INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED15
27-30 JULY 2015, POLITECNICO DI MILANO, ITALY

A SUSTAINABLE PRODUCT MODEL

Vadoudi, Kiyan; Troussier, Nadège
University of Technology of Troyes, France

Abstract

There are major challenges for the designer to include Sustainable Development aspects into product design activities; particularly related to the social and wider environmental aspects. One way of giving a more accurate meaning to sustainability is the territorial understanding of the term. A territorial interpretation can make sustainability a more articulate, current, and pragmatic theory. Literature review shows that the existing product design approaches are mostly general at global level and very little attention has been paid to integrate territorial characteristics into product information-modeling. Despite, in recent years, some agriculture products having been designed and developed based on territorial specifications, but this approach is needs to be expanded with other types of products. Therefore, in this paper we describe a general product information-modeling framework that we believe can help designers to optimize product performance in the design phase by taking into account territorial conditions and requirements. The framework is based on the Core Product Model (CPM) which is extended with geographical and environmental data models.

Keywords: New product development, Sustainability, Product modelling, Product lifecycle management (PLM), Geographical Information System

Contact:
Kiyan Vadoudi
University of Technology of Troyes
HETIC
France
kiyan.vadoudi@utt.fr

Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 20th International Conference on Engineering Design (ICED15), Vol. nn: Title of Volume, Milan, Italy, 27.-30.07.2015

1 INTRODUCTION

Among the methodologies available to evaluate the sustainability level of products, Life Cycle Assessment (LCA) provides a holistic approach that considers the potential environmental impacts from all stages of manufacture, product use and end-of-life (Finnveden et al., 2009; Hart, Clift, Riddlestone, & Buntin, 2005). Through the phases of LCA (Goal and scope, lifecycle inventory (LCI), lifecycle impact assessment (LCIA) and interpretation), the mandatory steps are impact category selection, classification, and characterization. The characterization factors convert and combine the LCI results into representative indicators of impacts to human and ecological health. The characterization factors can be site-generic, site-dependent, and site-specific. Site-specific as a regionalization in lifecycle impact assessment (RLCA), is a recognition that industrial production characteristics and the environmental impact of environmental flows vary among different scales and requires geographical information (Bartl, Verones, & Hellweg, 2012; Mutel & Hellweg, 2009; Mutel, Pfister, & Hellweg, 2012). Geographical Information System (GIS) is able to support this required information.

Geographical Information System is designed to capture, store, manipulate, analyze, manage, and present all types of spatial or geographical data (Burrough & McDonnell, 1998; Jarupathirun & Zahedi, 2005). It is a tool for decision-making and its powerful analytical and visualization capabilities provide the answers to important questions that must be answered in order to make sound and to inform for decision making. During last year's companies have recognized the importance of GIS on business and management functions such as logistics, site and facilities management, marketing, decision making, and planning (Azaz, 2011; Brimicombe, 2010; Meyers, 1999) but too little research has been done to understand the role of this technology on product design. Nowadays product designers have focused on achieving the required technical, aesthetic and economic aspects, but these are not enough and we need to be aware of the environmental and social impacts (Niemann, Tichkiewitch, & Westkämper, 2008). In the fulfilment of design tasks, sustainable development is difficult to attain, largely due to some significant challenges in case of integrating sustainability in eco-design.

There are different approaches to implement sustainable development and one way of giving more accurate meaning, is the territorial understanding of the term (Péti, 2012). This approach could make sustainability more articulate, actual, and pragmatic due to the fact that local people and stakeholders obviously know and manage better their own regional social, economic, and natural environment. Therefore, it could be possible for designers to adapt product to local resources for local use, leading then to shorten supply chain (Vadoudi, Allais, Reyes, & Troussier, 2014). The problem is then to know how to do. For that, we assume that the designers should define the product lifecycle using information about their geographical region (where the product will be manufactured, used and dismantled). Usual design methodologies integrate product, process and manufacturing information in design (Noël, Roucoules, & Teissandier, 2006). They also handle information about product definition, behaviour and functions (Gero & Kannengiesser, 2004). We are proposing here a case study to illustrate how the use of geographical information in engineering design can leads to new product definition. Based on the description of a specific information model based on CPM, the design of a lighting system is described comparing the actual life cycle to the new life cycle, designed using local use and resources information. The case study attempts to evaluate the interest of it for environmental purposes by comparing a globalized product definition with a local product definition

The paper divides in six sections. The 'Introduction' section describes the eco-design framework, analyses the relationships between eco-design and sustainability. It finally leads to the research question: Does an eco-design framework that integrates geographical information in product lifecycle development lead to more sustainable systems? Then 'Methodology' section explains the three steps' methodology adopted for this paper. This is followed by an analysis of the information used in product design and an analysis of the integration of geographical information. The "Proposed model" section describes the used data model that integrates product and geographic data. The "Case Study" section shows how this information of this data model can leads to new product life cycle design and finally the "Conclusion" presents the main conclusions and the next research steps.

