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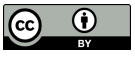

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Integrating Eco-design and PLM in the Aviation Completion Industry: A Case Study

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Abstract. Aviation represents 12% of the CO2 emissions from all transport sources in the world. These pollutants are even stronger in their impact because they are released at high altitudes. Therefore, aeronautical companies have adopted the eco-design and PLM perspective to integrate the environmental concerns into the development of their products. PLM permits to include the environmental matters into every phase of the development process, not forgetting traditional arguments such as function, costs, production and aesthetics. Research regarding ecologically concerned textiles in aviation completion industry is not available in literature, especially those regarding its whole lifecycle and supply chain. Therefore, this paper aims to analyse this unexplored concern by assessing the integration of eco-design and PLM perspective for the use of textile materials in this industry sector. Through a case study, the research team explored the completion function of a north-American company in general and, specifically, the use of textile materials for internal completion of the aircraft. Even though representing 1% of the total weight of the aircraft, textiles represent an important factor in the composition of an airplane and the fact that it is being thought off as another recyclable and not disposable part of it should mean a shift in the perception of its growing importance in the development of the plane as a whole.

Keywords: Green aviation, project lifecycle management, eco-design, product development, completion.

1. Introduction

Aviation, term used to define the design, development, production, operation, and use of aircraft represents 12% of the CO2 emissions from all transport sources in the world [1]. This industry sector emits large volumes of CO2 each year, and whilst only being 2% of overall global production it still amounts to an additional 670 million tonnes in a year. That volume has doubled since 1990 and is predicted to more than double again by 2025 [2]. Pollutants from aviation are even stronger in their impact because they are released at high altitudes [3]. Scientists predict in different research that the total warming impact of aviation's emissions can be multiplied anywhere between 1.9 and 2.7 times, or even more in some scenarios, to estimate their true impact [4].

Besides the concern with the development of new products, there are a growing number of companies interested in guaranteeing the ecological contribution of aviation companies. There is a clear interest in increasing their responsibility, what can also be seen in publications such as Egri and Ralston [5] where they analyse the considerable increase in interest on corporate ecological responsibility as an academic topic as well as a competitive tool for international business. In this context, the Eco-design concept emerged as a trendy concept, integrating the environmental demands to the development of new products [6]. Integrated into the designer's practices and tools, eco-design provides more space for innovation and creativity within the industrial environment. Thus being a new opportunity for differentiation and a future competitive factor [7].

Coming from a gap in the literature on the development of green aircraft completion textiles, the main contribution of this paper is to investigate how products development process can be used to improve the production and acceptance of ecological textile systems for the aeronautic completion industry and decrease its ecological footprint from the PLM (Product Lifecycle Management) perspective. The article is organized into four sections. Starting with a literature review about eco-design and its relation with the product life management, the section 3 describes the methodological strategy and the case study chosen in this research. Finally, the section 4 and 5 expose respectively the main results and the conclusions.

2. Literature review

2.1. Eco-design in the Completion Industry

Eco design is defined as a proactive environmental management approach that integrates environmental issues into the product development and their related processes [8]. Within the product development process, the eco-design represents the inclusion of environmental matter into every phase of the development process, not forgetting traditional arguments such as function, costs, production, aesthetics, etc. [6]. Such a change means to evaluate the used materials, the environmental performance during the fabrication, maintenance, logistics, reutilization, dismantling, re-manufacturing, recycling and final disposal [9]. When it comes to the ecological performance of a product or a service, there is not much to do once the product is released into the market (and when there is it usually originates an extremely high cost), that is why this aspect of the development has to be considered and a high influence from the initial phases of the process [10].

Morelli [11] explains that a more ecological approach towards products development is a challenge as it not only represents the creation of a new product, but also the reorganization of already (or not) existing elements throughout the supply chain according to new needs and values. In addition, for the development of an "eco-product" the cultural and social values are equivalent to people and technologies [12], adding more complexity to the development process.

In the aeronautic industry textile materials can be found in the exterior structures, technical and fibrous composite materials applied to the fuselage, coating and internal items of the aircraft, as well as for special uniforms, parachutes, balloons, etc. Authors such as Dexter [13] and Suarez et al. [14] have already published a wide range of material regarding textile composites and its use in the exterior structure of the airplane. They believe that it is important to emphasize that designers who work with the performance of textiles in the aeronautic industry must develop further and try to standardize more, thus ensuring repeatability and structural integrity, needing considerable insight into the processing methodology to adequately define the

part (through modelling tools), design the tooling and be confident in the end-product performance.

