Ergonomic Considerations in Product Design Through PLM Technologies

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Abstract. This article presents an integration of a product design methodology with emphasis in ergonomics with PLM. The articulation requires a comparative overview of the management levels offered by both approaches. PLM focuses on procedural activities and task performance and supports the ergonomic design methodology into a project and process management level in which decisions and control claims a mayor role. As result, workflow and indicators solutions attached to PLM strategy approach are structured accordingly to particular needs of the methodology in question.

Keywords: Product Lifecycle Management · Product design · Ergonomics · Design methodology · Business Process Modeling

1 Introduction

Product development balances the interactions between context, artifacts and users in the performance of an activity to generate wellbeing. Ergonomics aims to apply knowledge of human abilities, human limitations, and other human characteristics in the design [1]. Ergonomics, integrated with the design process, provide the tools to assist a more reliable design [2, 3]. Although, design methodologies include ergonomic criteria to optimize the product successful coupling with ergonomic needs of the end users, when addressing projects with high ergonomic expectations these criteria are often insufficient. Moreover, ergonomic methods are not necessarily applied by designers and engineers on a regular basis, which increases the need of a closed follow up and a strict guidance to gather appropriate information for ergonomic analysis [4]. Such needs can be support with Product Lifecycle Management (PLM) strategy that allow industries to align their intellectual capital in order to create products more efficiently, integrating the complex dynamics around product development [5] creating synergy in collaborative work, concurrent engineering, process management and project management methods to support the product development decision making process. This ensures benefits related to accelerated product development [6], change management, traceability, extended enterprise and knowledge management capabilities.

PLM tools are usually adapted with pre-configured applications or modules to guide a basic implementation. However, specialized working methodologies and strategies need a more detailed configuration, according to the complexity of processes, projects and information management. As the context of this work is the usability and

R. Harik et al. (Eds.): PLM 2016, IFIP AICT 492, pp. 32–42, 2016.
DOI: 10.1007/978-3-319-54660-5_4

product/user interaction, the research intends to integrate these aspects into a product development process. Consequently, the work will be supported in an Ergonomic Oriented Design Methodology (EODM) for which it can be found in the literature different alternatives, such as the ones proposed by Rincon [7]; Stanton et al. [8]; and Hoyos et al. [9]. For the present work, the EODM corresponds to the H2A[1] methodology proposed by Hoyos et al. 2015, as it was selected in terms of its completeness and design oriented approach which include balance between the interactions of human-artifact-environment dimensions solved through the application of ergonomic methods and tools such as biomechanics analysis, RULA assessments, cognitive ergonomic evaluation lists among others [9]. The objective was to experience the implementation of an EODM following a PLM strategy. The emphasis requires adaptations to the process, project support and monitoring. To enable the integration of the methodology into the PLM strategy, an analysis in the structure of the EODM and the PLM software must be done.

2 Background

The EODM is used in the local market for specialized consultancy, in recent cases was applied in two separate projects (1) the redesign of a working space for the musicians of a symphonic orchestra and (2) a small appliance redesign for a local appliance industry. The projects comprised conception to conceptual design stages. During the 4 month application, weaknesses such as, difficulty to update schedules, missing information resulting from the lack of information management mechanisms, difficulty to sort out between the different documents and absence of communication strategies to enhance collaborative work were noticeable. Moreover, 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 activities 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.

The applications showed that, the EODM requires support during management, given that while product design projects vary on scope and complexity, product development decisions remain consistent [10]. Hence, a PLM approach may resolve the issues through automated guidance, smart follow ups and knowledge management applications.

PLM offers managerial capabilities to product development process. To take advantages of such versatile capabilities, the PLM strategy relies on Business Process Modeling tools to revise and adapt their current working process according to suggestions from the PLM strategy. This processes might be represented with a graphic model using Event-Driven Process Chain (EPC) diagrams that integrate the interactions

[1] H2A: H2A methodology stands for "*Hombre-Artefacto-Ambiente*" (human-artefact-environment); Hence, the name takes the first letter of the word and the 2 capital A's. This methodology is a result of previous work within the authors' research group.

between activities, decision events, information and roles, providing a chain of function and logical connectors [11, 12] that facilitates logical understanding of the general system. The analysis of the resulting model gives insights in to the most efficient way to integrate the entities in to a holistic process that adds value to the customer [13]. In addition, PLM solutions provide a series of specialized pre-configured modules that provide managerial capabilities. Once the software is acquire, a process of configuration must take place in order to load the product lifecycle used in the organization, under the PLM strategy conditions. For this article, authors worked with *Aras Innovator* (AI) from Aras Corporation as the selected PLM software, due to its open source benefits, which include high flexibility to adapt unique workflows and projects configuration among other specialized arrangements.