2 METHODOLOGY

Based on our hypothesis (Design of product based on territory's characteristics in order to be closer to the concept of sustainable development), the objective of this paper is to analyze the relation between product information with territory information to integrate and include them in design process and evaluate the impacts (positive and negative) of the designed product on the territory. In order to evaluate our assumption, the methodology had been divided in three main steps. First of all, a data model including product and geographic information is presented and is used as a basis to develop the proposed case study. The choice of the case study had been made identifying the main criteria for its choices and evaluating ideas coming from brainstorming (Table 1).

Table 1. Evaluation table used to choose the case study

Item	Product	Data accessibility	Less Complex	Mechanical System	Manufacturing system	Sum
1	Flashlight	3	3	3	2	11
2	Office Chair	3	3	2	2	10
3	Filter (Car)	2	2	3	3	10
4	Urban lights	2	3	3	2	10
5	Bicycle	3	3	2	2	10
6	Toothbrush	3	3	2	2	10
7	Wire Basket	3	3	2	2	10
8	Knife	3	3	2	2	10
9	Lawn Mover	2	2	3	2	9
10	Urban Bin	2	3	2	2	9
11	Lamp	2	2	2	3	9
12	Fan	3	2	2	2	9
13	Glass	2	3	2	2	9
14	Battery	2	2	3	2	9
15	Coffee Machin	2	2	3	2	9
16	Pencil	3	3	1	2	9
17	Wire	2	2	2	2	8
18	Scooter	2	2	2	2	8
19	Shoes	3	3	1	1	8
20	Refrigerator	2	1	3	2	8
21	Phone	1	1	2	2	6

Low =1, Medium = 2, High = 3

Among 21 products, a simple flashlight is selected based on four primary criteria; First access to product Data, Second level of complexity, Third using mechanical System and finally to be a manufacturing system. This case study illustrates the use of the information provided by GIS in eco-design. It then attempts to evaluate the interest of it for environmental purposes by comparing a globalized product definition with a local product definition.

3 PRESENTATION OF THE USED CONCEPTUAL DATA MODEL

A previous paper from the authors had analyzed the literature review concerning data model for Product Lifecycle Management (PLM) dedicated to eco-design and the added information coming from geographic information systems (GIS) (Vadoudi et al., 2014). From this analysis, a conceptual model had been drawn and among all the product models, Core Product Model (CPM) is selected, because its core model focuses on artifact representation including function, form, behavior and material, physical and functional decompositions, and relationships among these concepts. Moreover, CPM is open, non-proprietary, generic, extensible and UML (Unified modelling language) based with the contribution of covering the design process information. This model is extended to CPM2 for supporting a broad range of information relevant to product lifecycle management and CPMe³, which allows data capturing from the whole product lifecycle with its link to the environmental evaluation (Da Silva, Guyot, Remy, & Reyes, 2013; Steven J Fenves, Foufou, Bock, & Sriram, 2008; Steven Joseph Fenves, 2001).

The main classes of CPM model, as seen in figure 1, are: Artifact, represents any physical entity in a product; Feature, the artifact's form with a function; Form, Geometry and Material; Function, the intended Behavior; Behavior, how the Form fulfils the Function; OAMFeature is a specialization of Feature, from the Open Assembly Model (Sudarsan, Fenves, Sriram, & Wang, 2005) extension, to support the product structure, i.e. the relation between assemblies and parts. The environmental impact of product is defined by Flow, so the impact of a Process is the sum of the impacts of the Flows. A Flow is classified by its Resources. EOL (End of life) covers the reuse and waste: recycle (waste materials reprocessed into products), energy recovery (waste recover as a combustion fuel or composting) and disposal (landfill or incineration). Finally, class Use is related to the consumptions of the product during the use phase.

