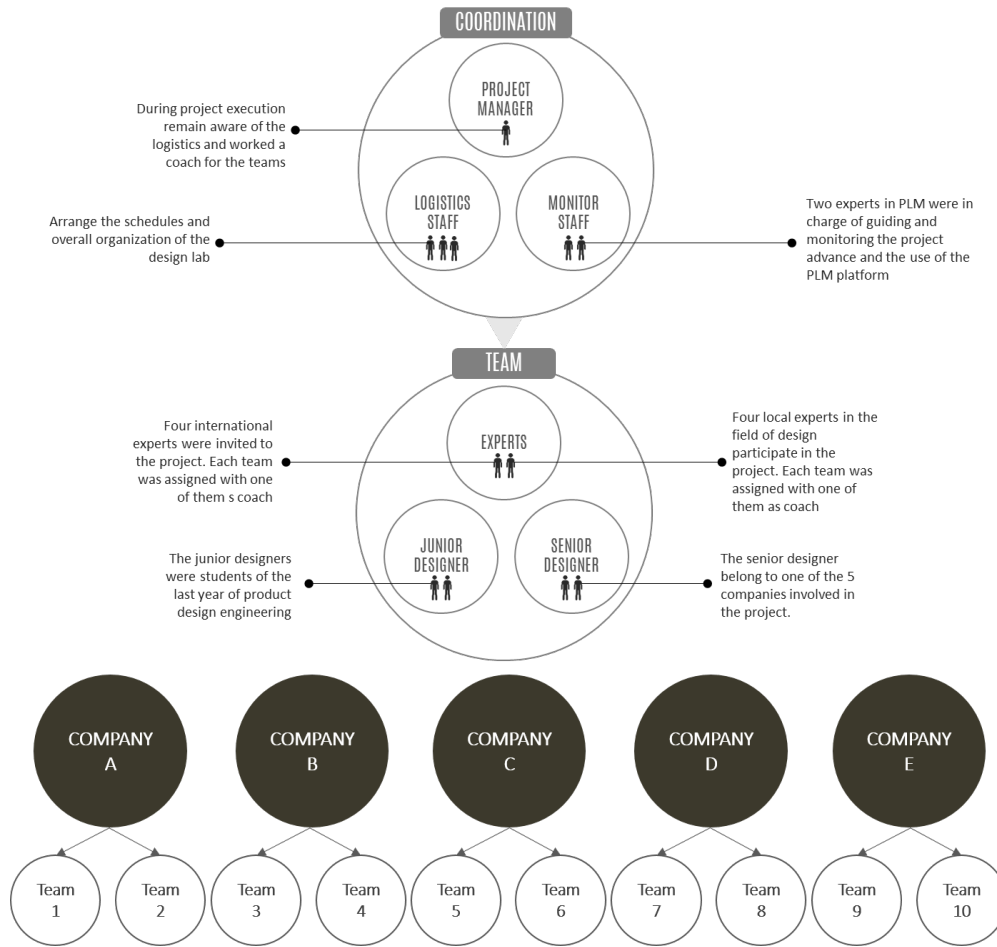


Figure 5.1: First View team configuration

5.2 Method application

Given that the coordination team already had a thoughtful plan for the project and a proposal of Design Activities organized, the contribution made by the proposed framework was on defining Design Indicators and Design Best Practices monitoring strategy. Thereby, the team chose to keep the Design Activities and move towards indicator selection and Design Best Practice follow up (see figure 5.2).



Figure 5.2: Method framework for FV

The team had three weeks to follow the method, set the monitoring strategy and ensure the PLM software configuration according to the necessary functionalities related to project schedule, information management and idea management. Moreover, the introduction week included a PLM training session for the students in charge of working with the PLM software. The overall schedule for the project including the application of the proposed method is shown in figure 5.3.

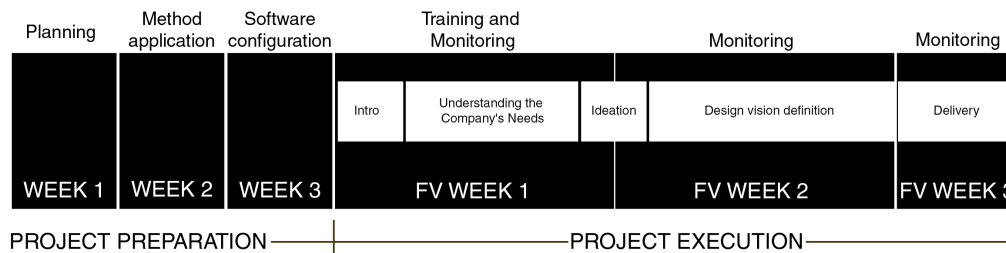


Figure 5.3: First View schedule

Path 1 of the method was chosen for application. The steps are developed as shown in the sections below.

5.2.1 Step 1: Select Design Activities (Ai)

The Design Activities set by the coordination need to undergo a matching procedure in the activity database. The coordination schedule merged project Design Activities and training activities. Only the project activities were matched on the method activity database. Therefore, the method starting point was related to the 28 Design Activities showed on table 5.3

To chose the Design Activities in the repository database the following options need to be chosen:

- The stage of the innovation design process
- The entity if you are seeking for specific items in the design process, for instance if you are choosing Design Activities for idea, concept or testing, etc.
- The activity that best matches your needs

The Design Activities classification was based on their entities and operations allowing the connection with their matching Design Indicators and Design Best Practice. The project had a total of 8 entities focused on the management of company background, portfolio, brief, resources, consumer, opportunities, ideas, concepts, and tests (see table 5.4). The entities also showed compatibility with another 125 possible Design Activities from models established in the literature.

Table 5.3: FV schedule detail

PHASE	ACTIVITY	TASK	ENTITY	OPERATION
INTRO	Kickoff	(Intro to Fuzzy Front End)		
UNDERSTANDING THE COMPANY'S NEEDS	Opportunity identification	Collect general information.	Company	Research
		Visiting the company.	Company	Visit
		Analyze Company's product/service portfolio	Portfolio	Analysis
		Brief revision	Brief	Revision
		Receiving First View Kits for analysis	Resource	Allocation
		Socialization: DESIGN LAB INTRO lecture/documents on principles, objectives, learning goals. Four companies presentation and briefs.	Brief	Communication
		Sets Design Criteria (brief)	Brief	Selection
		User research: field work	Consumer	Research
		User research: Insights Analysis	Consumer	Research
		Set Opportunity areas	Opportunity	Definition
	Opportunity analysis	Brief Redefinition with Company and Users.	Brief	Definition
Developing a Design Vision (choose opportunity area)		Opportunity	Selection	
Milestone 1: The Design vision and design brief (DUE Morning 12)		Brief	Approval	
IDEATION	Idea generation	Creative weekend: Idea Inventory and Analysis. First Round	Idea	Generation
		Creative weekend: Idea Inventory and Analysis. Second Round	Idea	Generation
		Report idea generation	Idea	Generation
	Idea selection	Idea selection criteria	Idea	Selection
		Idea evaluation and final selection with companies and users.	Idea	Evaluation
		Milestone 2: Ideas selected	Idea	Approval
DESIGN VISION	Concept definition	Idea redesign into concept	Concept	Definition
		Concept Mock up creating	Concept	Definition
		Concept Design & Engineering	Concept	Development
		Concept Prototype/model building (Physical and 3D models)	Concept	Prototyping
		Consumer / User testing: Depending on concepts but in any case with actual users)	Test	Execution
		Concept Redesign and improvements	Concept	Improvement
		Report and final presentation.	Concept	Communication
		Milestone 3: Concept definition report	Concept	Report
	Concept approval	Final socialization of result with companies	Concept	Approval

Table 5.4: Activity entities

ENTITIES SUMMARY	OPERATION SUMMARY
<i>Company</i>	Research
	Visit
<i>Portfolio</i>	Analysis
<i>Brief</i>	Revision
	Definition
	Communication
<i>Resources</i>	Allocation
<i>Opportunity</i>	Definition
	Selection
<i>Consumer, user</i>	Research
	Research
<i>Idea</i>	Generation
	Selection
	Evaluation
	Approval
<i>Concept</i>	Definition
	Development
	Prototyping
	Improvement
	Communication
	Report
	Approval
<i>Test</i>	Execution

5.2.2 Step 2: Select Design Indicators (Kj)

Select and score Design Indicators: The selection of the Design activities narrow the available Design Indicators for application to the FV project case. The Design activities associated with 32 possible Design Indicators for deployment (see table 5.5).

Those Design Indicators within the expected time frame set for the project were selected. In this case, the intensive nature of the project only allows to use short term Design Indicators. A total of 26 Design Indicators ranked in this time frame as specified in table 5.6.

The Design Indicators were scored under the value scale explained in section 4.5.1. From a total of 212 Design Indicators 24 were implemented, 2 were discarded given the low scores. The database reduce the information excess presenting only 11% of the available Design Indicators. The Design Indicators that better fit the project Design activities are related to 3 main entities, Opportunity

Table 5.5: Fv Design Indicators available for deployment

Ki#	STAGE	AUTHOR	Indicator (Ki)	DIMENSION	ENTITY
18	DM	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dziobczenski, Mauricio Moreira e Silva Bernardes.2031	Reputation among customers (qualitative)	Strategy	Consumer, customer, user
44	DM	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dziobczenski, Mauricio Moreira e Silva Bernardes.2059	Internal customer satisfaction (quali) ☒	Process, Programmes and procedures (process planning) / Project	Consumer, customer, user
49	DM	Koen, P., Ajamian, G., Burkart, R., & Clamen, A. (2001). Providing clarity and a common language to the "fuzzy front end". Research Technology Management, 44(2), 46.	Percentage of ideas that resulted in patents,	Process, Programmes and procedures (process planning) / Project	Idea
112	DM	Product Development Metrics. Kenneth Crow, DMR Associates. 2001	Percent R&D resources/investment devoted to new products (versus total of new products plus sustaining and administrative)	Investment and finance	Resources
163	DM	Product Development Metrics. Kenneth Crow, DMR Associates. 2055	Portfolio balance by project/development type (percent of each type of project: new platform/new market, new product, product upgrade, etc.)	Process, Programmes and procedures (process planning) / Project	Portfolio
1	FFE	FFE (Fuzzy Front End) Effective Methods, Tools, and Techniques. Peter A.Koen,	Opportunity analysis time frame	Process, Programmes and procedures (process planning) / Project	Opportunity
23	FFE	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dziobczenski, Mauricio Moreira e Silva Bernardes.2036	Ideas generated at the beginning of the product project (#)	Process, Programmes and procedures (process planning) / Project	Idea
46	FFE	Koen, P., Ajamian, G., Burkart, R., & Clamen, A. (2001). Providing clarity and a common language to the "fuzzy front	Number of ideas retrieved and enhanced from an idea portfolio	Process, Programmes and procedures (process planning) / Project	Idea

Table 5.6: Indicator score

KI	STAGE	METRICS	TIME FRAME FOR MEASUREMENT	SCORE
163	DM	Portfolio balance by project/development type (percent of each type of project: new platform/new market, new product, product upgrade, etc.)	Short term	5
1	FFE	Opportunity analysis time frame	Short term	3
23	FFE	Ideas generated at the beginning of the product project (#)	Short term	5
46	FFE	Number of ideas retrieved and enhanced from an idea portfolio	Short term	4
47	FFE	Number of ideas generated/enriched over a period of time	Short term	3
51	FFE	Quality of the opportunities 0 Not enough information to make a determination; 1 A product or service identical to an existing product/service offered to an underserved market; 2 A product or service similar to an existing product/service offered to an underserved market; 3 A new application for an existing product/service, with little/no modification or a minor change to an existing product; 4 A significant improvement to an existing product/service; 5 A combination of two or more existing products/services into one unique or new product/service; 6 A new-to-the world product/service, a pure invention or creation.	Short term	5
52	FFE	Quantity of opportunities: Amount of opportunities identify during the course of the project or process	Short term	3
58	FFE	Number of champions assigned to ideas	Short term	2
61	FFE	Personnel assigned to analyse opportunities	Short term	2
65	FFE	Concept definition activities: Amount of activities performed to define a concept in each project or process	Short term	4
66	FFE	Idea generation activities: Amount of activities performed to generate ideas in each project or process	Short term	4
67	FFE	Idea selection activities: Amount of activities performed to select ideas in each project or process	Short term	4
68	FFE	Ideas with science orientation	Short term	1
72	FFE	Number of discarded solutions	Short term	4
76	FFE	Number of notifications vs. number of ideas received	Short term	1
77	FFE	Number of radical ideas selected	Short term	4
78	FFE	Opportunity analysis activities: Amount of activities performed to analyse opportunities in each project or process	Short term	4
79	FFE	Opportunity identification activities: Amount of tasks, methods or techniques performed to identify opportunities in each project or process	Short term	4
80	FFE	Opportunity attractiveness	Short term	5
83	FFE	Science oriented chosen ideas	Short term	1
89	FFE	Opportunity identification efficacy: Expected amount of opportunities identified	Short term	4
159	FFE	Pipeline throughput rate	Short term	5

(O), Idea (I) and Concept(C). The project focuses mainly on Opportunity Identification and Analysis (OIA), Idea Generation and Selection (IGS) and finally Concept Definition and Approval (CDA).

5.2.3 Step 3: Select Design Best Practice (Bs)

The narrowed list of Design Indicators is connected with several Design Best Practice. The approach shows 74 Design Best Practice in which the project is focused (table 5.7).

Table 5.7: FV Design Best Practice available for deployment

BI	STAGE	BEST PRACTICE	DIMENSION	ENTITY
19	FFE	Creation of a scope for putting ideas back into people's brains – creative idea loop;	Process, programmes and procedures (process planning) / Project	Idea
20	FFE	Definition of company-specific idea categories	Process, programmes and procedures (process planning) / Project	Idea
21	FFE	Idea selection based on rules	Process, programmes and procedures (process planning) / Project	Idea
22	FFE	Installation of a broad idea-collection point.	Process, programmes and procedures (process planning) / Project	Idea
23	FFE	Installation of an intelligent interface between employees' brains and an idea-collection system;	Process, programmes and procedures (process planning) / Project	Idea
26	FFE	Number of stages and gates in the tailor-made idea management.	Process, programmes and procedures (process planning) / Project	Idea
27	FFE	Predefined and transparent criteria for selecting and implementing ideas.	Process, programmes and procedures (process planning) / Project	Idea
28	FFE	Sustainable flow of ideas	Process, programmes and procedures (process planning) / Project	Idea
29	FFE	Systematic idea clustering.	Process, programmes and procedures (process planning) / Project	Idea
30	FFE	The concept identification phase (idea management = phase before the project decision) is structured and conducted systematically.	Process, programmes and procedures (process planning) / Project	Concept, solution
31	FFE - NPD	The ideas are linked with companies' strategic goals at a very early stage of the innovation process	Process, programmes and procedures (process planning) / Project	Idea
32	FFE - NPD	The ideas will give rise to superior products with obvious benefits for customers and users	Process, programmes and procedures (process planning) / Project	Idea
35	FFE	Exclusive individual rewards for implemented ideas	Rewards and evaluation	Idea
38	DM - FFE	Enhancement of sensitive idea management leadership in accordance with complexity and diverse approaches towards handling ideas.	Strategy	Idea
40	FFE	Commitment to the owner of the idea management process	People, structures, culture and climate	Idea
41	FFE	Cross-functionality of the decision-making gatekeepers in the idea management process	People, structures, culture and climate	Idea
44	FFE	New product ideas rewarded	Rewards and evaluation	Idea

Given that the project implementation was the priority, there was no analysis of the Design Best Practice. They only serve as information during the project.