From the most sophisticated system to the less complex component, aeronautic pieces could get several benefits from ecodesign. Vezzoli and Manzini [12] claim that even low impact products may require clean technologies, but it demands for secure new design capacities, promoting sustainable consumption and behaviour. This is clearly the case of textiles for the aircraft completion. It was noticed that there is almost no academic research on textiles applied in the aeronautic industry, especially on what regards refurbishment, completion and its ecological aspects, what led to a need to research information not only in academic publication but also through a wide number of companies and white-papers in order to understand the development and disposal of textile material in the aviation industry.

2.2. Product lifecycle management (PLM)

UNEP [14] conceptualised PLM as tool permitting to achieve sustainable development and study the ecological impact of product throughout their lifecycle. PLM vision has been adopted by the eco-design to improve the conceptualisation of the new product and their relative processes. PLM was developed as a business activity of managing, in the most effective way, a company's products all the way across their lifecycles; from the very first idea for a product all the way through until it's retired and disposed of [16]. It is considered, by Abramovici and Sieg [17], to be the conversion of a combination of a multitude of acronyms: Product Data Management (PDM), Collaborative Product development (cPDM), Collaborative Product Commerce (CPC), Product Knowledge Management, etc.

PLM provides benefits throughout the product lifecycle (see Table 1). The main concept behind it is how to integrate people, processes, business systems and information in an efficient manner [18]. For Stark [16] examples include getting products to market faster in the Beginning-of-Life, providing better support for their use during the Middle-of-Life, and managing their End-of-Life better.

Table 1: Benefits provided by PLM implementation in companies [16]

Area	Benefit
Financial performance	increase revenue with earlier market introduction; reduce product development costs
Time Reduction	reduce project overrun time; reduce engineering change time
Quality Improvement	reduce manufacturing process defects; reduce the number of returns; reduce the number of customer complaints
Business Improvement	increase the innovation rate; increase the part reuse factor; increase product traceability; ensure 100% configuration conformity

On the other hand, Schuh et al. [19] states that, besides its clear advantages, PLM has serious limitation as the difficulty of implementing PLM in some industries due to its high complexity, what tends to lead to a very specific focus in particular aspects of it (such as for instance the supply chain), without the necessary holistic approach to the whole life-cycle and its underlying processes.

On an environmental perspective, with particular interest in the completion industry, PLM will play a key role in addressing all these positive and negative issues because it provides the opportunity to get control of products across their lifecycles. The problems it addresses, and the ideas for their solution, aren't new. Over the years, population growth, lack of disposal sites, and scarce natural resources have led to all sorts of reduction, reutilisation, recycling and recovery programs.

2.3. Research gap

Research regarding ecologically concerned textiles is not available in the visited literature, especially those regarding its whole lifecycle and supply chain. We believe that it is, on one hand, due to privacy issue, and on the other, due to a known lack of interest in this line of textile products, also seen as superfluous by many (see case study later). This paper was built from this literature gap and criticism, the absence of interaction between the researched methodologies and the textile industry, for their potential to add interesting insights to each other.

The Product-Service Systems (PSS) [20] and the Systemic Design [21] propose to switch the production-consumption activities into a production-consumption system which would reduce the effects of all stages of life cycle throughout the whole supply chain. Thus, the relationship between supplier and buyer would not end with the moment of purchase, but perpetuates over time [22]. Within this scenario, PLM's five main phases: Imagine, Define, Realise, Use/Support, and Retire/Dispose [16], can then be used to assist the development team as it is supposed to manage a well-structured and valuable product portfolio. By doing so, it can help maximizing project's financial return, managing and providing control and visibility over products throughout the lifecycle, as well as feedback about products from customers, product & field engineers and the market, above all, enabling collaborative work between supply chain partners and customers, thus unifying the whole concept behind sustainable development.

In order to guide the empirical part of this study, we employed a clear and objective approach that takes into account three aspects: the literature on traditional development of products in aviation, the development of green products using PLM-based methodologies and the existing literature available on aviation.

First, the literature about the development of products is immense and focuses on the different existing approaches to the development of new products but Literature on aviation ecodesign is quite limited. It provides a broad overview of the history, current situation and forecasts of the aviation industry as a whole, also evidencing a great level of concern with the industries' carbon emissions, not ignoring its environmental and social impacts. It does, oppositely, completely disregards the development and improvements being implemented by the industry, only providing forecasts of what is being intended, especially when considering green completion.