Class LifeCycleInventory is the data collection portion of LCA, consisting of detailed tracking of all the flows in and out of the product system, including raw resources or materials, energy by type, water, and emissions to air, water and land by specific substances. Resources class is source or supply, from which benefit is produced with three main characteristics of utility, limited availability, and potential for depletion or consumption (Economic resources, Biological resources, IT resources, Land resources, Human resources and Capital resources).

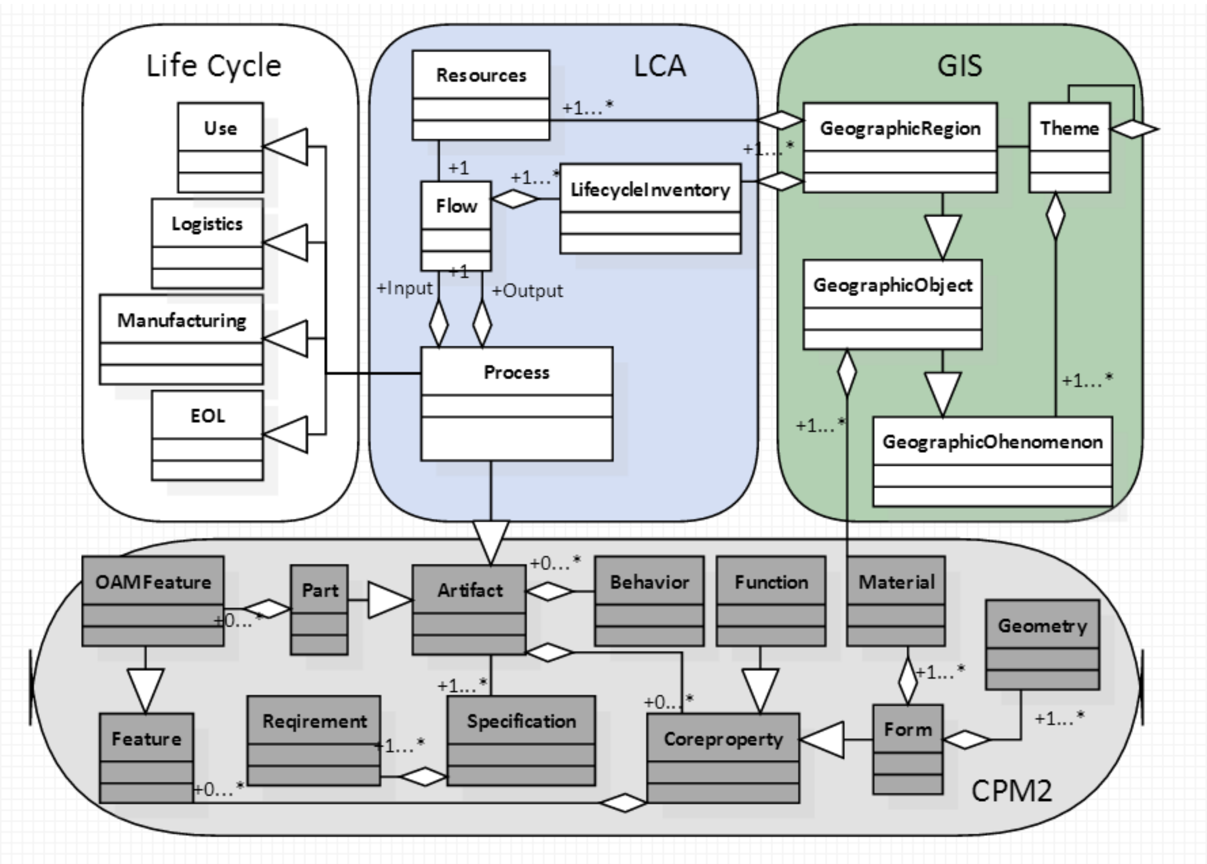

Figure 1. Proposed Model

The classes Theme and GeographicRegion as the basis of any geographic application have as their main objective the management and the manipulation of a data set for a certain region, constituting a geographic database. Class GeographicRegion has aggregate impact with LifecycleInventory. Theme class presents the five themes (Location, Place, Human-Environment Interaction, Movement and Region) of geography. A collection of themes can be specified for each geographic area (Iochpe, 1999). A theme defined during conceptual design can lead to the implementation of several layers, for example a simple theme such as Rivers can generate more than one data layer, one containing only linear spatial objects and another containing polygonal spatial objects. GeographicRegion class defining regions that are areas broadly divided by physical characteristics (physical geography), human-impact characteristics (human geography), and the interaction of humanity and the environment (environmental geography). The abstract class GeographicPhenomenon generalizes any phenomenon whose location in relation to the earth's surface is being considered. For example, a land parcel could be considered as an instance if its spatial attributes were to be represented in the database (De Oliveira, Pires, & Medeiros, 1997). GeographicObject class is a generalization of all classes of geographic phenomena that can be individualized.