5.2.4 Step 4: Dashboard deployment

The Design Indicators scored were organized in the dashboard layout according to their relevance score (Rs) and the user type 4.13. Figure 5.4, shows the tactical dashboard arranged for FV project. In this case, due to time constraints, the dashboard was design after the project as a mock up of the possible layout. Further exploration is required for deployment in a PLM software (See subsection 5.6.

The Design activities, Design Best Practice and Design Indicators now show a clear vision of the project for study in regards to the compatibility with the strategy pursued.

5.3 PLM software configuration

Aras innovator (AI) is a PLM software that supports collaborative work, innovation and management of the product lifecycle, including design innovation processes. The software cover a wide array of business needs necessities that range from project execution and quality management aids to knowledge management assistance and process planning. As a software, AI is flexible for configuration and adaptation to organizational needs and evolves as companies do.

Some of the AI features are (i) AI's open source code facilitates the deployment of business solutions in real time (ii) The software interface is based on windows environment to familiarize the user with known navigation buttons and functionalities (iii) AI is available with no license cost.

AI defines all existent objects in the software as items, each item is contains properties, views, life cycles, workflows, permissions, relationships with other items. An item is designed to contain data and complex information required according to the business purpose. All the items have an ItemType. It allows defining the item type that distinguishes it from other items.

The configuration of AI aims to structure the functionalities demanded by the method. The application requires personalized settings and some of the default functionalities available in the software. A basic configuration must take place before proceeding with more in-depth settings.

- Acces configuration: AI requires an user name and password to access the application. The software is installed on the EAFIT University server.
- The first step to configure the system is the creation of users and identities. A user is a person that has permissions to access the application. Each user has an identity that allows associating access permissions to other fuctionalities and assignations to group identities. A group identity is constituted by users, the groups has its own permission configuration. The use of identities

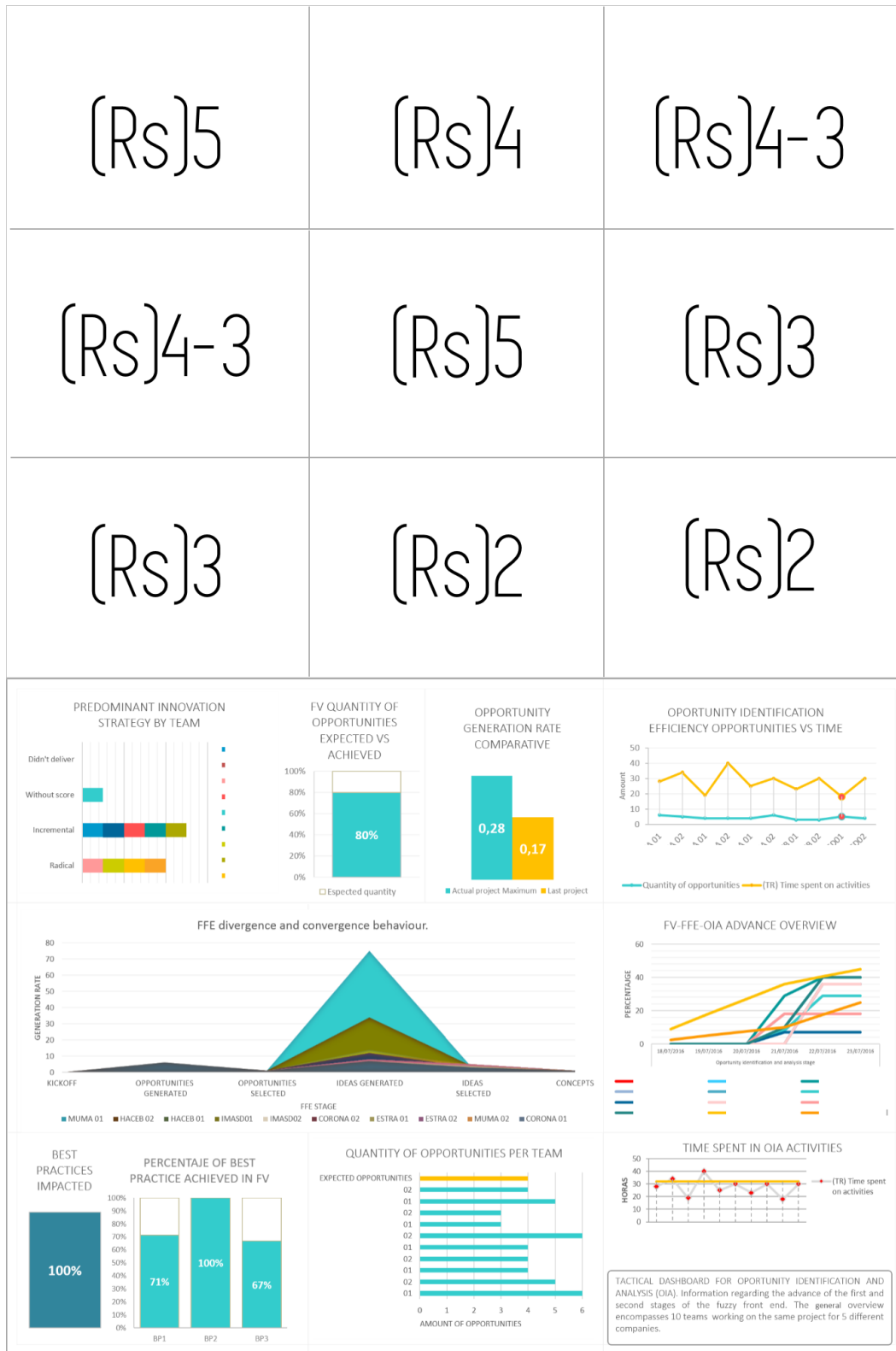


Figure 5.4: FV dashboard design

generates a role and access hierarchy that permits to structure membership for controlling and manage functionalities in the software.

- **Permissions:** each identity can be assigned with rights to view, update, delete, discover or change access to the information stored in the software.
- **Information:** Ai centralizes the storage of documents with standardize conditions to facilitate location of files and ensure updates without duplication or inconsistencies. The information and knowledge gathered, is accessible at any time, allowing not only knowledge generation through document creation, but also knowledge transmission. As a result, data, information, and knowledge are integrated within the PLM. An adequate document management allows to effectively re-use information for future projects. Also, it reduces the project execution time due to a correct information management that support the decision making process.
- Besides the management of information the software requires the creation of g conventions to differentiate items. This provides order to the information display. In AI each item can be assigned with a sequence of prefixes and numbers that change automatically. Nomenclature can be managed manually as well, making use of codes, such is the case of this project.
- In order to manage the information for each project developed, it is necessary to define a module that store and manage the information generated during the execution of a project. This module allows creating and controlling the execution of a project. To create a project the first step is to enter the project code and name. Once the project is created, one may add different phases with different Design activities and assignations. Within the company processes, it is required to planning, monitoring and executing Design activities. To do so, AI allows defining project schedules in the project management module. This module allows the definition and sequencing of each activity, the execution date, role assigned, predecessor Design activities, and amount of hours estimated. Additionally, this module uses a color scale to indicate the status of the activity. The monitoring and control of the project is achieved through an activity completion form which is filled by each role assigned. The information filled is updated in the project schedule in order to inform the manager the status of the activity. The assignment of the Design activities is assisted by the system using automatic notifications that inform the assigned when an activity should be completed. The progress of the project may be observed though a Gantt chart report.
- The process module contains the information for each phase defined in a project. It is important to know that the process module executes the different workflows modeled in the software. NPD, FFE can be standardize using this module A workflow is defined as a sequence of Design activities that represent a business process. A workflow often includes branches and parallel Design

activities. Workflows permit to guarantee that all steps in a business process are completed, in the correct order, and making them repeatable. In AI, a workflow map represents the template for a business process that may repeat over time. An instance of a workflow map is called a Process. A process records the persons involved and the decisions or votes taken.

- The software configuration includes the definition and implementation of lifecycles for each item. These lifecycles allow defining different permissions for each item depending on its current state. The states identified in the item may be used to create a lifecycle map for it. The lifecycle controls when an item is pending or when it is approved.
- Each Item is assigned a category in the TOC. These categories facilitate grouping common functionalities into modules. The TOC defined for this project is presented in. Each category represent a module and the elements inside are the items created.

The PLM software is the source of the information for Design Indicators measurement. Hence, each indicator has a strategy for data handling that specifies the necessary actions to extract the information, the operations necessary to provide the values for the indicator and the steps to adequate the software to ensure these data. An example appears in table 5.8.

The indicator above requires a report template to capture each opportunity found, a project schedule or workflow to associate the opportunity Design activities with the template, a clear record of the hours spent in this Design Activities and the tools used for posterior correlation to create a graphic representation of the indicator. The first configuration made was the creation of all participants as users of the PLM software and their respective division in teams and groups according to the previously planned hierarchy. The identity diagram is show in figure 5.5.

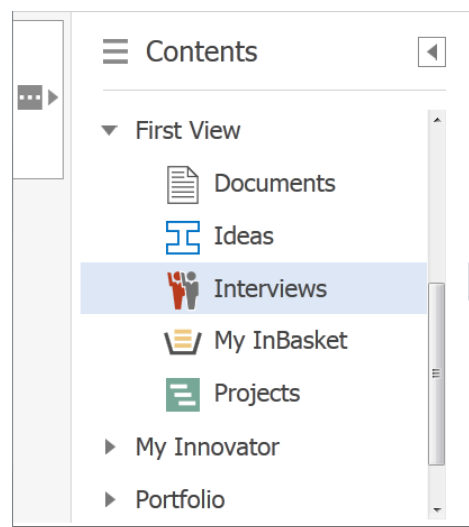


Figure 5.5: FV identity hierarchy

Table 5.8: Indicator configuration details

INDICATOR	Quantity of opportunities: Amount of opportunities identify during the course of the project or process		
LEVEL	Tactical		
WHEN DO YOU GET RESULTS?	Short term		
ENTITY	Opportunities		
VARIABLES	Amount of opportunity Time (hours) spent in opportunity finding		
INTERPRETATION	ACTIONS	SOURCE	OPERATION
The quantity of opportunities shows how consistent are the activities for opportunity identification in each project and if they are delivering the necessary amount of opportunities to increase the chance of a competitive advantage	Report of each opportunity identify	OI template	Count each opportunity set
NECESSARY CONFIGURATIONS FOR THE EXTRACTION FROM THE PLM SOFTWARE			
<p>Template to report at the end of the stage: Number of opportunities identify Number of opportunities expected</p> <p>Workflow or project schedule: Activities and task (Number and description) Create a mandatory task to fill in the templates</p> <p>Workflow map and project schedule Estimated hours for each activity</p> <p>Workflow history and project update form Effective hours spent in each activity Effective time spent in the stage</p>			

The identities are:

- FV: Groups the entire participants of the First View projects
- FV201602: Groups the entire participants of the 2016 First View project
- Teachers: The group of experts available for advisory is divided according to universities Eafit or TuDelft respectively
- Students: Groups the participants into teams, two per company
- Coordination: Gathers the teachers (experts) and head designers of each company and divides them into their respective groups
- Administrators: In charge of coordination and advisory

A group identity gathers all users in their respective roles. In the case of the identity "designer" gathers all designers both senior and junior (student). A hierarchy began to take shape, and the distribution provides the foundations for permissions assignments in the software. Therefore, the permissions for a senior designer are broader than those of a junior designer and narrower than those of the project manager.

Access was configure next. A The TOC category named "design management" was defined for this project and it is presented in figure 5.6.

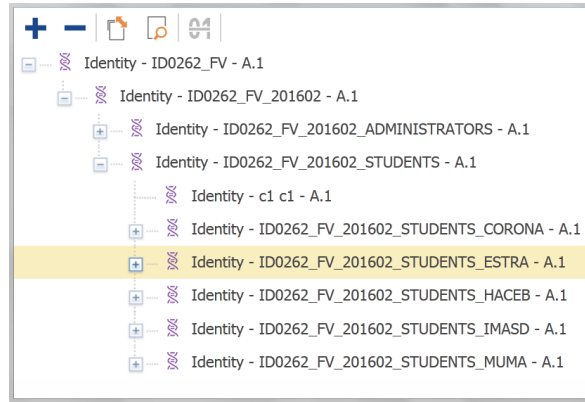


Figure 5.6: First View TOC in ARAS PLM

Since every existing entity in AI is an Item, the software item configuration menu allows to create a new item or add special properties to an existing, to provide new personalized functionalities. For the FV project, several items lined up for creation and modification as shown in table 5.9.

Table 5.9: Aras innovator functionalities

ITEM	EXISTENT OR NEW
Project schedule	Existent
Documents	Existent
Idea	New
Interview	New

5.3.1 Idea management module in PLM software

The PLM software configuration implemented in the FV project provide a functionality to ensure idea capture and storage. A new item type called "idea" allowed to capture the developments of each team during the project creating a new module active on the TOC for all identities for use in any moment of the FFE process(see figure 5.7.

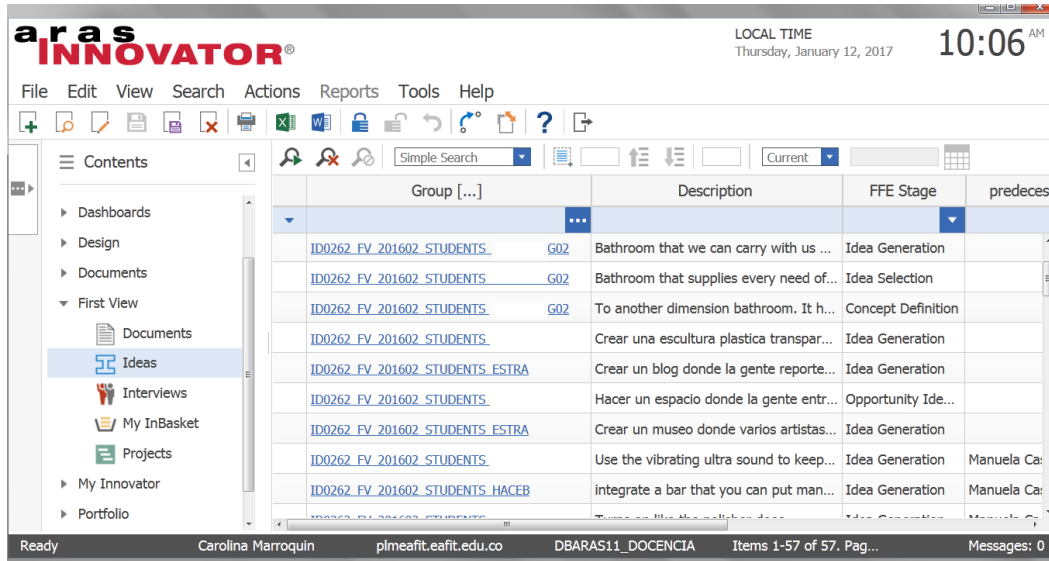


Figure 5.7: Idea functionality in ARAS PLM

The open use of the idea functionality gave freedom to report ideas and encourage them to do so on their own time, without interfering with their creative process. Each time a participant reported an idea a form needs to be filled with the information shown in figure 5.8.