This analysis then suggests the importance of the combinations of the missing factors examined in the literature review: a comparison between traditional and environmental development of products using the supply chain viewpoint as a strategic differential; a combination of the theoretical and practical aspects of the development process; and the study of the state-of-the-art of the development of green completion, aiming to also involve the supply chain, the final consumers and local communities.

3. Methodology

3.1. Methodological approach

To better respond to the gaps found during the literature review it was decided to develop a case study [23] as it is the preferred methodology when studying in-depth a contemporary problem. This was considered the best alternative to deal with different sorts of evidence: visits, interviews, artefacts, and observations.

During the literature review, in order to evaluate the current situation of the matter researched, many data about companies and manufacturers have been found. Such material was considered complementary to the theoretical information gathered. Considering companies environmental management, governments increasing concern regarding pollution and ecological disturbances, as well as the particular way used by each company to develop their products, the companies were scanned and highlighted. Thus, to properly assess the priorities to be analysed in the case study it was decided to develop a comparing, broader, conceptual framework using the best practices of the methodologies discussed during the literature review.

3.2. Designing the case study

The case study was executed into the North-American context for a period of six months. Ten Canadian and U.S. companies were chosen for a first screening according to their proximity to the Green Aircraft Completion subject. From them, one, named in this paper as 'the Company' due to privacy issues, was chosen for being the most suitable for the research, for providing a broader view of the whole supply chain and, finally, for being a highly environmentally forwarded business. Indeed, the Company not only deals with refurbishment and completion activities, but also with the production of new aircrafts and the development of both products through partnerships with companies around the globe. This company has adapted an environmental focus which shapes the future of its technological innovations. Environmental challenges are therefore being addressed by the Company from a global perspective using a four pillars approach (see table 1).

Table 2: Environmental focus of the studied organisation

Organisation	Environmental pillars	
The Company	Technology	New aircraft designs, new lightweight materials, new engine advances
	Operations	Improved operational practices, more efficient flight procedures, weight reduction measures
	Infrastructure	More efficient air traffic management and airport infrastructure
	Economic measures	Consistency in addressing and assessing noise and emissions within the industry, incentives supportive of environmental sustainability

The case study focuses on the completion function of the Company in general and, specifically, on the use of textile materials for internal completion of the aircraft. Completion function is crucial for the Company because it permits to personalise products in function of customers' needs. The completion team establishes a strong relationship with them to identify their requirements and adding more value to the final product. The Company estimates that a customized aircraft could increase it value by 50 to 100 million dollars. Textile materials could also add value to the aircraft. The company propose several types of textile products for aircraft walls, carpets, seats and sofas. These textiles have different characteristics, such as resistance, safety issues, cleaning characteristics, composition (natural sources), among others.

During our visits, three main representatives of the company were interviewed: two engineers (the Interior Completions Manager – ICM and the Interior Completion Engineer – ICE) and a designer in charge of stylist and sales of the completion centre (DSSCC). These participants were chosen either for their connection to the completion as a department (ICM), for the contact with suppliers (ICE) or for being the link between the company and the final consumer (DSSCC), as well as for their academic backgrounds.

These three participants provided us interesting insights of the product lifecycle for textile materials and the actual efforts to include the green perspective into aircraft completion. For

instance, they enable to identify the different phases of the textile lifecycle for aircraft completion (production, transportation, setting up, completion, dismantling and disposal or recycling) and the organisations involved for each phase (see the right hand-side of the Figure 1).

4. Results

4.1. Green initiatives

Empirical evidence highlights that the Company has included the ecological perspective into its strategies for ensuring its "neutral emission commitment". In its 2011 Market forecast, the Company claims that it environmental focus was based on building on a strong track record of technological innovation and, in addition, it has formally committed to a future of carbon-neutral growth and increased environmental sustainability. These statements, during the visit were proved to be true, but the Company's greatest concern is the fuel consumption of the aircrafts. As the consumption is directly related to the weight of the aircraft, development companies and suppliers are more concerned with decreasing the weight of the airplane parts, than the composition or production techniques. This disregards the intense usage of highly pollutant composites in the aircraft structure, and a minimal concern with different development techniques on the used fabrics and textiles components (which represent around 1% of the total weight).

In addition, it is interesting to highlight that the social aspects of the Company and its ecologically forwarded initiatives are also visible throughout its mission. One of them is to enable and motivate its workers to buy and sells carbon credits during their trips with the company's aircrafts; the company also encourages its employees to suggest environmental improvements through projects, which might be implemented. Being then a company interested in the well-being and environmental development not only of its consumers but also its personnel.