4 CASE STUDY

As stated in the introduction, the aim of this research is to design product based on local resources for local use. Redesign of a plastic flashlight (Both design and manufacturing processes in US) is chosen as the case study. Champagne-Ardenne as one of 27 French regions, located in the northeast of French is defined as the target territory to re-design based on this region's characteristics. The product and some stages of its life cycle are simplified in order to limit the data involved during the design process. Moreover, a simplified LCA rather than a detailed one is selected using openLCA software. The life cycle phase included is Materials selection and the potential impact category is just acidification. The Cambridge Engineering Selector (CES) software (http://www.grantadesign.com/) package is selected as the local material engineering software because of the quality of the method which allows us to deal with effective environmental properties when choosing material and process. Figure 2 presents the product model with the product structure and its life cycle for the current plastic flashlight.

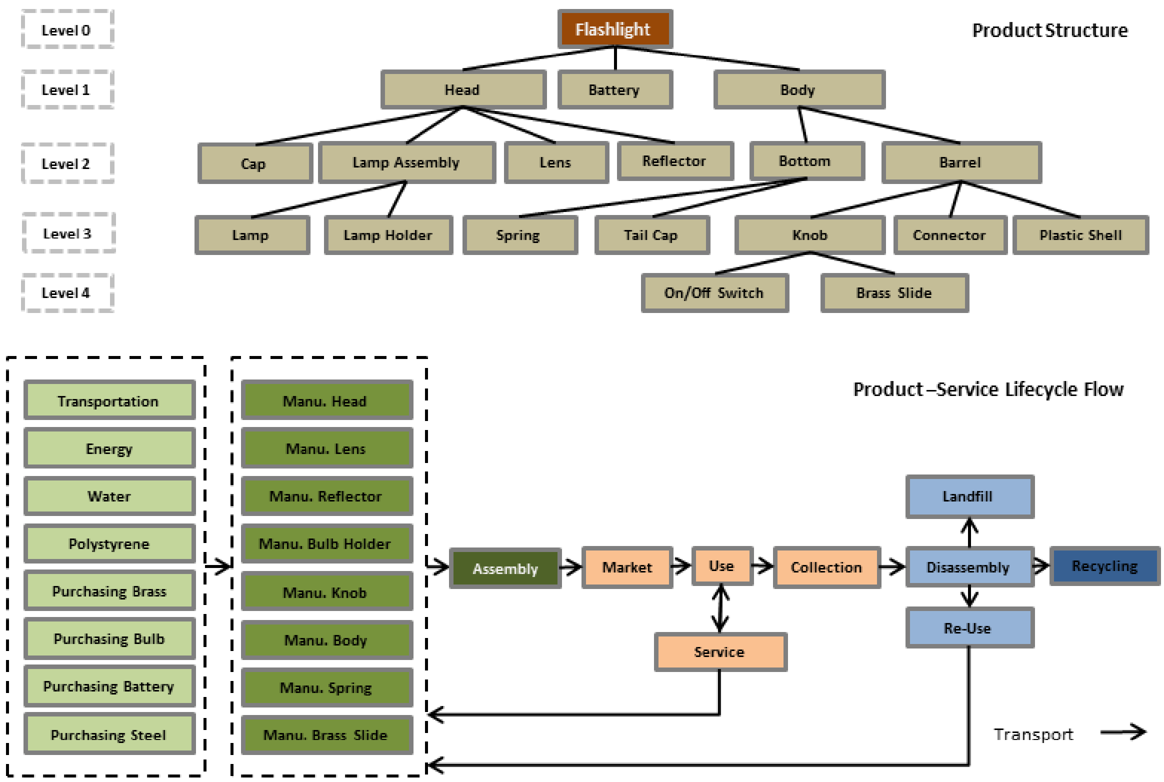

Figure 2. Plastic Flashlight's lifecycle and bill of material

The original flashlight's manufacturing plant is located in Ontario, US. Company is purchasing battery from a US manufacture located in Bethel (US), LED from China, Polypropylene from producer in

New Jersey (US) and finally steel and brass from another US producer in Ohio. Figure 3 illustrates the geographical distribution of lifecycle phases, which is crossing from several countries, without any specific and clear plan for disposal step.