Despite the capabilities of PLM strategy there are little details reported in regards of the use in ergonomics oriented developments. Projects with such orientations are often supported by tools attached to CAD and simulations software's [14], only a few approaches focus on the capabilities of PLM itself [4, 15], focusing on the extraction of ergonomics information from PLM and the use of tools and expert knowledge to support design. However, the application of a complete ergonomic oriented working methodology for design, supported under PLM dimensions of process, organization, tools and resources are yet to be addressed.

3 Analysis of the Ergonomic Approach with PLM Concepts

In order to articulate a PLM strategy that may be able to support a design methodology with emphasis on ergonomics, four dimensions are considered: Process, Information, Organization, and Resources [16]. This method seeks to integrate the PLM strategy and PLM software requirements for data management in a holistic way. As mentioned in Sect. 1, this research work uses the H2A [9] as design methodology with emphasis in ergonomics. Consequently, the aforementioned dimensions were aligned with the EODM approach:

- *Information:* The EODM includes the creation of CAD first approximations to concept design. The data associated with product, such as drawings, parts and images is available for use.
- *Resources:* technological tools to support the EODM
- *Process*: The EODM is not articulated, by default, as a management process. However the EODM structure has implicit in the description of stages, activities and overall structure, a general process. Following Business Process modeling (BPM) methods and tools, the general workflows can be identified and made explicit. This enables PLM software configuration and allow the EODM management in an operational level (project) and a management level (workflow).
- *Organization*: The product development activities depend on the capabilities and skills of the teams. In order to understand the people dynamics into the proposed EODM a characterization of the human aspect was performed based on interactions and contributions. This information is the input to configure the software users, identities (groups of users) and permissions.

Identifying and analyzing the mentioned dimensions, is the easiest way to understand the EODM in a PLM environment. EODM was implemented in PLM as a new "Module". To do so, some hierarchical differences were found in terms of how to refer to modules, activities, tasks, etc. and its equivalence with the structure of the EODM (phases, activities, etc.). Those structures differ; hence, a comparison was made to find a way to articulate the methodology and the software as shown in Fig. 1. As it can be seen, a set of hierarchical levels can be identified in each side. Each level is associated with a level of the structure. Thus, the taxonomy levels can be named as $LevelNumber_{Structure}$ (Example: $L1_{H2A}$ or $L1_{PLM}$). Consequently, they can be identified as follows:

- $L1_{H2A} = L1_{PLM}$ = Ergonomics
- $L2_{H2A} = L3_{H2A}$ = Stages (not managed in PLM)
- $L3_{H2A} = L2_{PLM}$ = Phases
- $L3_{H2A} = L3_{PLM}$ = Workflow activities
- $L3_{H2A} = L4_{PLM}$ = Workflow task
- $L4_{H2A} = L5_{PLM}$ = Project schedule
- $L5_{H2A} = L6_{PLM}$ = Project activity
- $L6_{H2A} = L7_{PLM}$ = Project task

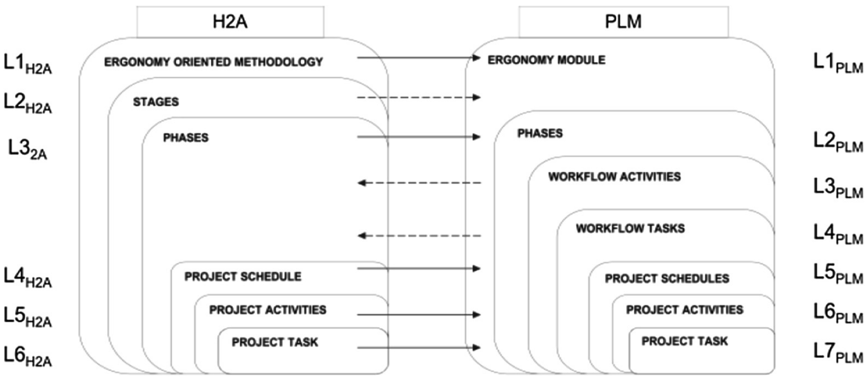

Fig. 1. Articulation of the EODM (H2A) to the PLM (AI) strategy

The EODM (corresponding to the H2A) is organized in five management levels ($L1_{H2A}$ to $L5_{H2A}$); unlike the PLM software where two additional levels exist ($L1_{PLM}$ to $L7_{PLM}$). However, they do not match at the hierarchical level. Two main differences are evidenced:

- The absence in PLM of an equivalent to $L1_{H2A}$, called "stages" is not present in the PLM software $L2_{H2A} \neq L2_{PLM}$.
- PLM adds workflow configurations at $L3_{PLM}$ and $L4_{PLM}$ to assist management.