On what regards the development of green products in the aircraft's industry, it is clear that there is an entrance gap in which the conceptual framework can be inserted and from where the eco-development can grow and expand, initially using few suppliers and eventually growing, constantly ensuring the participation of the final consumer in the development as an essential stakeholder. Indeed, the company has established a strict control for choosing suppliers and materials that could consolidate its strategic goals. Suppliers and their products are screened by an external consultancy company to guarantee aviation authority certification and product quality. Due to carbon neutral commitment of the aviation industry, most of the suppliers seem to be interested in supplying green products but actual efforts are limited. The company also focuses on the consumer's vision. The customer becomes an important stakeholder of the aircraft design process and its participation for defining ecological initiative is crucial for ensuring product profitability.

As the company holds an ISO1400, it has a great concern with the disposal of its trims and leftovers. However, this concern only regards the company if the remains are created within the company's propriety. In order to guarantee the accordance to the ISO rules, the company hires the disposal services of a third party. Therefore, the Company is not directly connected to the disposal or aware of its destination and eventual uses.

4.2. Eco-design for the aircraft completion

In order to better identify and discuss the results of the interviews, the Table 3 was organized highlighting the similarities on the interviewees' arguments, the main points discussed. According to this table, the interest of the industry and practicality of the conceptual frame-

work are in harmony as they exist in the same level. However, it also led to an important initial finding: the lack of interest coming from the final user towards green completion. Even though, there is a strong trend towards this practice and that suppliers are constantly increasing the availability of ecologically sound product, its request and acceptance is minimum, reaching only 2% of the requests (mainly by environmental companies or young trend followers).

Table 3: General Green Aircraft Completion (GAC) topics discussed during the interviews

Topic	Points discussed	Answer similarities	Parallel with eco-design and PLM perspectives	Highlights
Demand	Number of GAC per year; price difference; offer of colours, materials, textures, etc.	None of the interviewees believe there is an interest coming from consumers to acquire GAC in their planes	It is in this matter that the framework could provide important improvement measures as it aims to use the final consumer as an asset of the development, thus creating a product consumer-oriented	Lack of interest from consumers
Consumer's acceptance	Sales manager believe the main problem for consumers to accept GAC in their jets is the fact that they don't consider it an improvement in their completion, they consider it a poor/no value adding investment	In order to satisfy the company's neutral carbon emission commitment, they say that the Company try as much as possible to convince costumer of the qualities and improvements offered by this line of products	With the creation of a product that answers to consumer-oriented criteria the level of acceptance and persuasion should raise as a response to a product oriented to those who actually need to be convinced of its quality, advantages and features	Doubts about the quality of GAC products have to discussed with clients and final consumers
Disposal	Recycling processes by for this sort of materials; What happens with the trims of the upholstery which is not used for the refurbishing; how can the 3 main sorts of materials used in a completion (leathers, carpets, wood and natural fibres) be reused or recycled	The company uses a third-party to dispose the left-over material, however all the interviewees agree that, due to the high-end characteristic of the materials they are ordered by quantity, an amount very close to the actual need, what, in the end, leaves few left-overs to be sent to this third-party partner	Essential aspect of the eco-development the disposal gains a new level of importance and its characteristics change as the supplier will have to consider its recyclability or 'compostability' and the producer will aim to provide end-of-life services	Possibility of a new system for the disposed material internally in the company
Importance of green completion in aviation as a whole	How GAC is better for aviation: through the decrease of the aircraft's total weight; by the reduction of waste produced; through the diminution of the use and emission of chemicals; better marketing; decrease the company's footprint; reduce carbon emission; etc.	For the interviewees (specially the completion manager) percentage of weight GAC accounts for is minimal, however it still represents an improvement in the aircraft as a whole	When dealing with the framework, the importance of every feature in the aircrafts raises size and the responsibilities are shared, therefore, even if representing one per cent of the total weight of the aircraft, it can increases the environmental value of the aircraft as a whole	It does not account for great changes in aviation as a whole but is an improvement nevertheless. In addition, textiles are in direct contact with costumers, what can in future be an important element of as customers become more aware and demanding
Usage of textile left-overs in different projects	Start a handicraft atelier or cooperative within the company's community	Once again the interviewees were not very faithful on the possibility of implementing some activity which would use the left-over materials	The completion manager believes this might be a possibility in some of the plants which already have programmed with the local community	Investment in projects within the companies' community can contribute to its targets connected to sustainability

Since development risks are shared between the company and its suppliers, they are already working together and dealing with the environmental problems, as summarized in Figure

1. However, so far they do not fully satisfy the whole cycle of PLM as it does not yet integrate completely the end-of-life stages of the development. On the other hand, the company's suppliers had been working mainly with two concepts when dealing with textiles: its decomposta-bility and production (to ensure recyclability and rapidly renewal - produced of an organic source and be 100% decomposed within a 10-year or shorter cycle).