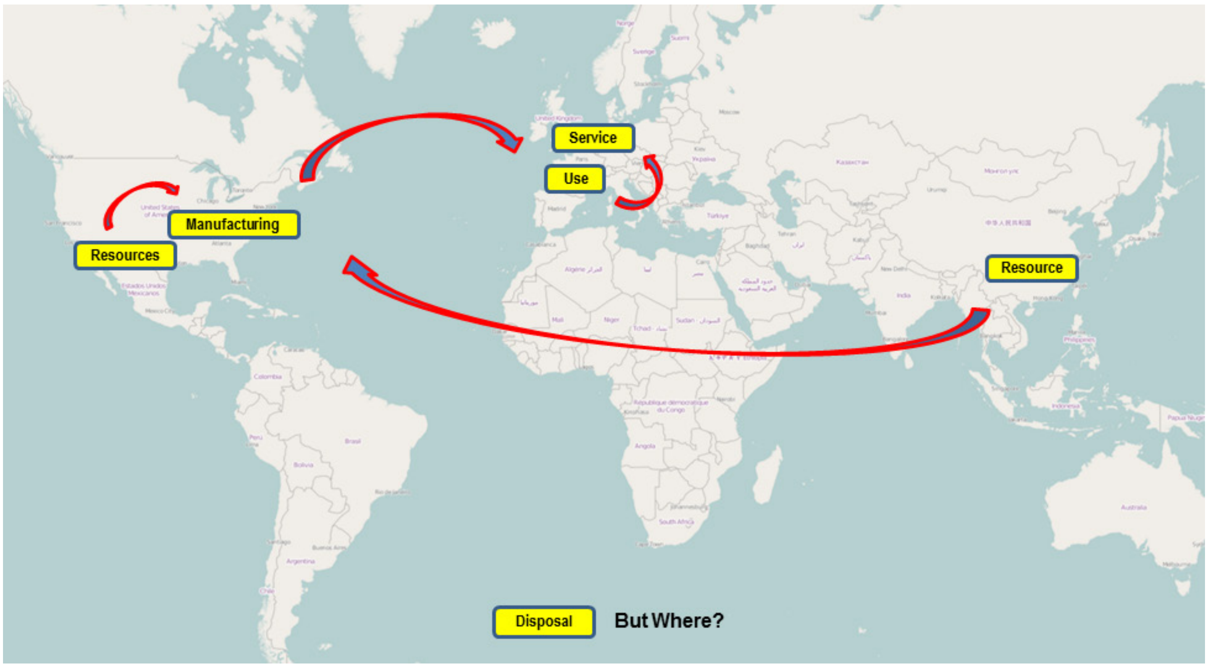

Figure 3. Geographical presentation of lifecycle steps for existing Flashlight

In order to redesign the flashlight based on specified region, we need to access all information related with lifecycle steps. This information is presenting by different layers through GIS. Figure 4 is an example about available biotic and abiotic resources for Champagne-Ardenne.