The absence of an equivalent $L2_{H2A}$ in PLM is due to its use in EODM as midpoint control, which can be managed differently in PLM. On the other hand, $L3_{PLM}$ is subdivided, given that the EODM was implemented by workflows that include a new level of managing activities.

The EODM does not include coordination activities, however PLM offers workflow modules to support management, thus, $L3_{PLM}$ and $L4_{PLM}$ in which workflow activities such as planning, revision and correction loops are integrated sources of guidance for the coordination team. Also, project schedule creation became a mandatory automated workflow task rather than an isolated activity launched by human will, need or believe, this ensures that all projects regardless of instruction will use project Gantts and schedules for activity completion.

The PLM software images presented in the article correspond to the module created for application in the local context, hence the images are only shown for demonstrative purposes and its contents are further explained on the body of the presented work.

4 Ergonomic Module Implementation in PLM

The implementation principle set the EODM to be managed through a main workflow that coordinates activities of planning, execution, evaluation and delivery of each phase. An EPC model named "coordination workflow" was created for the five phases. This model was implemented in AI, using the workflow module as shown in Fig. 2.

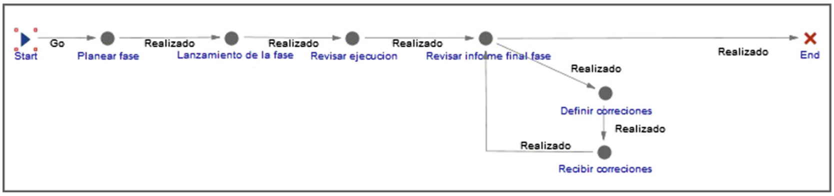

Fig. 2. Workflow map for phase management in AI

The workflow is built with activities and transitions. Each activity is defined with a sequence of tasks necessary to achieve successful completion and subsequent approval as depicted in Fig. 3. Additionally, a decision must take place after every tasks is completed.

Fig. 3. Workflow decisions in AI

The design project itself is managed through the AI's "Project Management" Module which is automatically activated from the workflow in an activity named "phase revision of execution". A project's Work Breakdown Structure (WBS) is suggested by the EODM in every phase. Thus, a total of 6 phases and 53 activities are pre-configured in the software templates, with a suggested predecessor assignation. The use of the activities suggested in the WBS allows rational decision making regarding the ergonomic approach of the project (See Fig. 4).

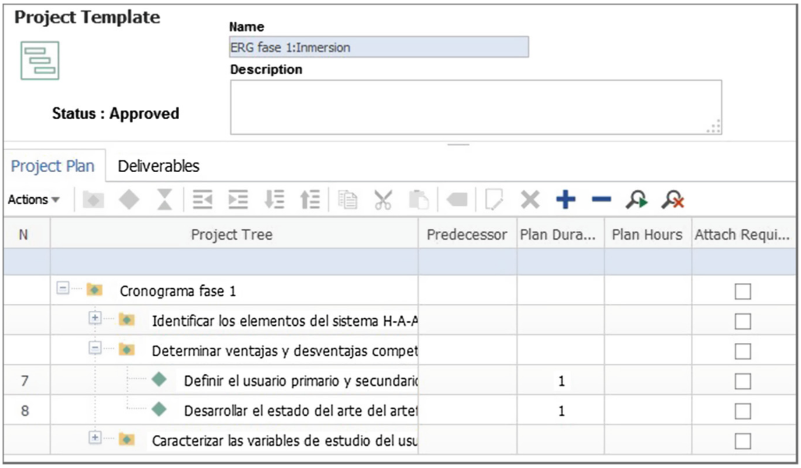

Fig. 4. Project break down structure in AI

In terms of "document management", usually design projects base their body of knowledge on CAD files. However, the PLM, as an evolution of Product Data Management (PDM) systems, fosters the management of the whole lifecycle documentation. For that purpose, four additional types of documents (Manuals, Procedures, Templates, Records) were implemented according to the ISO-9000 standard [17]. Additionally, as PLM strategies recommends, a nomenclature was built in order to facilitate document retrieval. The Prefix was the initial of the type of document, followed by the project type (ERG) and the suffix is a consecutive number (*e.g.* F-ERG-23). The EODM, under its standardization purposes, suggests 30 templates to register the activities completion (to obtain project's "Records") and two manuals to clarify to users the stages and the interactions in them.