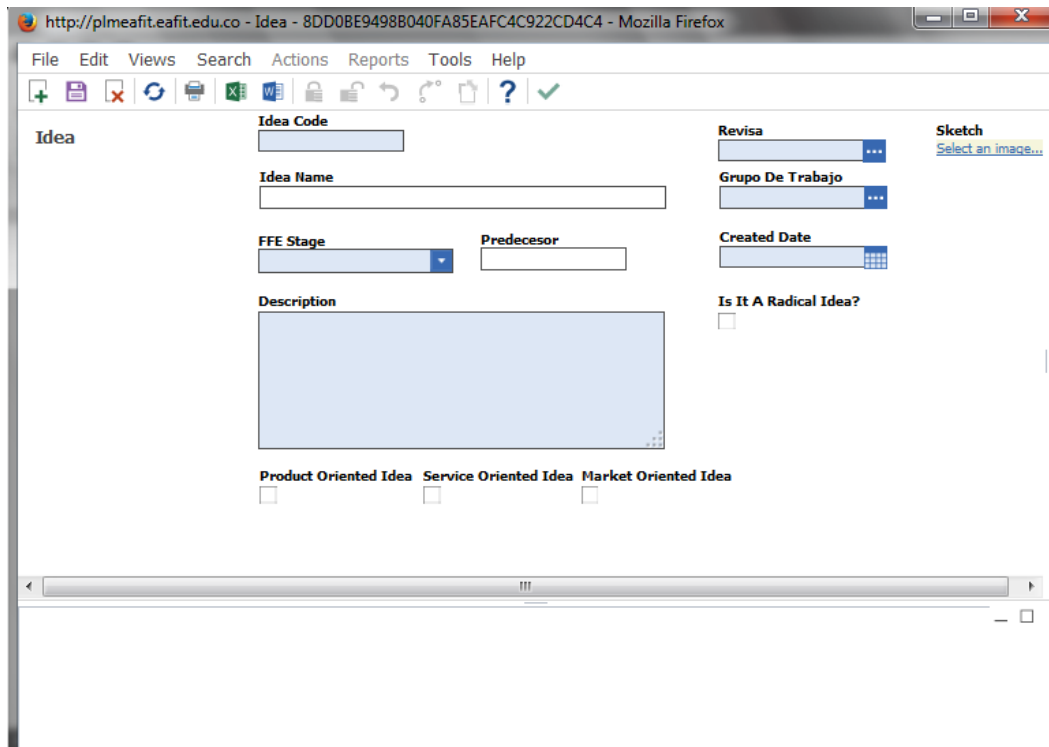


Figure 5.8: Idea report in ARAS PLM

- Idea code and name: Is an identification that facilitates retrieval of records. The code includes the group name, the group number and an automatic consecutive.
- FFE stage: The fuzzy nature of the project gives the participants the opportunity to generate ideas despite the stage of the process. Therefore it is necessary to record which stage they were are working on and analyze the behavior of the process.
- Description: The idea explanation. The form allows the attachment of images, drawings and other file types that support idea explanation.
- Radical idea: The idea creator might consider its proposal seems to step away from all the company current endeavors and expectations. Radical ideas create unexplored innovation areas in the long term.
- Idea orientation: Is it a product, a service or a marketing oriented idea?
-

5.3.2 FV Project management in PLM software

AI allows defining the project schedule to visualize and manage activity sequences, execution dates, leaders, predecessors, and work hours estimated. Once the project is active, the schedule uses an automatic color scale to indicate the status of the activity. The status is updated when the leader of an activity fills an activity completion form (figure 5.9).

The system assists the assignment of Design Activities through automatic notifications that inform the leaders when an activity is due for completion. The progress of the project can be visualized in a Gantt chart report (see figure 5.10).

The intensive nature of the project provided the opportunity to test two different management styles. Two type schedules were assigned to the groups and all companies had one team with a traditional schedule and other with an open and more flexible schedule.

- Traditional management schedule: guides the team with detailed tasks and requires many separate deliverables and time records. This schedule has a total of 19 Design Activities separated into five stages. The expectations are for them to spend a considerable amount of time in the software as they move through the FFE. The tasks may lead to a more thoughtful recording of the results, but it will also demand more time spent on reports, forms and information clustering which may cause discomfort in the designers and their creative Design Activities (Figure 5.11).
- Open management schedule: Consist of three stages and six Design Activities, unlike the traditional project version this consist mostly of milestones in which a consolidated report is handed.

Activity2

Project
 Project Number: 1471
 Name: 02_ID0262_FV_2016
 Project Manager: ID0262_FV_201602_TEACHER

Activity
 Name: Milestone 2: Idea eva
 Leader: Paula Bustamante Echavarría
 Work Estimate: 7/22
 Deliverable Type: [Dropdown]
 Deliverable Required: []
 Due Date: 7/25/2016
 Perc: 100

Tool/Method	Who [...]	Date From [...]	Date To [...]	Hours
How to's	ID0262_FV_201...	7/22/2016	7/22/2016	5 (5h each) we

Figure 5.9: Project schedule in ARAS PLM

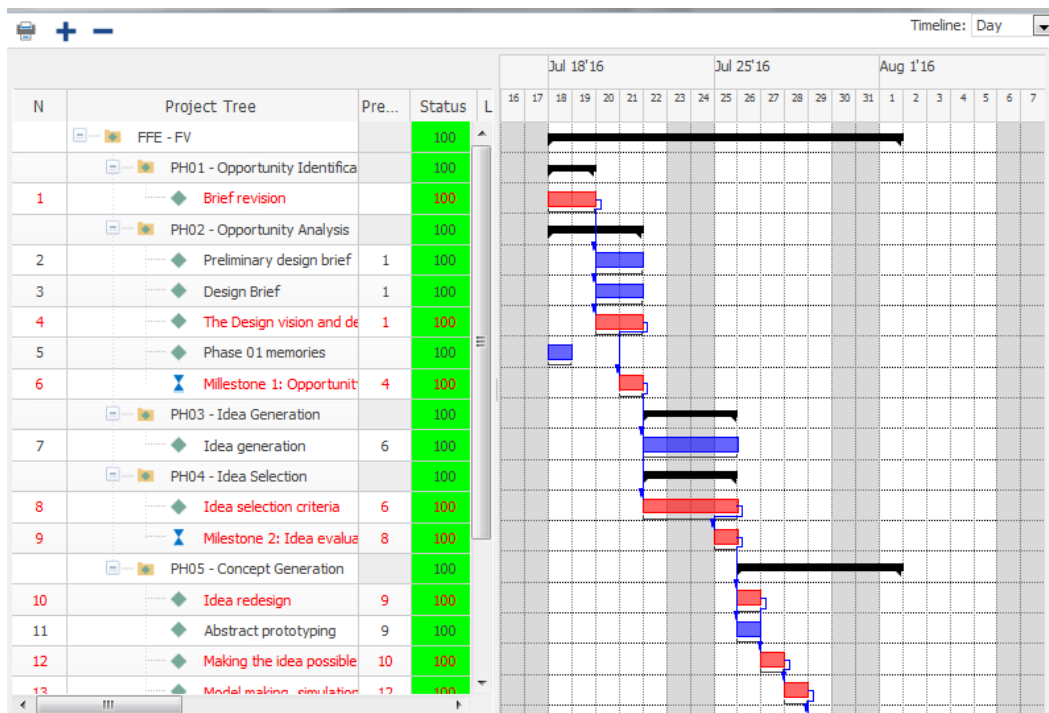


Figure 5.10: Project Gantt chart in ARAS PLM

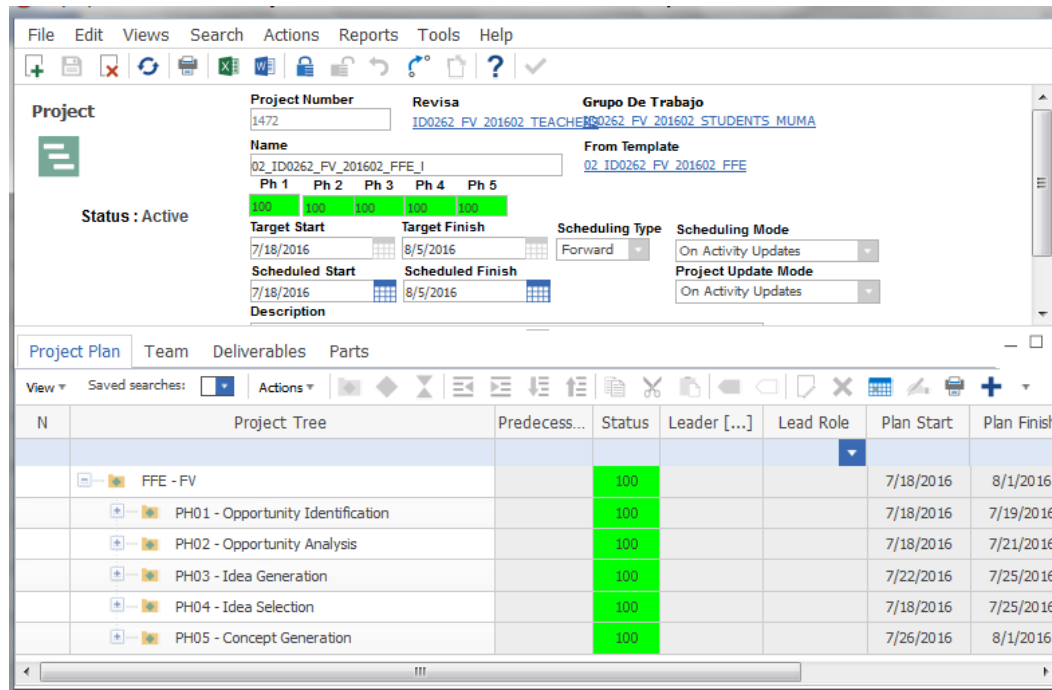


Figure 5.11: FV traditional Project schedule in ARAS PLM

The reduced complexity of the schedule gives more room to create a team management style of their own. However, the lack of guidance may result in the loss of information, since not all designers may understand the importance of the different pieces of information. The coordination team has to increase revisions over the information handed (Figure 5.12).

The follow-ups of the project summarize in a single screen that shows the advance of each project by stage percentage of completion as shown in figure 5.13.

Another important aspect of the documents functionality is related to the naming conventions used to retrieve information. All items created for the project carry the label FV as prefix or suffix. The documents carry a broader naming convention an example of the project convention is shown in figure 5.14.

The intensive nature of the project inspired the creation of only three templates that gather the necessary information for indicator measurement. These templates combined with the existent functionalities of the software completed the data for further correlation. The templates were mandatory and required in each project scheduled milestone.

The first template (see figure 5.15) is associated with the entity "opportunities". It gathers all information regarding the quality and amount of opportunities generated and their innovation direction. The report Opportunity Identification and Analysis (OIA) also records the tools used by each team and wherever the approval was effective or not.

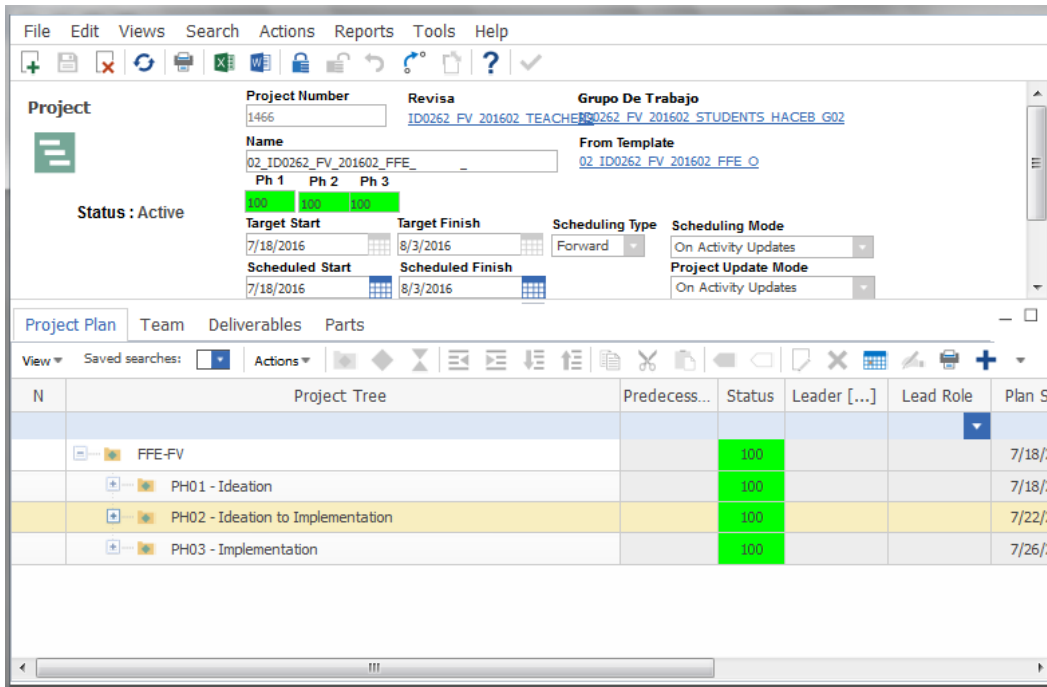


Figure 5.12: FV Open Project schedule in ARAS PLM

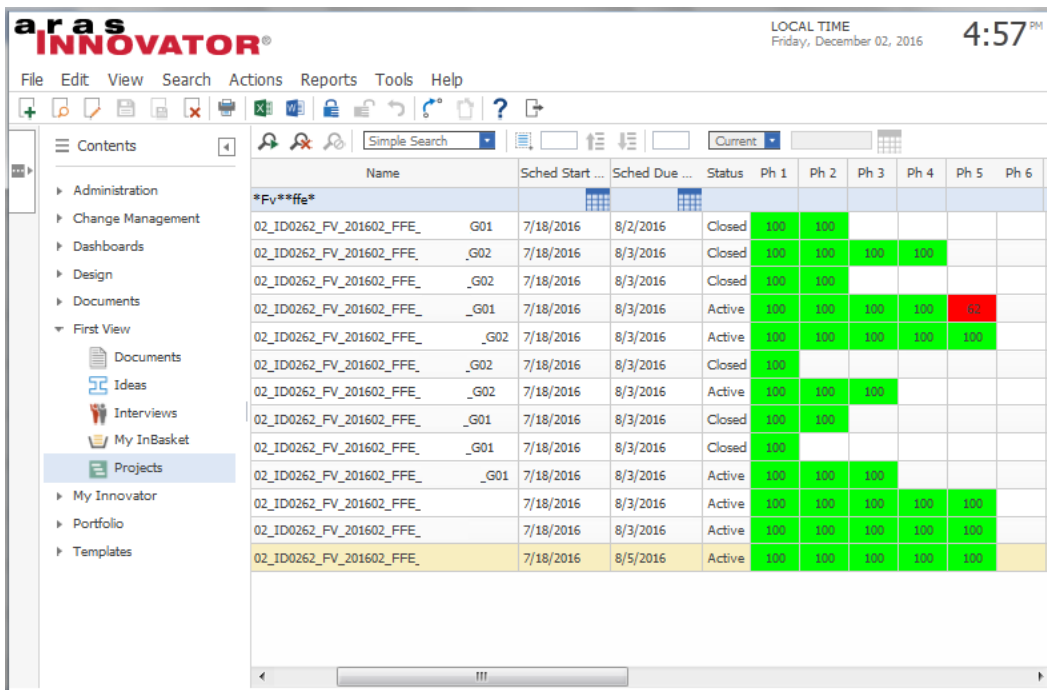


Figure 5.13: Project dashboard in ARAS PLM

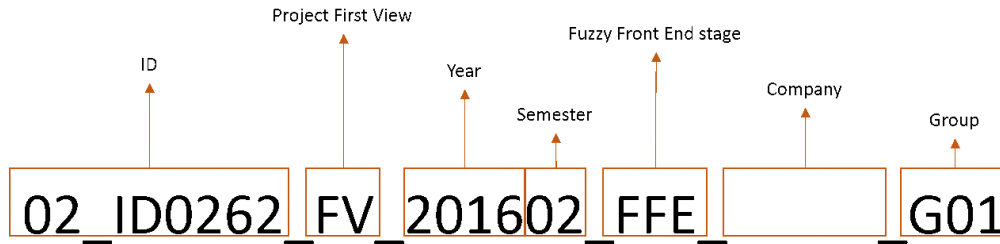


Figure 5.14: FV naming convention in ARAS PLM

The lack of experience using a PLM software may prevent the use of the idea functionality, resulting in idea lose. Therefore during idea related Design Activities, a milestone with a mandatory report form captures all group creations, the Idea Generation and Selection template (IGS) carries the information on idea generation decisions (figure 5.16).