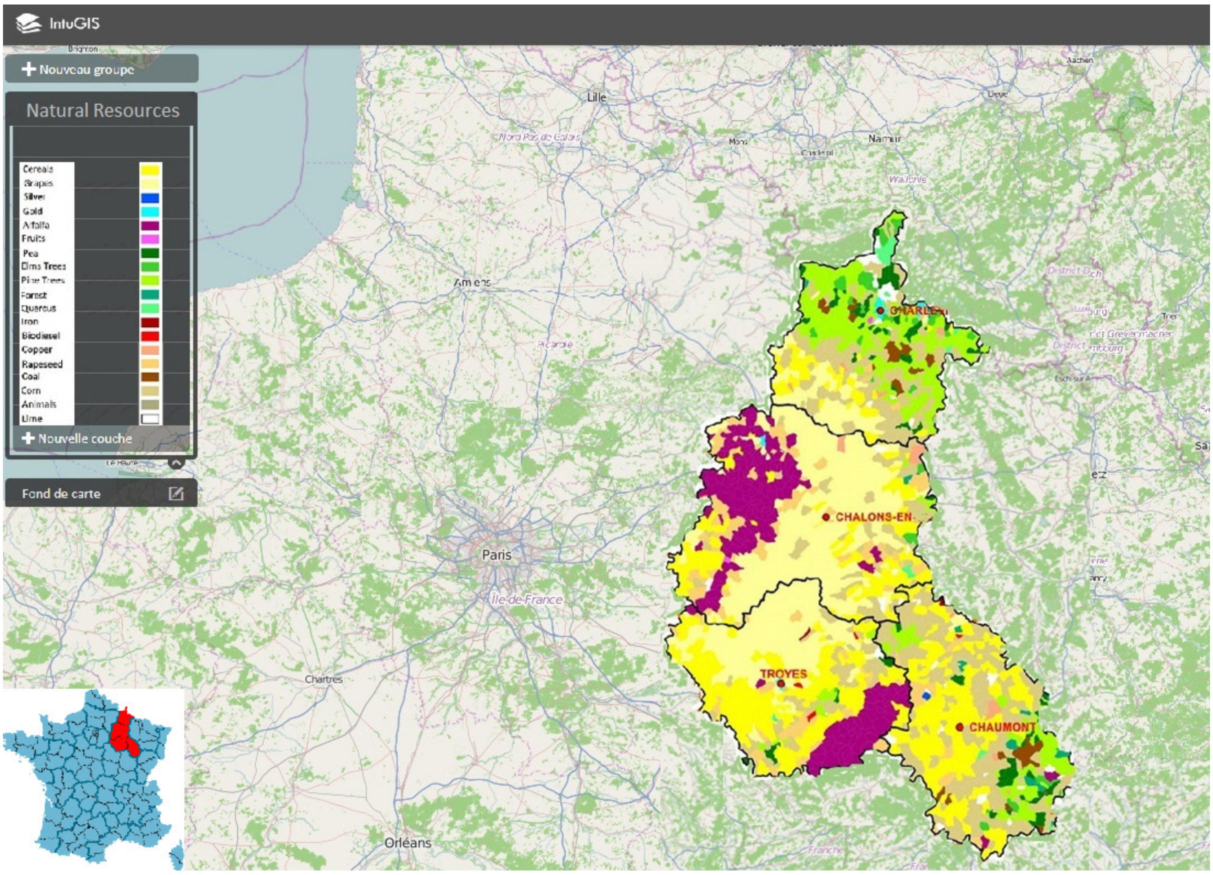

Figure 4. Available Natural resources in Champagne-Ardenne (France)

In original design, head, barrel and cap of the flashlight are made from polypropylene. In the new design, wood is replaced with polypropylene based on availability in the region. This change material then involves cascading changes on transformation processes to mobilize and organize the supply chain. The result would be a different product structure as shown in Figure 5.

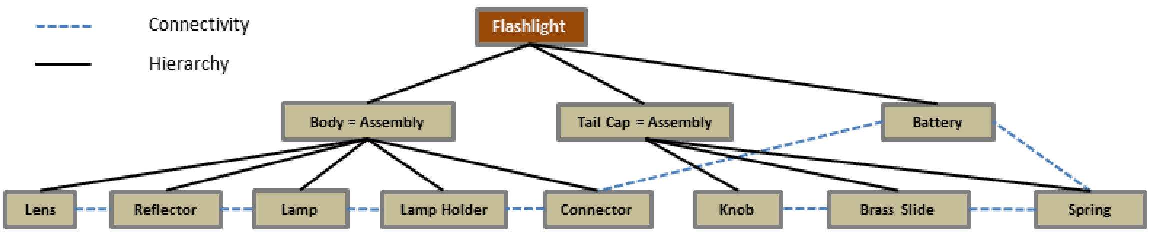

Figure 5. New product structure for redesigned flashlight

The new LCA results have demonstrated that replacing wood instead of polypropylene is better in term of environmental impacts and fulfil all initial requirements (Figure 6). In this study battery and LED are not considered, because these products are used in redesigned too.