The files are centralized in the PLM database and available for access accordingly to permissions assigned to each role. In PLM the distribution of responsibilities goes according to their skills, authority and resources, this is implemented as Gantt Charts and Workflows not only through activity assignment, but also through permissions definition over the decisions and access to the entire system. Thus, an external party will have a limited view of the product lifecycle, whereas a project manager will have view, vote and access to every step of the product development project. The organizational structure proposed in the EODM is composed of two categories (Internal &

External) with seven roles, where three of them (Coordinator, Advisor and Designer) are internal staff directly related to the product development and the other four (User, Client, Expert and Third party) are external stakeholders that remained outside the PLM software. Figure 5 shows the implementation of this structure in AI for permission assignation and workflow configuration.

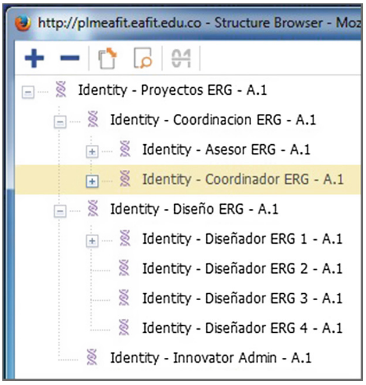

Fig. 5. Identity hierarchy in AI

As a final step on the EODM implementation, a monitoring view was considered. Ergonomics and management indicators were identified and selected from the literature about performance indicators [18, 19]. Six quantitative indicators were selected for the PLM software and they are detailed in Table 1.

Table 1. Management indicators

Item	Name	Equation	Scale (unit of measure)
1	Project deviation	(Real weeks of execution)/(Planned weeks of execution)*100	# Weeks
2	Phase deviation	(Real execution days)/(Planned execution days)-1	# Days
3	Activities on time	(Activities executed)/(Activities planned)	# Activities
4	Delivery performance	(Real weeks needed to delivery)/(Planned weeks to delivery)	# Weeks
5	Tutoring compliance	(Executed tutoring)/(Planned tutoring)	# Tutoring
6	% of executed activities (Executed activities)/(Programmed Schedule)		# Activities

The purpose of those indicators is explained below:

- *Project deviation*: It quantifies the delays on the complete project schedule
- *Phase deviation*: It represents the delays associated with the planned schedule of every phase and the real progress of the execution.
- *Activities on time*: Sets which activities were conducted within the expected time.
- *Delivery performance*: Quantifies compliance with the milestones in each phase.
- *Tutoring Compliance*: It represents the points of tutoring by a consultant or an advisor regarding project development.
- *Percentage of executed activities*: Quantifies the percentage of activities executed within the implemented schedule, the activities discarded multiple times should be reviewed.

In addition to the performance indicators, ergonomic metrics for physical and cognitive assessment were established based on the RULA method [20]. This enabled to record information related to posture, effort, movement and repetition of movements, providing insights about the reduction of the ergonomic risk.

The indicator proves the efficiency of the new design and the advantages over commercial products. The indicators were structured before implementing them in the software to get a first insight in the variable association and the meta-data needed to support each measure. Finally, the indicator web form to capture ergonomic product data was implemented in AI, as shown in Fig. 6.