The continuous flow of ideas offers information on the FFE stage health, provides consistent records and quantifies a number of ideas reported. The questions resulted from the requirements of information from the chosen Design Indicators.

Finally the "concept" entity was monitored with the information provided in the Concept Definition and Approval template (CDA). See figure 5.17

The Design Activities performed to develop and select the final concept are detailed in the CDA template, as well as all the test made with and without the customer.

5.3.3 Training sessions in PLM usage

The PLM software update was a task assigned to junior designers (students). Given the shallow knowledge of the participant about the software. A training session conducted in four hours by two PLM experts, explained the fundamentals of a PLM strategy, the software functionalities under deployment in the project and the expected results for the project. The following table 5.10 provides the topics of the session

A close follow-up was offered to the participants the first week to solve any issues regarding the software usage.

5.4 Monitoring plan

The monitoring team set a follow-up schedule to review the data capture, gather insights and report the follow ups on the teams. Table 5.11 show the focus of the monitoring plans

The team also monitored the creation of documents and the delivery of the templates. This monitoring task requires longer periods of time because it entails the revision of the content as well.


Milestone 01 – 21/07/2016		
	OPPORTUNITY IDENTIFICATION AND ANALYSIS (OIA)	
LIST THE OPPORTUNITIES IDENTIFIED WITH A LITTLE DESCRIPTION		
List the activities, methods, tools, techniques you like most to identify and analyse opportunities		
List the activities, methods, tools, techniques you didn't like to identify and analyse opportunities		
IDEA SELECTION		
Describe the business ideas selected (Include doodles or pictures of discussions)		
Evaluate the quality of the final business idea selected: Evaluate the business ideas selected. This evaluation will let us know how the opportunity analysis worked in this project. Select the statement you consider more appropriate for your opportunity.		
1	Not enough information to make a determination	<input type="checkbox"/>
2	A product or service similar to an existing product/service offered to an underserved market	<input type="checkbox"/>
3	A product or service identical to an existing product/service offered to an underserved market	<input type="checkbox"/>
4	A new application for an existing product/ service, with little/no modification or a minor change to an existing product	<input type="checkbox"/>
5	A significant improvement to an existing product/service	<input checked="" type="checkbox"/>
6	A combination of two or more existing products/services into one unique or new product/ service	<input type="checkbox"/>
7	A new-to-the world product/service, a pure invention or creation.	<input checked="" type="checkbox"/>
Tell us why you have selected that aspect		

Figure 5.15: OIA report template


		IDEA GENERATION					
TEAM MEMBERS		Did you spend time outside the project hours searching for ideas? If you did please state how many hours?					
LIST THE ACTIVITIES, METHODS, TOOLS OR TECHNIQUES USED TO IDENTIFY IDEAS							
#	ACTIVITIES, METHODS, TOOLS OR TECHNIQUES	TIME SPENT IN THE ACTIVITY					
1							
2							
LIST THE IDEAS GENERATED AND EVALUATE THE ORIENTTION OF THE IDEA WHEREAS AS RADICAL OR INCREMENTAL. ALSO STATE THE ORIENTATION YOU CONSIDER HAS THE IDEA.							
#	LIST THE IDEAS IDENTIFIED DURING THE WEEKEND SESSION	OWNER	RADICAL	INCREMENTAL	PRODUCT/TECHNOLOGY ORIENTED	SERVICE ORIENTED	MARKET ORIENTED
1							
2							
LIST THE IDEAS SELECTED FOR YOUR PRESENTATION WITH THE CLIENT							
			Why?				
			Why?				
LIST THE CRITERIA YOU USE TO SELECT THE IDEAS							
LIST THE IDEA(S) APPROVED							
How long did it take for the company to approve the opportunity?					Ej: 15 min		
Thoughts you want to keep from the company: Is there anything the company said that got your attention or interest?							
Final thoughts: (What do you think about this stage of the project as a team or individual) you are free to comment on everything. Gather the inputs from your team members.							

Figure 5.16: IGS report template


		IDEA GENERATION					
TEAM MEMBERS		Did you spend time outside the project hours searching for ideas? If you did please state how many hours?					
LIST THE ACTIVITIES, METHODS, TOOLS OR TECHNIQUES USED TO IDENTIFY IDEAS							
#	ACTIVITIES, METHODS, TOOLS OR TECHNIQUES	TIME SPENT IN THE ACTIVITY					
1							
2							
LIST THE IDEAS GENERATED AND EVALUATE THE ORIENTTION OF THE IDEA WHEREAS AS RADICAL OR INCREMENTAL. ALSO STATE THE ORIENTATION YOU CONSIDER HAS THE IDEA.							
#	LIST THE IDEAS IDENTIFIED DURING THE WEEKEND SESSION	OWNER	RADICAL	INCREMENTAL	PRODUCT/TECHNOLOGY ORIENTED	SERVICE ORIENTED	MARKET ORIENTED
1							
2							
LIST THE IDEAS SELECTED FOR YOUR PRESENTATION WITH THE CLIENT							
			Why?				
			Why?				
LIST THE CRITERIA YOU USE TO SELECT THE IDEAS							
LIST THE IDEA(S) APPROVED							
How long did it take for the company to approve the opportunity?					Ej: 15 min		
Thoughts you want to keep from the company: Is there anything the company said that got your attention or interest?							
Final thoughts: (What do you think about this stage of the project as a team or individual) you are free to comment on everything. Gather the inputs from your team members.							

Figure 5.17: CDA report template

Table 5.10: Training topics

TOPICS
PLM context
Product lifecycle
Product lifecycle definition
PLM benefits
Product development
Information Standards
Naming conventions for documents
PLM software characteristics
Introduction to Aras Innovator
Functionalities: Documents, inbox, activity report, ideas, interviews

The information in the templates is vital for indicator measurement any mistake will change the results. The report of other records in the idea and the interview functions of the TOC were left without revision. The monitoring team expected to see how useful the modules were and if they represent any value for the project.

5.5 FV Results

After the kickoff of the project, the coordination assigned a working space area for each team and a set of tools (books and worksheets) to guide the process. The project had a very tight schedule. The daily routine includes an hour of training on a topic necessary for the project, then the teams proceed to their working areas and interrupt only for breaks and lunch (figure 5.18).

The expert's prepare meetings at least twice a day with their teams to solve doubts, offer guidance and suggest methods or tools for problem-solving. Since every company brief is different, each team required different tools. The monitoring team continuously visits the teams to solve doubts on the PLM software or give reminders about the deliverables, delays or time reports.

In addition to the monitoring Design Activities, there was also a close follow-up to help the participant upload the information to the software. Two advisors were assigned to conduct the support service during the two weeks of the project.

5.5.1 Indicator compatibility

The database of Design Indicators available for the Fuzzy Front End of innovation gathered a total of 42 Design Indicators. The First View project, under the starting conditions of the project schedule could implement 28 Design Indicators, meaning 67% of the available Design Indicators fit the Design

Table 5.11: Monitoring plan

MONITORING ACTIVITY 1: PROJECT ADVANCE REVIEW	
Objective	Monitor the project advance to identify possible delays in project deliverables
Source of the data	PLM project module
Revisions	Once daily
Monitoring tasks	
Access the project module denominated First View Access the project schedule Fill the hour of review and fill the percentage of completion of the project and state whatever it is delayed or not accordingly to the baseline. Take the monitoring time in the template Perform the same procedure once a day	
RESULTS	
Project name	
Date and hour of review	
Project percentage of completion	
Delays	Yes/No
Time spend in the revision of the project	
Observations:	

Activities in the schedule. Figure 5.19 shows the summary of Design Indicators per stage. The Design Indicators covered all stages using over 50 % of the available measurements. The Design Indicators adjusted to the project, despite its nature.

An analysis of the coverage by stages showed that the efforts in the project depend on the time spent on each stage. The opportunity identification and analysis stage demanded most project efforts with 54 % of the project time. The concept definition stage followed with 32 % of spent and the idea generation and selection stage with only 14 percent of the project time. Hence, the opportunity stage requires a close follow-up to avoid delays snowballing in the next stages. The opportunity stage has a wide range of Design Indicators, as did the ideation stage, the weakest follow-up associated with the concept definition stage. The indicator database for this Design Activities can be further enhanced.

All chosen Design Indicators require precise data to ensure consistency in the final measures. Hence, the monitoring team task was to revise not only the upload data, but also the adequacy of the data in the PLM software. The time spent in monitoring task reveals the amount of work for the coordination spent only in controlling the development of the project and the difficulties derived from the manual extraction of Design Indicators. The subsections below will elaborate on the results reported by the monitoring team.



Figure 5.18: FV daily snapshots

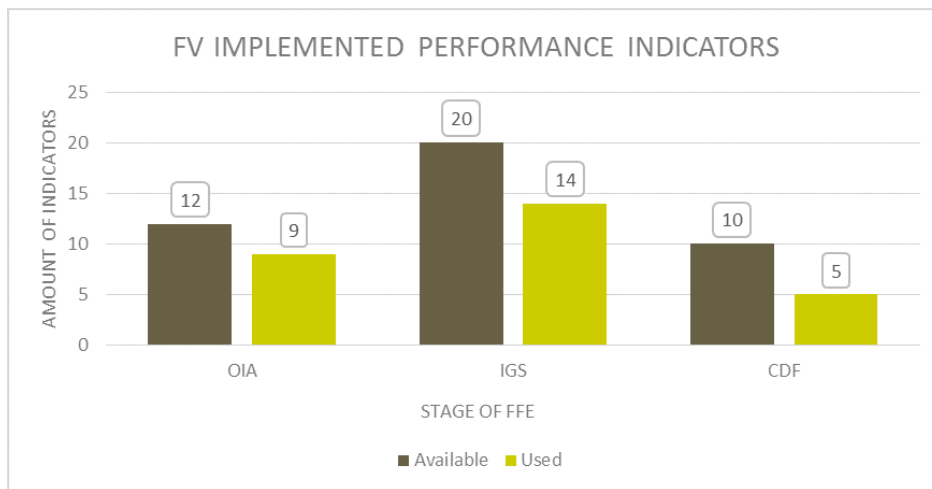


Figure 5.19: FV Implemented Design Indicators

5.5.2 Project monitoring time

The project progress is one of the features to monitor through the PLM software. The time spent in the daily follow up of projects provides information on how much will take the project manager in a

revision of project under its supervision. The follow up in question ensures the frequent revision of the projected percentage of completion. The store records can be further analyzed to detect improvements. The project dashboard in PLM also shows at a glance the state of the phases of the project making use of a color notation in which Red means delayed, Yellow means close to delivery and green means it's currently on development, but with enough time for delivery. The daily project advanced monitoring took an average of 3.9 minutes of revision for all ten projects as shown in figure 5.20.

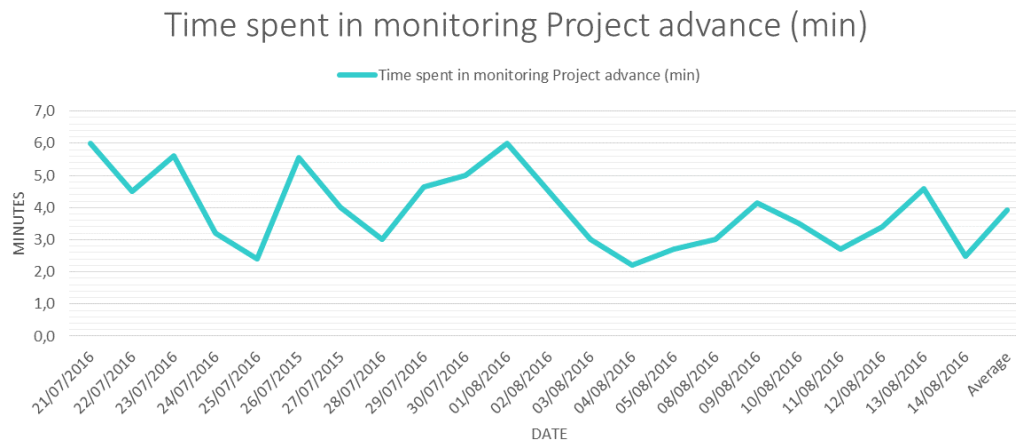


Figure 5.20: FV project monitoring time

If a project is delayed, the project manager can verify its daily progress and take actions such as: find the source of the delay by inspecting the detail of the projects, arrange meetings and execute corrective actions.

On the other side, the PLM software does not keep a visible baseline. Hence, project changes require careful planning. Once a change is introduced in the schedule, the software updates and the new plan cannot be compared to the old plan any longer

In addition to the project monitoring activities, there was also a close follow-up to help the participant upload the information to the software.

5.5.3 Time record monitoring

Time record monitoring: To support the measurement of Design Indicators the First View participants reported the effective hours for each activity (figure 5.21).

The PLM software offers a project report of assigned hours but does not offer the details of the effective time per activity. Extracting this information manually from the software entailed the revision of each project activity. The time spent in the manual assessment is shown in table 5.12.