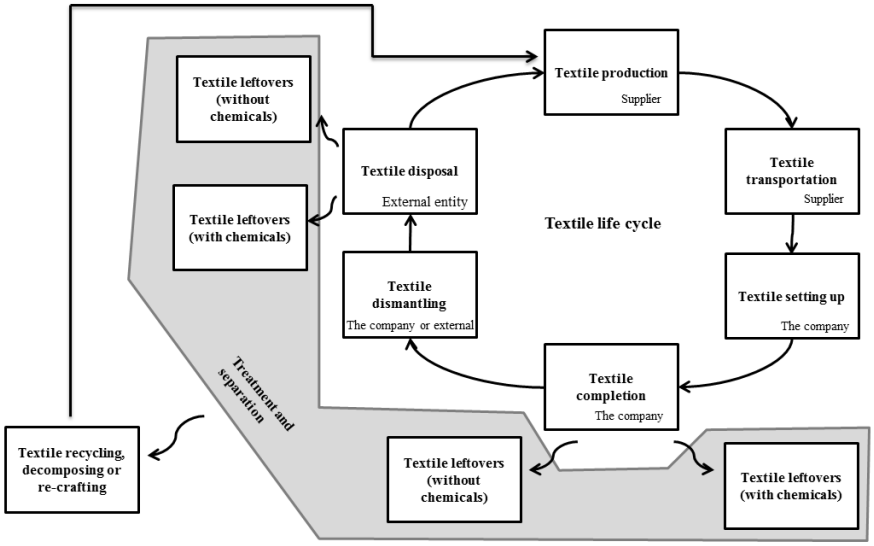

Figure 1: Ideal PLM cycle for textiles used in the completion process

Regarding this matter, Lee et al. [24] highlights that the ideal PLM approach should be able to manage inspections and maintenance records throughout the product life spam, but these elements are not included so far in the model.

5. Conclusions

Aiming to decrease their carbon footprints, adapt to regulations or to lean towards a neutral carbon emission industry, the aviation industry is investing largely in the improvement of a large number of aspects in its assembly, one of them being the use of ecologically sustainable textiles. Even though the aeronautic industry is currently one of the biggest pollutants world-wide, its concern in becoming green is mainly a response to directives and environmental regulations than an answer to consumer's interests and demands.

Elaborated from the need to better understand and to identify the development and ecologic requirements of the aeronautic industry this research was developed to understand the use of fabrics in the aeronautic industry and possible applicable improvements. Thusly the presented article served to provide an initial idea of what was being considered 'eco' in Aviation, what could be done for it to be more ecologically forwarded and the main ecological objectives of the industry, as well as its consumer's behaviour.

Quality is not yet associated to GAC in this sector as the consumers tend to demand opulence rather than sustainability. Consumers played a very important role in the quest for the use and implementation of ecologic methodologies and products in the aviation industry, even though they seem to be working as a barrier to the introductions and diffusion of the green air-

craft completion concept and fundaments, the industry believes that will change once they become an active stakeholder of the process.

The most important aspect seen for the industry when 'becoming green' is directed to a need to emit less carbon dioxide. Along with an increasing interest coming from the textile suppliers to produce more ecologic solutions for aviation, not only regarding weight (and fuel consumption) but also the materials used, its recyclability or clean disposal. Most of the problems currently associated to textiles used inside the aircraft have a chemical and highly pollutant source, however a solution or suitable alternatives do not seem to have yet been found in a reasonable price and in accordance to the supply and demand expectative. But the raw material or the fabrics before the finishing phase are leaning gradually towards 'greener' development and production approaches.

In conclusion, it is important to emphasise that, even though representing 1% of the total weight of the aircraft (not considering composites), textiles represent an important factor in the composition of an airplane and the fact that it is being thought off as another recyclable and not disposable part of it should mean a shift in the perception of its growing importance in the development of the plane as a whole. Especially when considering the fact that this industry is the biggest adopter of PLM [24], and that PLM represents an important production shift for aviation and can be a key asset towards a more sustainable industry.