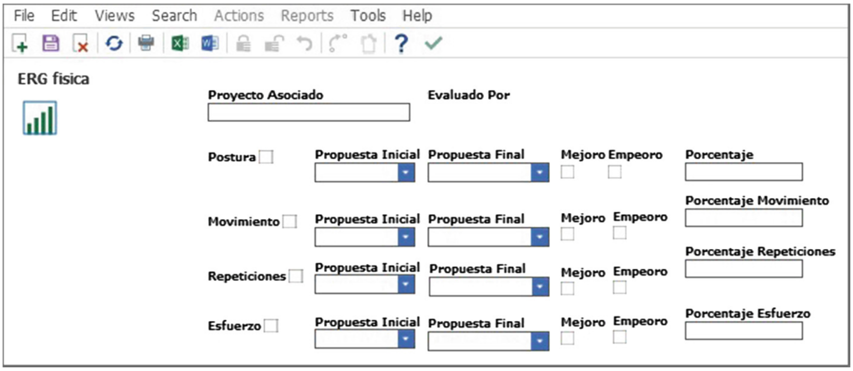

Fig. 6. Ergonomic factors indicators form in AI

5 Results

Once the Ergonomic module was finished, a test environment was set in order to validate (i) the proper performance of the lifecycles and workflows (ii) ensure the automated assignations compliance and (iii) test the interactions between lifecycles, workflows, projects and information. Eight tests were executed focusing in the automated workflow and verifying the proper activities assignation, the trajectories of the decisions and the permissions, as well as identities synergy. The identified software mistakes (such us unlinked activities, workflow nomenclature, lifecycle malfunctioning, mistaken assignations, etc.) were corrected progressively in every testing cycle. The final balance of the PLM "ergonomics module" is shown in Table 2 were it is evidenced how the EODM proposes items that were successfully implemented in the PLM module in AI.

Table 2. Articulations from the PLM strategy to the EODM

	EODM proposals	PLM implementation	Module completeness
Template schedule	6	6	100%
Activities supported in schedules	40	53	133%
Delivery points	6	6	100%
System document	32	32	100%

The second row shows the additions made to the methodology into the PLM module. This is related to the enhancement of management capabilities, thus control points and explicit decision-making strategies were added by incorporating a main workflow to control all phases under the same parameters. This is an effort to increase operability consistency. The PLM strategy enhances the items shown in Fig. 7.

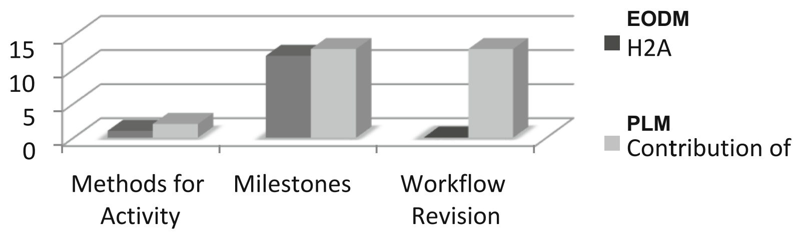

Fig. 7. Detail on the activities supported in schedules

Finally, after the PLM Ergonomics Module was implemented, activities from the EODM may now be controlled, not only through schedules but also through a new workflow for high level management. The milestones increased in 8% due to milestone addition. Six management indicators and two ergonomic tables, enables control over the execution and the end results in terms of ergonomic aspects in the product design. During the software configuration 32 documents were created, as well as 30 templates and 2 manuals that consolidates the complete content of the EODM. Additionally, 53 activities were automated and supported in the software.

6 Conclusions

The adoption of any working method or methodology to PLM software must be articulated under the PLM strategy and technological requirements. Thus, the implementation in the software requires previous understanding of the methodology and a restructuration to fit the levels and requirements of PLM strategy concerning the four dimensions: people, project, product and processes. The PLM module effectively allows recording all lifecycle information generated in the design process, creating traceability of design activities and generates an understanding of the decisions made. The configured module enables to monitor the activities of a project schedule in real time. This result in consistency and availability of information to identify significant deviations from schedules, thus strategic actions might be proactive.

Specific knowledge is required in the field of Business Process, Project Management and Product Development Process in order to achieve a successful integrated implementation of a PLM module. Communication between the software administrators and the responsible of the strategy must be direct; otherwise, efforts will be made in separated fronts causing compatibility issues between software configuration and the methodologies to be supported.

The proposed indicators, both at managerial and technical level, in particular in terms of ergonomics, should be implemented to assess long-term effectiveness. The approach of both types of indicators facilitates decision-making and it is recommended the graphical representations on the PLM software. Further implementations will ensure the collaborative effectiveness of the EODM Supported under a PLM approach. All suggested indicators are quantitative due to the numeric nature of the web templates. As further research, the implementation of qualitative indicators is an action to be included. This involves creating qualitative templates within the software with value ranges lead to a measurable and comparable level.

Acknowledgments. Special thanks to Colciencias (Colombian Administrative Department of Science, Technology and Innovation) and EAFIT University, who jointly sponsored the "Young Researchers Program" trough the call "*Conv. No. 617-2013*".

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