The project schedule had a total of 17 effective days and an estimate of 104 hours separated in 28 Design Activities. 4,2 % of the total project hours were spent on the revision of the effective hours

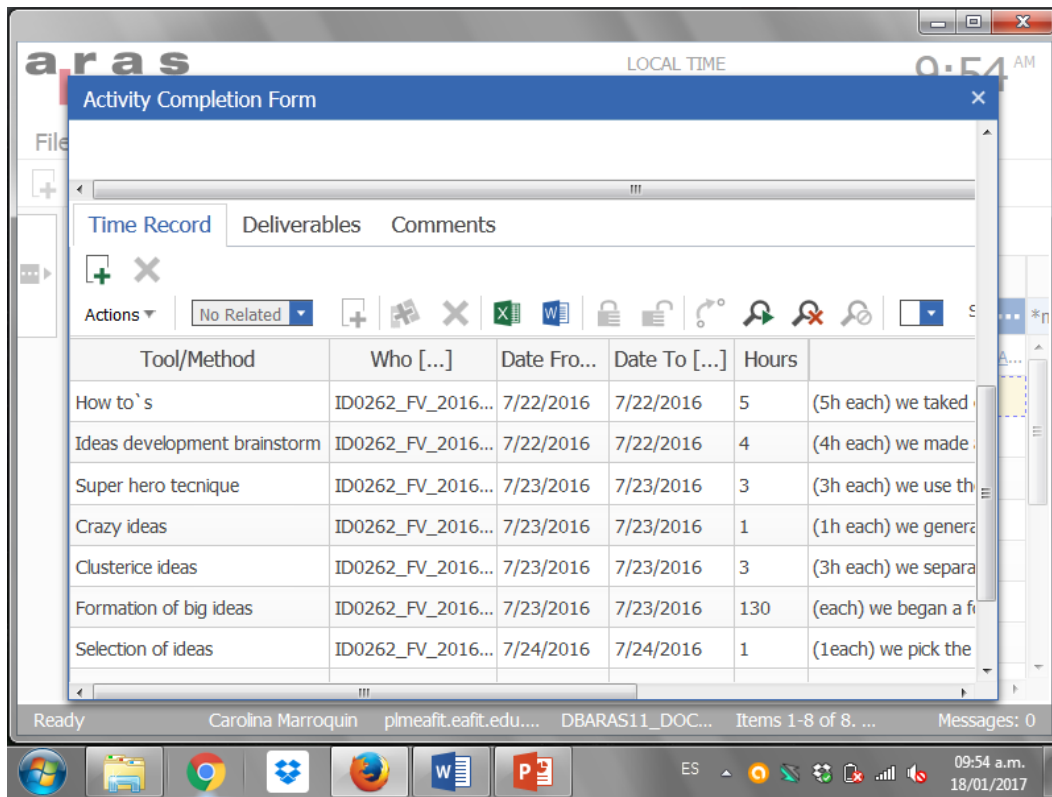


Figure 5.21: FV time record monitoring

Table 5.12: Time record

Monitoring time record	Rev 1	Rev 2	Rev 3	Rev 4	Rev 5	Rev 6	Rev 7	Rev 8	Rev 9	Total Time (min)	Average per revision (min)
Time spent in monitoring Phase time record time OIA	15	20	14	5	3	17	6	4	12	96	10,7
Time spent in monitoring Phase time record time IGS	10	9	35	3	2	30	30			119	17,0
Time spent in monitoring Phase time record time CDF	3	15	17	12						47	11,8
Total time spent in monitoring time record in the FV project										262	13,1
Estimated hours for First view entire project	104										
Total project hours spent only in reviewing time records	4,4										
Percentage of the project spent in reviewing time records	4,2 %										

worked by participants on the project stages. The revision of the time report took an average of 13 minutes. Unlike the project monitoring task this activity does not require a daily follow up, but twice a week assessment. But it demands at least 4 hours of the total project time. The Design Indicators related with this time record are shown in figure 5.22.

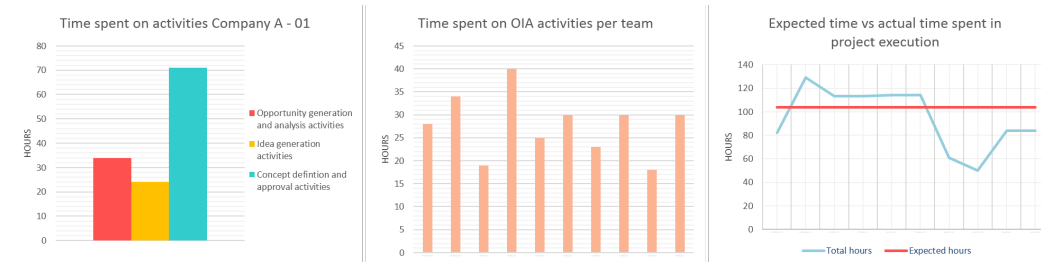


Figure 5.22: FV time record Design Indicators

The worked hours determine the effective time spent in each activity. This information allows the coordination team to plan more accurate schedules for future projects. The Design Indicators can set a baseline to compare values of future projects and establish the value of the activity deliverables, this analysis can lead to the conservation of the activity or its elimination. If the project is successful the hours spent in the Design Activities can give a baseline for other initiatives.

5.5.4 Tools, methods and techniques monitoring

The Design Indicators related to design techniques, tools and methods under deployment provided records on the frequency of usage and the type of methods used in the project. The tools were reported on the same template than the hours as shown in figure 5.23. The idea is to analyze patterns of methods that fit the idea and opportunity generations efforts and optimize the know-how by encouraging the use of the most successful Design Activities. This creates the initial baseline for analysis.

Although the PLM software keeps the record of the used method, the monitoring team still has to carry out a manual countdown and analysis of this tools. Table 5.13 shows the revisions made to the record. Only 1% of the project hours was spent in the extraction of data, an average of 3 minutes per revision. The number of revisions depends on the monitoring team availability.

Six Design Indicators from the repository associate with the data of this monitoring record. Figure 5.24 shows the summary of the methods, tools, and Design Activities used in the first stage of the First View project.

5.5.5 Design Indicators from templates

The templates provide an additional set of Design Indicators, but this require a lot of manual work. However, the information provided is of high value. Therefore, measures such as opportunity quality

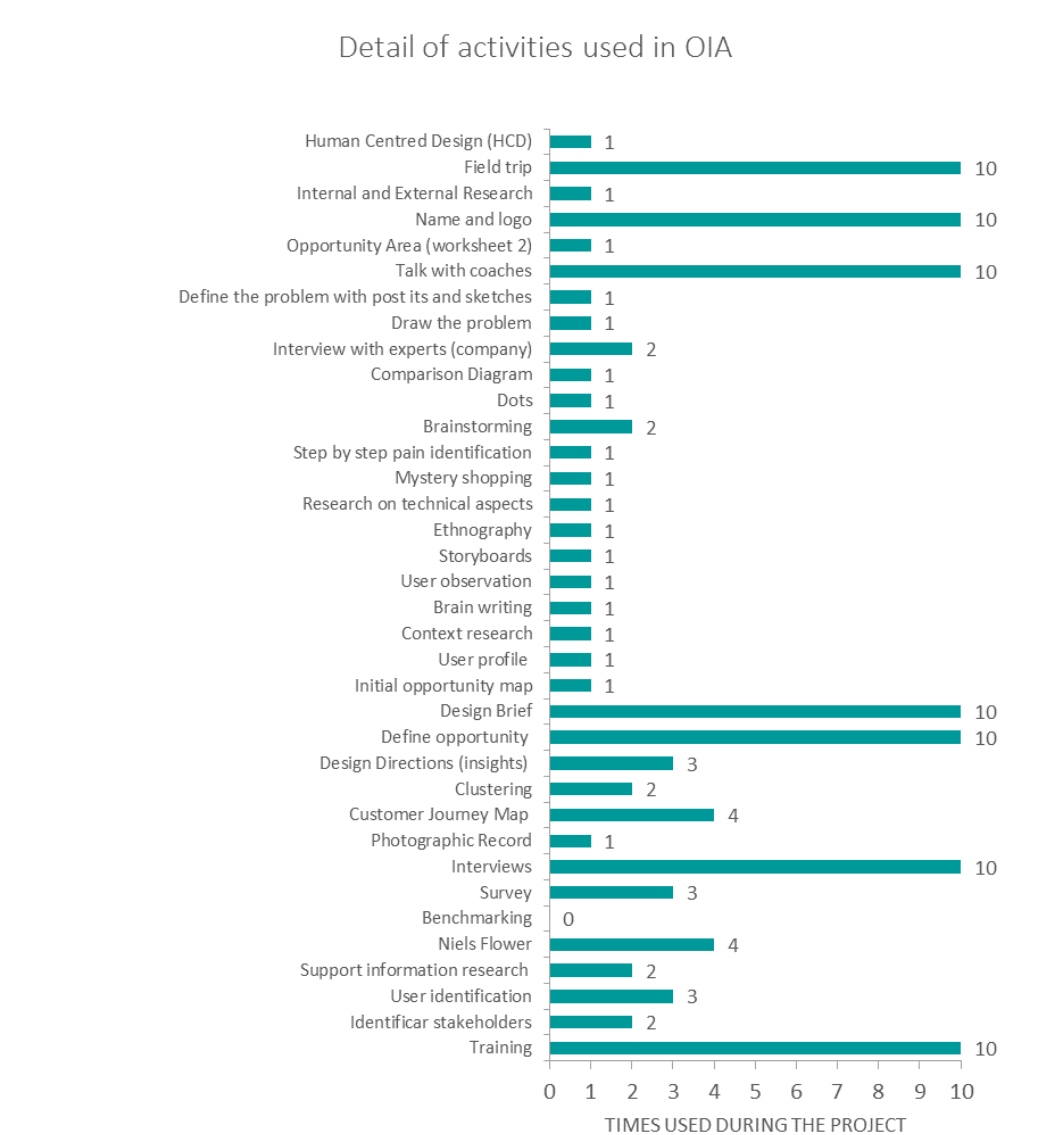


Figure 5.24: FV tools, methods and techniques indicator

and pipeline throughput rate need to be extracted from the templates data because they do not exist inside the PLM as items and properties yet, the PLM software only stores the Microsoft Word file with the information but it cannot retrieve the data. Figure 5.25 shows an example of the Design Indicators retrieved from the templates. The image has been modified to hide the information of the companies due to confidentiality.

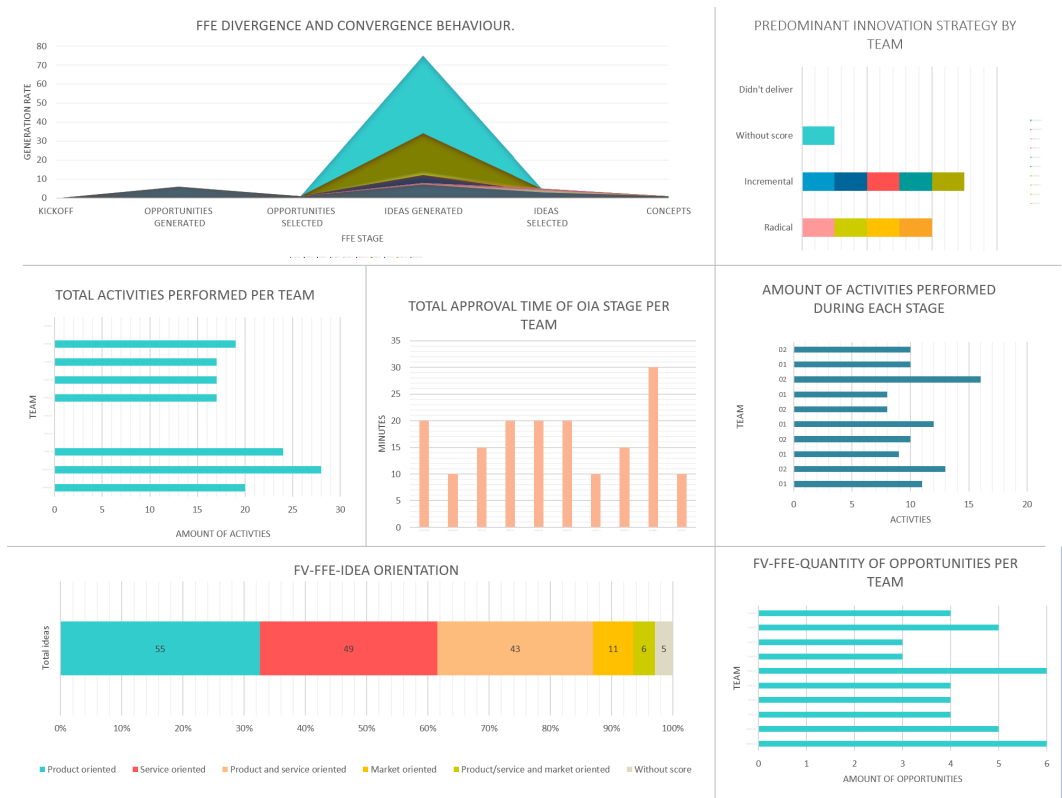


Figure 5.25: FV Design Indicators

From the 24 Design Indicators chosen for the project, 16 are still manual and only 9 are included directly on PLM software and still require manual analysis.

The indicator extraction from templates takes an average of 4,28 minutes per template. Around 2% of the project time was spent on the extraction of these data. The extraction does not include analysis time.

The monitoring team spent a total of 9 hours in monitoring activities, that is to say around 9% of the project assigned hours. The Activities only show the revision and manual extraction of data and not the interpretation and analysis to feed the Design Indicators. The overall monitoring process show the importance of a clear monitoring protocol when manual Design Indicators are developed. The ideal scenario is to have the PLM software analyzing the data and displaying this information in dashboards. However, the time spent in manual extraction and monitoring is also feasible for the

coordination team.

5.5.6 Indicator creation results

Comparing the obtained Design indicators in both AR cycles a rate of production can be calculated using the following equation:

$$I_x = R_x * T_x \quad (5.1)$$

Where:

I_x Is the number of Design Indicators produced

T_x Is the time it takes the creation process

R_x Is the rate in which the process is delivering the indicators

The creation of indicators in the first AR cycle took 158 days (steps 1 to five respectively) and resulted in a final selection of 26 Design Indicators. The FV project took 21 days and resulted in 32 Design Indicators. The throughput rate of the first methodology was the 0,16 indicators per day. Meanwhile the rate for the first view project was 1,52 indicators per day. 134% improvement was achieved in FV Design indicator creation.

5.6 Final PLM module design

The experience gained in the case study provides insights for the direct application of the method in an a PLM module. The module requires the following functionalities

- Creation and storage of the vector information (Design Indicators, Design Activities and Design Best Practices)
- Assignation of the compatibility between vectors
- Creation of reports to visualize the relationships between vectors
- Dashboard design

A design management module was created on the Table Of Contents (TOC) of ARAS innovator (AI) software, to access the creation creation forms for each vector (See subsection 4.5.2). Each creation form brings several fields to fill when entering the vector in the software, such as name, description, author, dimension, management level and the entity in which it operates. In the indicator case, the creation form requires an equation and score field as well, the first is to state in mathematical terms the indicator calculation, the second is to allow the location of the graphic representation for dashboard design (see 5.26).

Figure 5.26: Indicator form

This design management module locates the tool called Keyfit that addresses the relations between vectors in an organized data based. The user creates the application vector and the tool stores each compatible relation for posterior consult (see 5.27).

In addition the key-fit tool has a report service that accelerates the steps of the method. The report allows to pick one of the vectors and it shows the possible matches when selecting one of the vectors (see 5.28) the use of the report accelerates the application of the method, given that it provides insights on how to choose according to the other two vectors loose. For instance if one is choosing an indicator, the report shows which Design Activities relate to it and which Design Best Practices fit.

The definition of the dashboard required a in-depth configuration due to the complexity of the application in the software. The dashboard item type is connected to 6 items for configuration, and uses queries to elicit the data to create the graphical representation of the said data. A query in this case is a line of code in which some of the item attributes are named, related and calculated. The query is design in AML coding language used by AI.