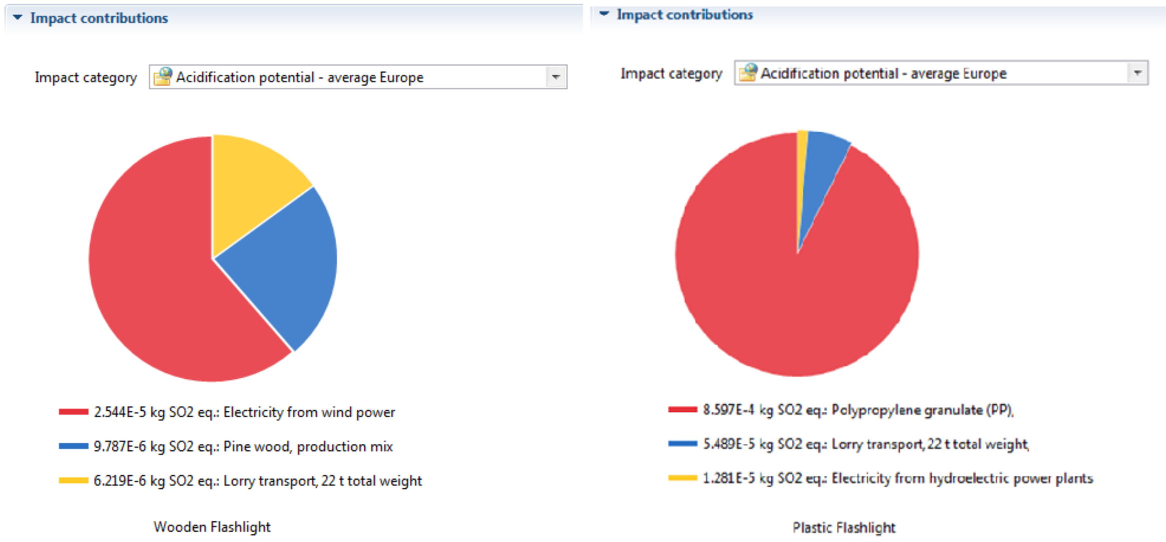

Figure 6. LCA results for wooden and plastic flashlight (OpenLCA)

Sulfur dioxide (WTW)
Acidification, damage caused to so.'s health [kilogram]

	TS Sea ship
Truck	12,04
Sea ship	8,93
Sum:	**20,97**

© EcoTransIT.org

Distances (WTW)
Distances per transport mode [km]

	TS Sea ship
Truck	2.506
Sea ship	6.652
Sum:	**9.158**

© EcoTransIT.org

Distance between Plant (US) and User (France)

Sulfur dioxide (WTW)
Acidification, damage caused to so.'s health [kilogram]

	TS Sea ship
Truck	0,47
Sea ship	21,17
Sum:	**21,64**

© EcoTransIT.org

Distances (WTW)
Distances per transport mode [km]

	TS Sea ship
Truck	251
Sea ship	22.496
Sum:	**22.747**

© EcoTransIT.org

Distance between LED supplier (China) and Plant (US)

Figure 7. Part of transportations and impacts (Eco-Transit)

Moreover, regionalization in product development process brings closer the different steps of lifecycle and causes a significant decrease in distance of transportation. In redesigned flashlight about 29000 km is decreased from overall transports (Figure 7).
Figure 8 illustrates the geographical distribution of lifecycle phases for redesigned flashlight with specific and clear plan for each step of lifecycle. When lifecycle steps of product are in regional scale, the supply chain will be shorter that makes it easier to manage the sustainability of product.