References

1. A.T.A.G., Facts and figures. ATAG, Air Transport Action Group, Geneva – Switzerland. (2012).
2. McCollum, D., Gould, G., Greene, D., Greenhouse Gas Emissions from Aviation and Marine Transportation: Mitigation Potential and Policies, in: Change, P.C.o.G.C. (Ed.), California - U.S.A., p. 56, (2009).
3. Keynes, J.M., Characteristics of the airline industry, The Airline Industry: Challenges in the 21st Century. Springer-Verlag, Berlin Heidelberg, pp. 13-44, (2009).
4. GreenAviation, Humans need to fly. Green Aviation International Ltd, (2011).
5. Egri, C., Ralston, D., Corporate responsibility: A review of international management research from 1998 to 2007. *Journal of International Management*, 14, 319–339, (2008).
6. Darnall, N., Henriques, I., Sadorsky, P., Do environmental management systems improve business performance in an international setting? *Journal of International Management*, 14, 364–376, (2008).
7. Riopel, D., Chouinard, M., Marcotte, S., Aït-Kadi, D. Ingénierie et gestion de la logistique inverse. Hermès – Lavoisier, Paris – France, (2011).
8. Pigosso, D.C. a., Zanette, E.T., Filho, A.G., Ometto, A.R., Rozenfeld, H., 2010. Ecodesign methods focused on remanufacturing. J. Clean. Prod. 18, 21–31.
9. Rozenfeld, H., Forcellini, F., Amaral, D., Toledo, J., Silva, S., Alliprandini, D., Scalice, R., Gestão de desenvolvimento de produtos: uma referência para a melhoria do processo. Saraiva, Sao Paulo – Brazil, (2006).
10. Dewulf, W., Willems, B., Duflou, J., Estimating the environmental profile of early design concepts. *Innovation in Life Cycle Engineering and Sustainable Development*, 321–334, (2006).
11. Morelli, N., Product-service systems: a perspective shift for designers. *Design Studies*, 24, 73-99, (2003).
12. Vezzoli, C., Manzini, E., Design for environmental sustainability. Springer, London – UK, (2009).
13. Dexter, H.B., Development of Textile Reinforced Composites for Aircraft Structures. 4th International Symposium for Textile Composites Kyoto Institute of Technology, Kyoto, Japan, (1998).
14. Suarez, J.A., Buttitta, C., Flanagan, G., DeSilva, T., Egensteiner, W., Bruno, J., Mahon, J., Rutkowski, C., Collins, R., Fidnarckis, R., Clarke, S., Michel, R., Novel composites for wings and fuselageapplications: textile Reinforced Composites and Design Guidelines. NASA contractor report, Hampton, United States of America, (1996).
15. U.N.E.P., Lifecycle management: How business uses it to decrease footprint, create opportunities and make values chain more sustainable. White paper. Consulted from: http://www.unep.fr/shared/publications/pdf/DTIx1208xPA-LifeCycleApproach-Howbusiness usesit.pdf, (2009).

16. Stark, J., Product Lifecycle Management: 21st century paradigm product realisation. Springer, London – United Kingdom, (2011).
17. Abramovici, M., Sieg, O., Status and development of product lifecycle management systems. in Proceedings of IPPD 2002. 2002. Wroclaw, Poland, (2002).
18. Zheng, L., McMahon, C., Li, L., Ding, L., Jamshidi, J., Key characteristics management in product lifecycle management: a survey of methodologies and practices. Proceedings of the Institution of Mechanical Engineers, Part B: *Journal of Engineering Manufacture*, 222, 989-1008, (2008).
19. Morelli, N., 2003. Product-service systems, a perspective shift for designers: A case study: the design of a telecentre. Des. Stud. 24, 73–99.
20. Schuh, G., Rozenfeld, H., Assmus, D., Zancul, E., Process oriented framework to support PLM implementation. *Computers in Industry*, 59, 210-218, (2007).
21. Bistagnino, L., Systemic Design: designing the productive and environmental sustainability. Slow Food Editore, Torino – Italy, (2011).
22. Manzini, E., Vezzoli, C., Product-Service Systems and Sustainability: Opportunities for sustainable solutions. UNEP, Paris - France, p. 18, (2003).
23. Yin, R., Case Study Research: Design and Methods. Sage, United States of America, (2009).
24. Lee, S., Ma, Y., Thimm, G., Verstraeten, J., Product lifecycle management in aviation maintenance, repair and overhaul. *Computers in Industry*, 59, 296-303, (2007).