To create the dashboards several tests were made with the following purpose:

- Ensure the availability of the data.
- Understand the language used in the query creation to acquire the data and correlate it.
- Understand the graphic options already available on the software

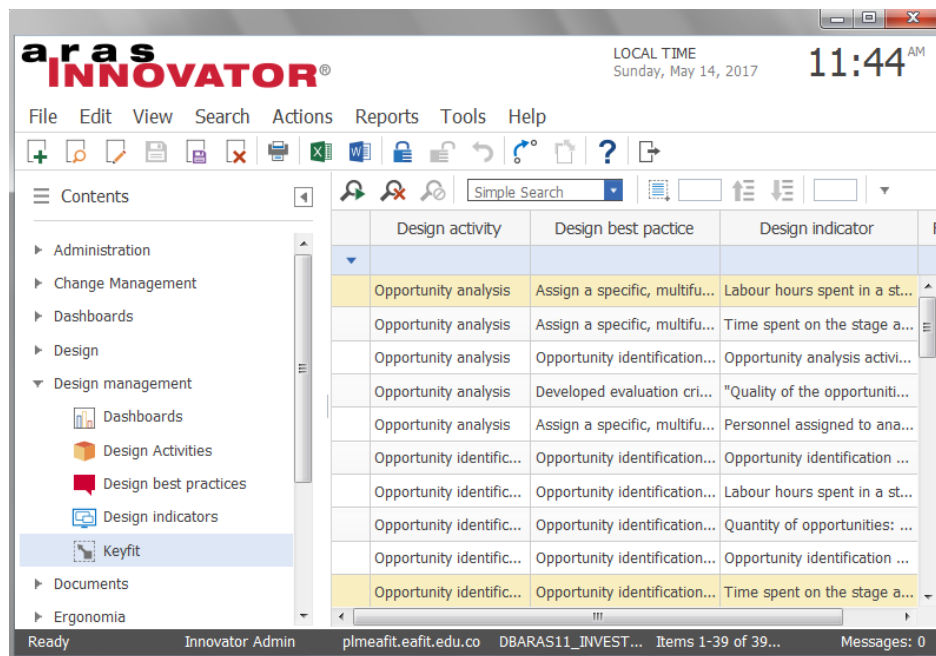


Figure 5.27: Key-fit data base

http://plmeafit.eafit.edu.co - Mozilla Firefox

Keyfit for Opportunity analysis

Design Activity	Design Best Practice	Design Indicator
Opportunity analysis	Assign a specific, multifunctional team whose members work full time to perform the opportunity analysis	Labour hours spent in a stage or phase of a process or project
Opportunity analysis	Assign a specific, multifunctional team whose members work full time to perform the opportunity analysis	Time spent on the stage activities
Opportunity analysis	Opportunity identification is ongoing and can redirect the strategic plan real time to respond to market forces and new	Opportunity analysis activities: Amount of activities performed to analyse opportunities in each project or process
Opportunity analysis	Developed evaluation criteria that help innovators determine if the opportunity is attractive Setting criteria for the c	"Quality of the opportunities 0 Not enough information to make a determination; 1 A product or service identical to an existing product/service offered to an underserved market; 2 A product or service similar to an existing product/service offered to an underserved market; 3 A new application for an existing product/ service, with little/no modification or a minor change to an existing product; 4 A significant improvement to an existing product/service; 5 A combination of two or more existing products/services into one unique or new product/ service; 6 A new-to-the world product/service, a pure invention or creation."

Figure 5.28: Keyfit relationship report

- Understand the graphic format (style-sheet) used to generate graphics
- Create a simple dashboard.

After four test, a dashboard was generated associated to the weekly worked hours and the hours worked by an specific person. The test result is shown in figure 5.29.

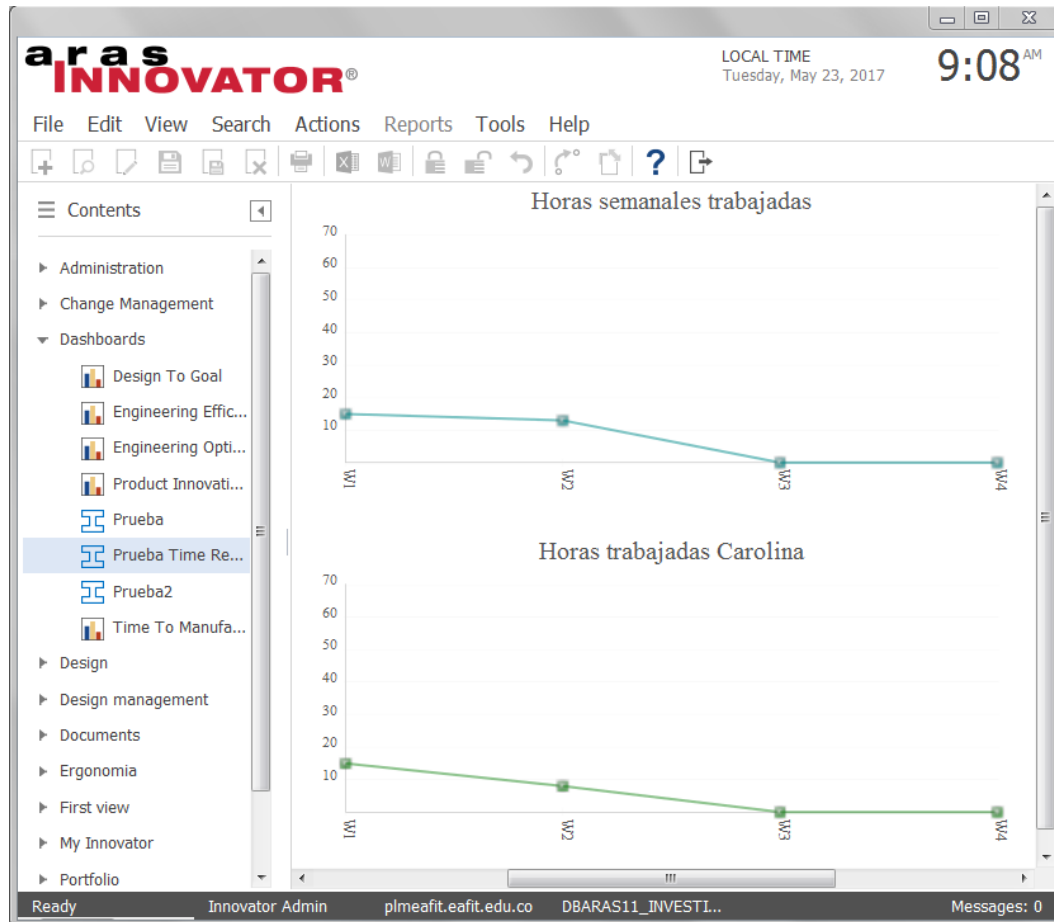


Figure 5.29: Dashboard Graphic in AI

Although a dashboard was successfully created, further exploration of the software requires the connection between the KeyFit tool and the Dashboard to automate its generation. The automation depends on a functionality that allows the scoring of Design Indicators. Such exploration exceeds the scope of the research project.

Chapter 6

Conclusions and future work

6.1 Project conclusions

Regarding the project research objectives:

The literature research and the explorative case reveal insights necessary to create a monitoring method. The literature shows fragmented efforts to measure and monitor design: the search for design indicators resulted on 64 results, 59% of the results focus on a particular indicator or a set of indicators covering one topic. The proposed method centralizes Design indicator information, providing 212 indicators from 9 re-known studies and categorize in 9 dimensions to facilitate their selection.

The method divides into three paths to create versatility for the design manager in term of availability of starting points for implementation. Other methodologies (such as BSC (Kaplan and Norton, 1996) or indicator creation by Beltran (1999)), use a lineal process for creation of Design Indicators with a single starting point. The method triad gives 2 more options to adapt the method to the needs of the design manager without overtaking a lineal process that focuses only in one of the three vectors. The triad approach adds options and depth to the design management decisions by relating three main dimensions (vectors) immerse in monitoring and decision making.

The configuration creates a causality between Design Activities, Design Indicators and Design Best Practices to suggest an overview of a strategy. Causal logic paths allow to associate Design Activities, Design Indicators and Design Best Practices vectors. However, it is difficult to establish their direct relations without the division into attributes and properties that provide depth to those vectors and determine their connection points. Four attributes were selected to create the correlations between vectors.

The AR cycle 1 case proved to be fundamental to find insights (11 in total) to construct a monitoring method. The observation of this case revealed information about the difficulties of designers

to monitor a project and the sources of relevant information and selection criteria for monitoring strategies, in this case, the three vectors that build the method and their attributes. The method tackle successfully all insights.

The second action research cycle revealed the efficiency of the method regarding the time of application, information identification and Design Indicator creation and selection on Design Activities, Design Indicators, and Design Best Practices.

- Time of implementation : The first case took over five months to address only the creation of Design Indicators, whereas in the second case the time spent on the identification and selection of Design Indicators was less than three weeks. The method shows a satisfactory distribution of the time spent in monitoring. Only 9% percent of the FV project time was used for monitoring Design Activities, allowing the design manager to spent time in other tasks.
- Information identification: The method narrowed the information options for decision making according to needs of the FV project. The project reported 181 documents created, but the tools to capture and extract essential data reduced the document usage for monitoring to only 23 documents, narrowing the information analysis in 87,29%.
- The creation of indicators: The first AR cycle took 158 days for Design Indicator creation and resulted in a final selection of 26 Design Indicators. The FV project took 21 days and resulted in 32 Design Indicators. The rate of production of the first methodology was the 0,16 indicators per day. Meanwhile the rate for the first view project was 0,65 indicators per day. The 49% improvement was achieved in FV Design indicator.

Decision making is supported through the accelerated rate of implementation of the monitoring strategy from 5 moths from the first case to the month spent in case two, which shows an improvement rate in time usage of 80% and the identification of information essential to asses the state of design. For further research two new validation cases should be performed. The method works to suggest a starting point for an adviser or design manager who wants to implement a new approach to design management and a monitoring strategy that can be further refined. It also shows some guidance on the direction in which the current design activity is going, by linking the Design Best Practices as strategies impacted in the middle and long term.

The best practice approach is more abstract in the sense that it can shift the current design process to pursue a completely different set of goals. Therefore, it requires further exploration and reflection, whereas the activity approach is more inclined to immediate implementation.

Several restrictions in the research should be addressed. First, due to the time constraints and resource availability, the explorative case of the method (AR cycle 1) was executed by junior design

managers. The perceptions of more mature and experienced design managers are still absent from the method.

Second, the repository was developed with Design Activities, Design Indicators and Design Best Practices that work in international industries and academics. A local view of design activity is still needed and could influence the direction of the monitoring strategies resulting from the method.

Third, the Design Activities, Design Best Practices and Design Indicators work differently in relation to the context of application. Therefore, the method suggest possible monitoring strategies but is the design manager who finally chooses the strategy to follow taking into the decisions their experience and circumstances.

Fourth, the Action Research approach, relies on qualitative exploration and validation in which the researcher plays an important role and is direct participant of the developments. Other approaches may offer a more detached and objective perspective to evaluate the correlations of the vectors and their application in the method.

The repository requires a continuous update with literature based Design Indicators, Design Activities and Design Best Practices integrated with lessons learned and inclusions made by companies. A blog ¹ would be started after the delivery of the project to share the repository of the method.

6.2 Future work

The analysis of the results gathered from the monitoring strategy in the FV project required a lot of manual work. Dashboard applications and information management tools are necessary to reduce such time with automated data analysis and display. In addition, the comparison of the Design Indicators became difficult due to the lack of historical data to provide a reference value, the method should suggest an approach in such cases in which experts in the project provide a marginal expected value to compare, with time the indicator could be proved against historical data.

The implementation of the method in a PLM software was difficult due to the intensive nature of the FV project. The application of the method and the configuration of the software were made in parallel, therefore, the PLM software only worked to capture, store and share the data necessary to gather the information linked to the results of the project. The method was not completely integrated into the software, dashboard displays are still necessary to achieve full PLM support

The deployment of the method in PLM requires IT experts and design managers working together to achieve a top solution in terms of method programming, information capturing and display. The design managers know where the inputs of information are and their relevance and those are configured by the IT expert to fill the method requirements in PLM.

¹keyfitgrid.wordpress.com

Further research is needed to extract Design Indicators, Design Best Practices and Design Activities used in local design based industries to expand the repository. An explorative case study is necessary to understand the needs of mature R&D departments, with senior designers to enrich the method and the selection strategies.

Excel sheets prove to storage and correlate information, but the method requires a more visual approach to meet designers and managers learning and communication needs, research on the visualization of information for designers and managers could be explored in secondary projects in the subject, tangible aids, such as cards and manuals could be developed as well with a light version of the method, to implement in an environment without PLM support.

The method provides information that after several uses could be integrated with a diagnosis tool for decision making, given that the information gathered by the method works as an input to analyze the design activity in the long term.

The First View project used the activity path of the method to create the monitoring strategy. However, further application in validation cases is required to test the other two paths of the method.

The repository doesn't always find relations between all vectors, some Design Best Practices stand alone which means further enrichment is needed. The properties used for correlations could also be enhanced as the compendium grows.

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Appendix A

Design Activity (Ai) Repository

The size of the Design Activity repository is too wide to put on the appendices. Hence, only a few pages are presented below.

The screenshot shows the Aras Innovator software interface. At the top, it displays 'LOCAL TIME Wednesday, May 24, 2017 7:37 AM'. Below the title bar, there is a menu bar with 'File', 'Edit', 'View', 'Search', and 'Actions'. A toolbar contains various icons for file operations and navigation. A search bar with the text 'Simple Search' is visible. The main content area displays a table with the following columns: 'Best Practice Name', 'Dimension', and 'Entity'. The table contains several rows of data, including:

Best Practice Name	Dimension	Entity
Complete focus on customer value	Strategy	Consumer
A special focus on enhancing divergent thinki...	Projects	Idea
Involvement of the customer even before pro...	Projects	Consumer
Predefined and transparent criteria for select...	Projects	Idea
A formal role for someone to coordinate ideas ...	People	Idea
Camping Out with Your Customers	Projects	Consumer
Success of this FEIP model depends on many ...	Projects	Idea
Idea selection based on rules	Projects	Idea

Bi	Stage	Authors	Best practice	Dimension	Entity	Operation
1	FFE	Abba Griffin. PGMA research on new product development practices: updating trends and benchmarking best practices. 1997	Not skipping steps in the FFE process	Process, programmes and procedures (process planning) / Project	Process	Follow-up
2	NPD	Abba Griffin. PGMA research on new product development practices: updating trends and benchmarking best practices. 1997	Using a formal NPD process and not skipping steps	Strategy	Process	Execution
3	NPD	Abba Griffin. PGMA research on new product development practices: updating trends and benchmarking best practices. 1997	Using a formal NPD process	Strategy	Process	Planning
4	FFE	Cooper, R. Scott, E and Kleinichmidt, R., Benchmarking best NPD practices in 2004. Abba Griffin. PGMA research on new product development practices: updating trends and benchmarking best practices. 1997	Using a formal FFE process	Strategy	Process	Planning
5	DM	Abba Griffin. PGMA research on new product development practices: updating trends and benchmarking best practices. 1997	NPD strategy at program level	Policy	Programme	Definition
6	FFE	Abba Griffin. PGMA research on new product development practices: updating trends and benchmarking best practices. 1997	Improvements in simultaneous aspects of FFE	Process, programmes and procedures (process planning) / Project	Process	Improvement
7	NPD	Abba Griffin. PGMA research on new product development practices: updating trends and benchmarking best practices. 1997	Improvements in simultaneous aspects of NPD	Process, programmes and procedures (process planning) / Project	Process	Improvement
8	DM - NPD	Abba Griffin. PGMA research on new product development practices: updating trends and benchmarking best practices. 1997	Measuring the outcomes of product development	Process, programmes and procedures (process planning) / Project	Outcome	Measurement
9	DM - FFE	Abba Griffin. PGMA research on new product development practices: updating trends and benchmarking best practices. 1997	Rewarding FFE personnel	Rewards and evaluation	Personnel	Rewards
10	NPD	Abba Griffin. PGMA research on new product development practices: updating trends and benchmarking best practices. 1997	Performance against objectives	Rewards and evaluation	Objective	Evaluation
11	NPD	Abba Griffin. PGMA research on new product development practices: updating trends and benchmarking best practices. 1997	Rewarding NPD personnel	Rewards and evaluation	Personnel	Rewards
12	FFE - NPD	Abba Griffin. PGMA research on new product development practices: updating trends and benchmarking best practices. 1997	Set expectation for future NPD performance	Strategy	Process	Measurement

Ai	Stage	Author	Phases/Stages	Activities	Entity	Operation	Main Dimension
1	FFE	*FFE (Fuzzy Front End) PDMA p21. Kenneth B. Kahn. 2012	NA	Initial idea screening	Idea	Screening	Process, programmes and procedures (process planning)/project
2	FFE	FFE (Fuzzy Front End) Effective Methods, Tools, and Techniques. Peter A. Koen, 2003	NA	Idea generation and enrichment	Idea	Generation	Process, programmes and procedures (process planning)/project
3	FFE	Predevelopment activities determine product success. R. Cooper. 1988	Preliminary assessment	Preliminary technical assessment	Technical	Assessment, evaluation	Process, programmes and procedures (process planning)/project
4	FFE	Predevelopment activities determine product success. R. Cooper. 1988	Preliminary assessment	Preliminary market assessment	Market	Assessment, evaluation	Process, programmes and procedures (process planning)/project
5	FFE	Predevelopment activities determine product success. R. Cooper. 1988	Preliminary assessment	Preliminary evaluation	Idea	Assessment, evaluation	Process, programmes and procedures (process planning)/project
6	FFE	Predevelopment activities determine product success. R. Cooper. 1988	Concept	Concept identification	Concept, solution	Identification	Process, programmes and procedures (process planning)/project
7	FFE	Predevelopment activities determine product success. R. Cooper. 1988	Concept	Concept generation	Concept, solution	Generation	Process, programmes and procedures (process planning)/project
8	FFE	Predevelopment activities determine product success. R. Cooper. 1988	Concept	Concept test market study	Concept, solution	Test Market	Process, programmes and procedures (process planning)/project
9	FFE	Predevelopment activities determine product success. R. Cooper. 1988	Concept	Concept evaluation	Concept, solution	Assessment, evaluation	Process, programmes and procedures (process planning)/project
10	FFE	The delft innovation method. Circular Chaos. Jan Buijs. 2012	Strategic situation of the company	Internal analysis	Internal	Self assessment	Process, programmes and procedures (process planning)/project
11	FFE	The delft innovation method. Circular Chaos. Jan Buijs. 2012	Strategic situation of the company	External analysis	Context	Analysis	Process, programmes and procedures (process planning)/project
12	FFE	The delft innovation method. Circular Chaos. Jan Buijs. 2012	Strategic situation of the company	Search area generation	Opportunity	Generation	Process, programmes and procedures (process planning)/project

13	FFE	FFE (Fuzzy Front End) Effective Methods, Tools, and Techniques, Peter A.Koen, 2004	NA	Idea generation and enrichment	Idea	Enrichment	Process, programmes and procedures (process planning)/project
14	FFE	The deflt innovation method. Circular Chaos. Jan Buijs, 2012	Strategic situation of the company	Stage evaluation	Stage, gate	Assessment, evaluation	Process, programmes and procedures (process planning)/project
15	FFE	The deflt innovation method. Circular Chaos. Jan Buijs, 2012	Search area	Internal analysis of bottle necks	Bottle-neck	Analysis	Process, programmes and procedures (process planning)/project
16	FFE	The deflt innovation method. Circular Chaos. Jan Buijs, 2012	Search area	External needs analysis	Needs	Analysis	Process, programmes and procedures (process planning)/project
17	FFE	The deflt innovation method. Circular Chaos. Jan Buijs, 2012	Search area	Generating product ideas	Idea	Generation	Process, programmes and procedures (process planning)/project
18	FFE	The deflt innovation method. Circular Chaos. Jan Buijs, 2012	Search area	Stage evaluation	Stage, gate	Assessment, evaluation	Process, programmes and procedures (process planning)/project
19	NPD	The deflt innovation method. Circular Chaos. Jan Buijs, 2012	Design Brief	Technology development	Technology	Development	Process, programmes and procedures (process planning)/project
20	NPD	The deflt innovation method. Circular Chaos. Jan Buijs, 2012	Design Brief	Product development	Product	Development	Process, programmes and procedures (process planning)/project
21	NPD	The deflt innovation method. Circular Chaos. Jan Buijs, 2012	Design Brief	Market development	Market	Development	Process, programmes and procedures (process planning)/project
22	NPD	The deflt innovation method. Circular Chaos. Jan Buijs, 2012	Design Brief	Stage evaluation	Stage, gate	Evaluation	Process, programmes and procedures (process planning)/project
23	NPD	The deflt innovation method. Circular Chaos. Jan Buijs, 2012	Product Design	Manufacturing	Product	Manufacturing	Process, programmes and procedures (process planning)/project
24	FFE	FFE (fuzzy Front End) Effective Methods, Tools, and Techniques, Peter A.Koen, 2005	NA	Idea selection	Idea	Selection	Process, programmes and procedures (process planning)/project
25	NPD	The deflt innovation method. Circular Chaos. Jan Buijs, 2012	Product Design	Market introduction	Market	Introduction	Process, programmes and procedures (process planning)/project

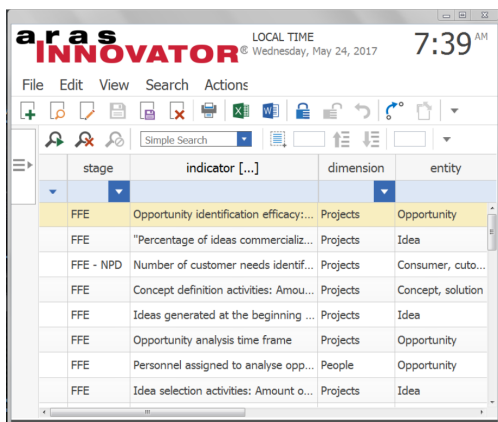
26	NPD	The deflt innovation method. Circular Chaos. Jan Buijs. 2012	Product Design	Distribution	Product	Distribution	Process, programmes and procedures (process planning)/project
27	NPD	The deflt innovation method. Circular Chaos. Jan Buijs. 2012	Product Design	Promotion	Product	Promotion	Process, programmes and procedures (process planning)/project
28	NPD	The deflt innovation method. Circular Chaos. Jan Buijs. 2012	Product Design	Sales	Product	Sales	Process, programmes and procedures (process planning)/project
29	NPD	The deflt innovation method. Circular Chaos. Jan Buijs. 2012	Product Design	Stage evaluation	Stage, gate	Evaluation	Process, programmes and procedures (process planning)/project
30	NPD	The deflt innovation method. Circular Chaos. Jan Buijs. 2012	Product Launch	Evaluation of product	Product	Evaluation	Process, programmes and procedures (process planning)/project
31	NPD	The deflt innovation method. Circular Chaos. Jan Buijs. 2012	Product Launch	Product use	Product	Use	Process, programmes and procedures (process planning)/project
32	NPD	The deflt innovation method. Circular Chaos. Jan Buijs. 2012	Product Launch	Evaluation of product use	Product	Evaluation	Process, programmes and procedures (process planning)/project
33	DM	The deflt innovation method. Circular Chaos. Jan Buijs. 2012	Product Launch	Stage evaluation	Stage, gate	Evaluation	Process, programmes and procedures (process planning)/project
34	FFE - NPD	New product development process after Steven D. Eppinger and Karl T. Ulrich. 1995	Concept development	Identify costumer needs	Needs	Identification	Process, programmes and procedures (process planning)/project
35	FFE	FFE (Fuzzy Front End) Effective Methods, Tools, and Techniques. Peter A.Koen, 2006	NA	Concept definition	Concept, solution	Definition	Process, programmes and procedures (process planning)/project
36	FFE - NPD	New product development process after Steven D. Eppinger and Karl T. Ulrich. 1995	Concept development	Identify leader customers	Consumer, user, customer	Identification	Process, programmes and procedures (process planning)/project
37	FFE - NPD	New product development process after Steven D. Eppinger and Karl T. Ulrich. 1995	Concept development	Identify competition products	Competition	Identification	Process, programmes and procedures (process planning)/project
38	NPD	New product development process after Steven D. Eppinger and Karl T. Ulrich. 1995	Concept development	Establish product design specifications	Specification, requirement	Establishment	Process, programmes and procedures (process planning)/project

39	NPD	New product development process after Steven D. Eppinger and Karl T. Ulrich. 1995	Concept development	Concept generation	Concept, solution	Generation	Process, programmes and procedures (process planning)/project
40	NPD	New product development process after Steven D. Eppinger and Karl T. Ulrich. 1995	Concept development	Concept selection	Concept, solution	Selection	Process, programmes and procedures (process planning)/project
41	NPD	New product development process after Steven D. Eppinger and Karl T. Ulrich. 1995	Concept development	Concept testing	Concept, solution	Testing	Process, programmes and procedures (process planning)/project
42	NPD	New product development process after Steven D. Eppinger and Karl T. Ulrich. 1995	Concept development	Establish final product design specifications	Specification, requirement	Establishment	Process, programmes and procedures (process planning)/project
43	NPD	New product development process after Steven D. Eppinger and Karl T. Ulrich. 1995	Concept development	Planning development	Concept, solution	Planning	Process, programmes and procedures (process planning)/project
44	NPD	New product development process after Steven D. Eppinger and Karl T. Ulrich. 1995	Concept development	Calculate manufacturing cost	Manufacture	Costing	Process, programmes and procedures (process planning)/project
45	NPD	New product development process after Steven D. Eppinger and Karl T. Ulrich. 1995	Concept development	Production feasibility analysis	Production	Analysis	Process, programmes and procedures (process planning)/project
46	FFE	FFE (Fuzzy Front End). Towards holistic "front ends" in new product development. A. Khurana. 1998	Pre-phase zero	Preliminary Opportunity Identification	Opportunity	Identification	Process, programmes and procedures (process planning)/project
47	NPD	New product development process after Steven D. Eppinger and Karl T. Ulrich. 1995	System design	Develop plans for extended product family	Portfolio	Definition	Process, programmes and procedures (process planning)/project
48	NPD	New product development process after Steven D. Eppinger and Karl T. Ulrich. 1995	System design	Fix selling price	Price	Definition	Process, programmes and procedures (process planning)/project
49	NPD	New product development process after Steven D. Eppinger and Karl T. Ulrich. 1995	System design	Define product architecture	Architecture	Definition	Process, programmes and procedures (process planning)/project
50	NPD	New product development process after Steven D. Eppinger and Karl T. Ulrich. 1995	System design	Identify supplier of primary components	Supplier	Identification	Process, programmes and procedures (process planning)/project
51	NPD	New product development process after Steven D. Eppinger and Karl T. Ulrich. 1995	System design	Acquisition analysis	Acquisition	Analysis	Process, programmes and procedures (process planning)/project

Appendix B

Design Indicator (Ki) Repository

The size of the Design Indicator repository is too wide to put on the appendices. Hence, only a few pages are presented below.



Ki	Stage	Author	Metrics	Dimension	Entity	Operation
1	FFE	FFE (Fuzzy Front End) Effective Methods, Tools, and Techniques. Peter A. Koen,	Opportunity analysis time frame	Process, Programmes and procedures (process planning) / Project	Opportunity	Analysis
2	NPD	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dolobczenski, Mauricio Moreira e Silva Bernardes. 2013	Project cost Product cost (%)	Investment and finance	Cost	Assessment
3	DM	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dolobczenski, Mauricio Moreira e Silva Bernardes. 2013	Increased sales through new products (%)	Investment and finance	Sales	Evaluation
4	DM - FFE - NPD	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dolobczenski, Mauricio Moreira e Silva Bernardes. 2013	Savings generated by project changes	Investment and finance	change	Assessment

Ki	Stage	Author	Metrics	Dimension	Entity	Operation	Primary Management level	Secondary Management level
1	FFE	FFE (Fuzzy Front End) Effective Methods, Tools, and Techniques. Peter A. Koen,	Opportunity analysis time frame	Process, Programmes and procedures (process planning) / Project	Opportunity	Analysis	T	O
2	NPD	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dziobczenski, Mauricio Moreira e Silva Bernardes, 2013	Project cost Product cost (%)	Investment and finance	Cost	Assessment	S	T
3	DM	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dziobczenski, Mauricio Moreira e Silva Bernardes, 2013	Increased sales through new products (%)	Investment and finance	Sales	Evaluation	S	T
4	DM - FFE - NPD	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dziobczenski, Mauricio Moreira e Silva Bernardes, 2015	Savings generated by project changes	Investment and finance	Change	Assessment	S	T

5	DM	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dziobczenski, Mauricio Moreira e Silva Bernardes.2016	Investment in research and development (R\$)	Investment and finance	Research	Investment	S	T
6	DM	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dziobczenski, Mauricio Moreira e Silva Bernardes.2017	Profitability of new products in comparison to existing products (%)	Investment and finance	Profit	Evaluation	S	T
7	DM	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dziobczenski, Mauricio Moreira e Silva Bernardes.2018	Profitability per customer (R\$)	Investment and finance	Profit	Evaluation	S	T
8	DM	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dziobczenski, Mauricio Moreira e Silva Bernardes.2020	Profit obtained from new products (R\$)	Investment and finance	Profit	Evaluation	S	T
9	DM	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dziobczenski, Mauricio Moreira e Silva Bernardes.2021	Relationship between investment in research and sales (%)	Investment and finance	Research	Investment	S	T

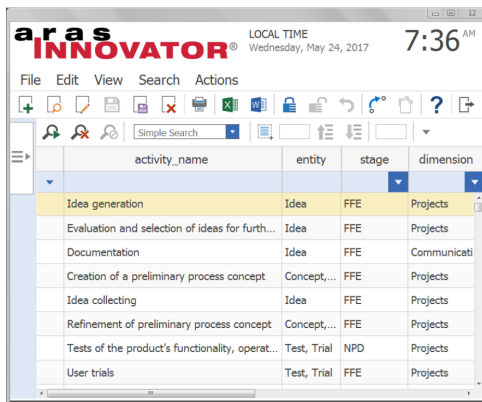
10	DM	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dziobczenski, Mauricio Moreira e Silva Bernardes.2022	Relationship between sales of new products and sales of existing products (%)	Investment and finance	Sales	Evaluation	S	T
11	DM	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dziobczenski, Mauricio Moreira e Silva Bernardes.2024	Value of company stock at the stock exchange (R\$)	Investment and finance	Stock	Assessment	S	T
12	DM	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dziobczenski, Mauricio Moreira e Silva Bernardes.2025	Actual sales X Forecasted sales(%)	Investment and finance	Sales	Evaluation	T	O
13	NPD	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dziobczenski, Mauricio Moreira e Silva Bernardes.2026	Number of positive comments (#)	Process, Programmes and procedures (process planning) / Project	Comments	Assessment	T	O
14	NPD	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dziobczenski, Mauricio Moreira e Silva Bernardes.2027	Number of new customers (#) □ Number of complaints (#)	Process, Programmes and procedures (process planning) / Project	Consumer, customer, user	Assessment	T	S

15	NPD	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dziobczenski, Mauricio Moreira e Silva Bernardes.2028	Number of new customers (#) □ Number of complaints (#)	Process, Programmes and procedures (process planning) / Project	Complains	Capture	T	O
16	DM	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dziobczenski, Mauricio Moreira e Silva Bernardes.2029	Market share (%)	Strategy	Market	Assessment	S	T
17	DM - NPD	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dziobczenski, Mauricio Moreira e Silva Bernardes.2030	Consumer satisfaction with products (%)	Process, Programmes and procedures (process planning) / Project	Consumer, customer, user	Evaluation	S	T
18	DM	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dziobczenski, Mauricio Moreira e Silva Bernardes.2031	Reputation among customers (qualitative)	Strategy	Consumer, customer, user	Assessment	S	T
19	NPD	Guidelines for the proposal of a system of design management indicators in product development companies. Paulo Roberto Nicoletti Dziobczenski, Mauricio Moreira e Silva Bernardes.2032	Customer retention (%)	Process, Programmes and procedures (process planning) / Project	Consumer, customer, user	Evaluation	T	S

Appendix C

Design Best Practice (Bi) Repository

The size of the Best practice repository is too wide to put on the appendices. Hence, only a few pages are presented below.



id	Stage	Author	Phases/Stages	Activities	Entity	Operation	Main Dimension
1	FFE	*FFE (Fuzzy Front End) POMM p21. Kenneth B. Kahn. 2012	NA	Initial idea screening	Idea	Screening	Process, programmes and procedures (process planning)/project
2	FFE	FFE (Fuzzy Front End) Effective Methods, Tools, and Techniques. Peter A. Koen, 2003	NA	Idea generation and enrichment	Idea	Generation	Process, programmes and procedures (process planning)/project
3	FFE	Predevelopment activities determine product success. R. Cooper. 1988	Preliminary assessment	Preliminary technical assessment	Technical	Assessment, evaluation	Process, programmes and procedures (process planning)/project
4	FFE	Predevelopment activities determine product success. R. Cooper. 1988	Preliminary assessment	Preliminary market assessment	Market	Assessment, evaluation	Process, programmes and procedures (process planning)/project
5	FFE	Predevelopment activities determine product success. R. Cooper. 1988	Preliminary assessment	Preliminary evaluation	Idea	Assessment, evaluation	Process, programmes and procedures (process planning)/project
6	FFE	Predevelopment activities determine product success. R. Cooper. 1988	Concept	Concept identification	Concept, solution	Identification	Process, programmes and procedures (process planning)/project
7	FFE	Predevelopment activities determine product success. R. Cooper. 1988	Concept	Concept generation	Concept, solution	Generation	Process, programmes and procedures (process planning)/project
8	FFE	Predevelopment activities determine product success. R. Cooper. 1988	Concept	Concept test market study	Concept, solution	Test Market	Process, programmes and procedures (process planning)/project
9	FFE	Predevelopment activities determine product success. R. Cooper. 1988	Concept	Concept evaluation	Concept, solution	Assessment, evaluation	Process, programmes and procedures (process planning)/project
10	FFE	The delta innovation method. Circular Chaos. Jan Buijs. 2012	Strategic situation of the company	Internal analysis	Internal	Self assessment	Process, programmes and procedures (process planning)/project
11	FFE	The delta innovation method. Circular Chaos. Jan Buijs. 2012	Strategic situation of the company	External analysis	Context	Analysis	Process, programmes and procedures (process planning)/project
12	FFE	The delta innovation method. Circular Chaos. Jan Buijs. 2012	Strategic situation of the company	Search area generation	Opportunity	Generation	Process, programmes and procedures (process planning)/project

Bi	Stage	Authors	Best practice	Dimension	Entity	Operation
1	FFE	Abbie Griffin, PDMA research on new product development practices: updating trends and benchmarking best practices. 1997	Not skipping steps in the FFE process	Process, programmes and procedures (process planning) / Project	Process	Follow-up
2	NPD	Abbie Griffin, PDMA research on new product development practices: updating trends and benchmarking best practices. 1997	Using a formal NPD process and not skipping steps	Strategy	Process	Execution
3	NPD	Abbie Griffin, PDMA research on new product development practices: updating trends and benchmarking best practices. 1997. Cooper, R. Scott, E and Kleinschmidt, R., Benchmarking best NPD practices-III. 2004	Using a formal NPD process	Strategy	Process	Planning
4	FFE	Abbie Griffin, PDMA research on new product development practices: updating trends and benchmarking best practices. 1997. Cooper, R. Scott, E and Kleinschmidt, R., Benchmarking best NPD practices-III. 2004	Using a formal FFE process	Strategy	Process	Planning
5	DM	Abbie Griffin, PDMA research on new product development practices: updating trends and benchmarking best practices. 1998	NPD strategy at program level	Policy	Programme	Definition
6	FFE	Abbie Griffin, PDMA research on new product development practices: updating trends and benchmarking best practices. 1999	Improvements in simultaneous aspects of FFE	Process, programmes and procedures (process planning) / Project	Process	Improvement
7	NPD	Abbie Griffin, PDMA research on new product development practices: updating trends and benchmarking best practices. 1999	Improvements in simultaneous aspects of NPD	Process, programmes and procedures (process planning) / Project	Process	Improvement
8	DM - NPD	Abbie Griffin, PDMA research on new product development practices: updating trends and benchmarking best practices. 1999	Measuring the outcomes of product development	Process, programmes and procedures (process planning) / Project	Outcome	Measurement
9	DM - FFE	Abbie Griffin, PDMA research on new product development practices: updating trends and benchmarking best practices. 1999	Rewarding FFE personnel	Rewards and evaluation	Personnel	Rewards
10	NPD	Abbie Griffin, PDMA research on new product development practices: updating trends and benchmarking best practices. 1999	Performance against objectives	Rewards and evaluation	Objective	Evaluation
11	NPD	Abbie Griffin, PDMA research on new product development practices: updating trends and benchmarking best practices. 1999	Rewarding NPD personnel	Rewards and evaluation	Personnel	Rewards
12	FFE - NPD	Abbie Griffin, PDMA research on new product development practices: updating trends and benchmarking best practices. 1999	Set expectation for future NPD performance	Strategy	Process	Measurement

13	DM	Abbie Griffin, PDMA research on new product development practices: updating trends and benchmarking best practices. 1999.	Create a Leadership mechanism	People, structures, culture and climate	Leader	Appointment
14	NPD	Abbie Griffin, PDMA research on new product development practices: updating trends and benchmarking best practices. 1999.	Set revenue targets	Strategy	Goal	Assignment
15	FFE - NPD	Abbie Griffin, PDMA research on new product development practices: updating trends and benchmarking best practices. 1999.	Leadership appointment	People, structures, culture and climate	Leader	Appointment
16	FFE - NPD	Abbie Griffin, PDMA research on new product development practices: updating trends and benchmarking best practices. 1999.	Leadership mechanism	People, structures, culture and climate	Leader	Appointment
17	FFE - NPD	Abbie Griffin, PDMA research on new product development practices: updating trends and benchmarking best practices. 1999 Nicholas, John and Ledwith, Ann and Perks, Helen. New product development best practice in SME and large organisations: theory vs. practice. 2011	Multi-functional teams Multi-disciplinary cross-functional group	People, structures, culture and climate	Team	Assignment
18	FFE	Boeddrich, Heinz-Juergen, "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and innovation management 13.4 (2004): 274-285.	Commitment to company-specific evaluation methods and selection criteria – especially with regard to K. O. criteria for approved projects.	Process, programmes and procedures (process planning) / Project	Project	Approval
19	FFE	Boeddrich, Heinz-Juergen, "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and innovation management 13.4 (2004): 274-285.	Creation of a scope for putting ideas back into people's brains – creative idea loop.	Process, programmes and procedures (process planning) / Project	Idea	Iteration
20	FFE	Boeddrich, Heinz-Juergen, "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and innovation management 13.4 (2004): 274-285.	Definition of company-specific idea categories	Process, programmes and procedures (process planning) / Project	Idea	Categorization
21	FFE	Boeddrich, Heinz-Juergen, "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and innovation management 13.4 (2004): 274-285.	Idea selection based on rules	Process, programmes and procedures (process planning) / Project	Idea	Selection

22	FFE	Boeddrieh, Heinz-Juergen. "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and innovation management 13.4 (2004): 274-285.	Installation of a broad idea-collection point.	Process, programmes and procedures (process planning) / Project	Idea	Capture
23	FFE	Boeddrieh, Heinz-Juergen. "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and innovation management 13.4 (2004): 274-285.	Installation of an intelligent interface between employees' brains and an idea-collection system;	Process, programmes and procedures (process planning) / Project	Idea	Capture
24	FFE	Boeddrieh, Heinz-Juergen. "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and innovation management 13.4 (2004): 274-285.	Investigation of stakeholders in the structured fuzzy front end and establishment of their participation.	Process, programmes and procedures (process planning) / Project	Stakeholder	Research
25	FFE	Boeddrieh, Heinz-Juergen. "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and innovation management 13.4 (2004): 274-285.	Managers have to know which creative technique suits a stated problem and need to develop their creative problem-solving skills;	People, structures, culture and climate	Skill	Development
26	FFE	Boeddrieh, Heinz-Juergen. "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and innovation management 13.4 (2004): 274-285.	Number of stages and gates in the tailor-made idea management.	Process, programmes and procedures (process planning) / Project	Idea	Revision
27	FFE	Boeddrieh, Heinz-Juergen. "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and innovation management 13.4 (2004): 274-285.	Predefined and transparent criteria for selecting and implementing ideas.	Process, programmes and procedures (process planning) / Project	Idea	Evaluation
28	FFE	Boeddrieh, Heinz-Juergen. "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and innovation management 13.4 (2004): 274-285.	Sustainable flow of ideas	Process, programmes and procedures (process planning) / Project	Idea	Generation
29	FFE	Boeddrieh, Heinz-Juergen. "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and innovation management 13.4 (2004): 274-285.	Systematic idea clustering.	Process, programmes and procedures (process planning) / Project	Idea	Clustering

30	FFE	Boeddrieh, Heinz-Juergen. "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and innovation management 13.4 (2004): 274-285.	The concept identification phase (idea management = phase before the project decision) is structured and conducted systematically.	Process, programmes and procedures (process planning) / Project	Concept, solution	Identification
31	FFE - NPD	Boeddrieh, Heinz-Juergen. "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and innovation management 13.4 (2004): 274-285.	The ideas are linked with companies' strategic goals at a very early stage of the innovation process	Process, programmes and procedures (process planning) / Project	Idea	Assessment
32	FFE - NPD	Boeddrieh, Heinz-Juergen. "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and innovation management 13.4 (2004): 274-285.	The ideas will give rise to superior products with obvious benefits for customers and users	Process, programmes and procedures (process planning) / Project	Idea	Assessment
33	DM - FFE	Boeddrieh, Heinz-Juergen. "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and innovation management 13.4 (2004): 274-285.	Definition of creative scopes for the company	Process, programmes and procedures (process planning) / Project	Design	Planning
34	FFE	Boeddrieh, Heinz-Juergen. "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and innovation management 13.4 (2004): 274-285.	Commitment to company-specific evaluation methods and selection criteria – especially with regard to K, O, criteria for approved projects.	Rewards and evaluation	Project	Evaluation
35	FFE	Boeddrieh, Heinz-Juergen. "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and innovation management 13.4 (2004): 274-285.	Exclusive individual rewards for implemented ideas	Rewards and evaluation	Idea	Rewarded
36	DM - FFE	Boeddrieh, Heinz-Juergen. "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and innovation management 13.4 (2004): 274-285.	Commitment to certain individuals or organizational units that promote innovation within the company.	Strategy	Innovation	Commitment
37	DM - NPD - FFE	Boeddrieh, Heinz-Juergen. "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and innovation management 13.4 (2004): 274-285.	Commitment to certain individuals or organizational units that promote innovation within the company.	Strategy	Innovation	Promotion

38	DM - FFE	Boeddrich, Heinz-Juergen, "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and Innovation management 13.4 (2004): 274-285.	Enhancement of sensitive idea management leadership in accordance with complexity and diverse approaches towards handling ideas.	Strategy	Idea	Enhancement
39	DM - FFE - NPD	Boeddrich, Heinz-Juergen, "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and Innovation management 13.4 (2004): 274-285.	System simplicity – making it easy to manage.	Strategy	Process	Assessment
40	FFE	Boeddrich, Heinz-Juergen, "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and Innovation management 13.4 (2004): 274-285.	Commitment to the owner of the idea management process	People, structures, culture and climate	Idea	Assignment
41	FFE	Boeddrich, Heinz-Juergen, "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and Innovation management 13.4 (2004): 274-285.	Cross-functionality of the decision-making gatekeepers in the idea management process	People, structures, culture and climate	Idea	Revision
42	DM - FFE	Boeddrich, Heinz-Juergen, "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and Innovation management 13.4 (2004): 274-285.	Influence of the top management on the fuzzy front end.	People, structures, culture and climate	Personnel	Approval
43	DM - FFE	Boeddrich, Heinz-Juergen, "Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process." Creativity and Innovation management 13.4 (2004): 274-285.	Existence of strategic guidelines for innovations	Policy	Innovation	Planning
44	FFE	Cooper, R. Scott, E and Kleinschmidt, R. Benchmarking best NPD practices-I. 2004	New product ideas rewarded	Rewards and evaluation	Idea	Rewarded
45	FFE - NPD	Cooper, R. Scott, E and Kleinschmidt, R. Benchmarking best NPD practices-I. 2004	Rewards for champions	Rewards and evaluation	Personnel	Rewards
46	NPD	Cooper, R. Scott, E and Kleinschmidt, R. Benchmarking best NPD practices-I. 2004	New product ideas rewarded	Rewards and evaluation	Idea	Rewarded
47	FFE - NPD	Cooper, R. Scott, E and Kleinschmidt, R. Benchmarking best NPD practices-I. 2004	Open communication	Communication and documentation	Communication	Deployment
48	FFE - NPD	Cooper, R. Scott, E and Kleinschmidt, R. Benchmarking best NPD practices-I. 2004	Cross functional cooperation on the team	People, structures, culture and climate	Team	Collaboration
49	FFE - NPD	Cooper, R. Scott, E and Kleinschmidt, R. Benchmarking best NPD practices-I. 2004	Cross functional project teams	People, structures, culture and climate	Team	Assignment