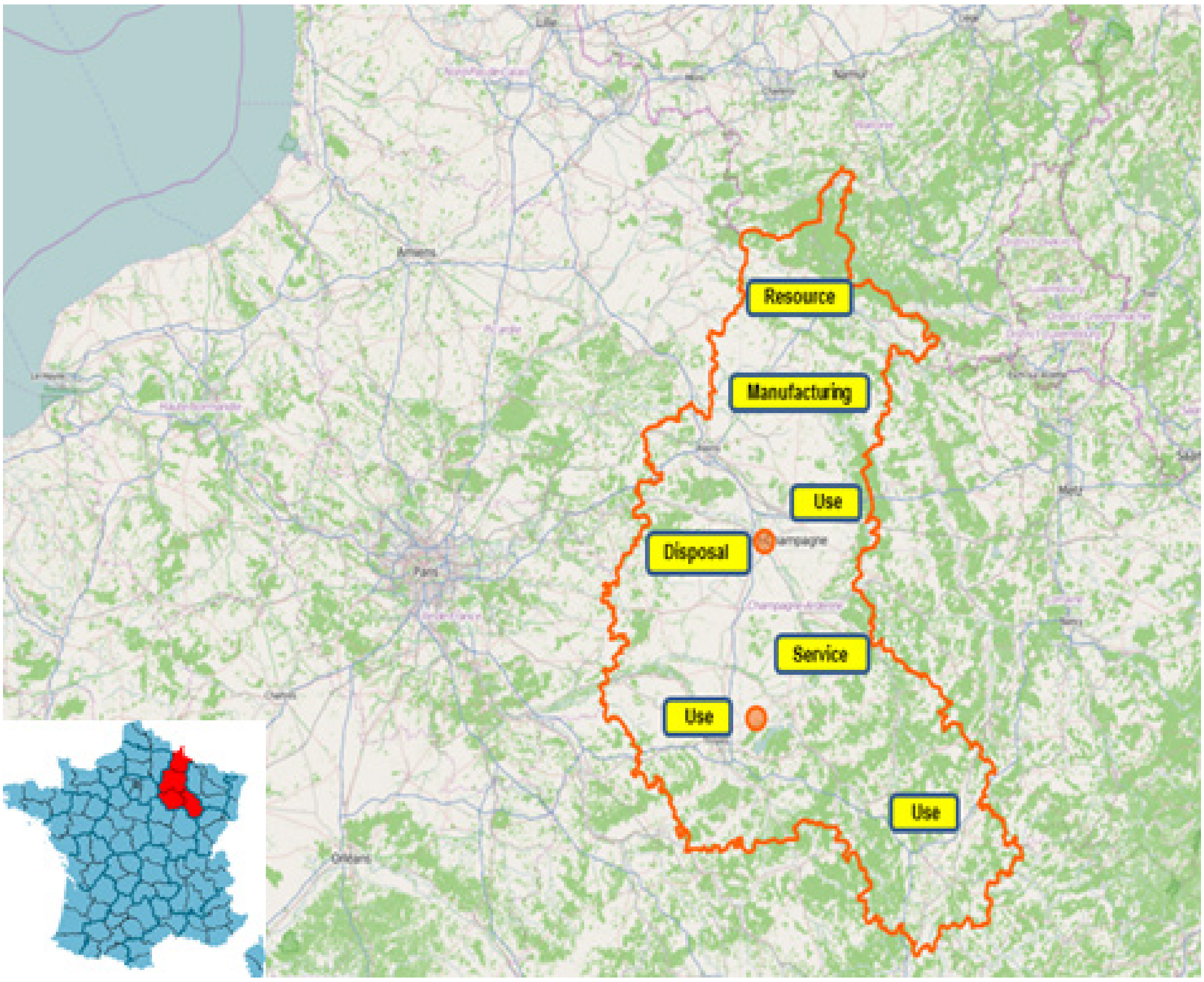

Figure 8. Geographical presentation of lifecycle steps for redesigned Flashlight in Champagne-Ardenne (France)

5 CONCLUSION

The case study is presented in this paper seeks to describe the relationship between the product (and its life cycle) and the territory. It had been achieved in order to evaluate the relevance to propose a new engineering design method, much more dedicated to territory specification, especially in terms of resources and use. The aim is then to change the usual reference data used in engineering design in order to better address sustainable development challenges.
The lighting case study shows the way local information and geographic data can be used in the design process in order to change design choices and then change the product lifecycle's environmental impacts.
This work must continue to consolidate and validate the assumptions made for the benefit of the provision of the designer new geographic information and impact to see if this allows eco-design products. The first step will be to use the case study in order to develop a specific design context to be used with students (first) and practitioner (second). An experiment will be built using control groups that will design a new system using usual information and experimental groups that will use added

geographic information. The objective of this experiment will be to compare the environmental impacts of the obtained results.

REFERENCES

Azaz, L. (2011). The use of Geographic Information Systems (GIS) in Business. International Conference on Humanities, 299–303.

Bartl, K., Verones, F., & Hellweg, S. (2012). Life cycle assessment based evaluation of regional impacts from agricultural production at the Peruvian coast. Environmental Science & Technology, 46(18), 9872–80.

Brimicombe, A. (2010). GIS, environmental modeling and engineering. CRC Press.

Burrough, P., & McDonnell, R. (1998). Principles of geographical information systems.

Da Silva, M. K., Guyot, E., Remy, S., & Reyes, T. (2013). A Product Model to Capture and Reuse Ecodesign Knowledge. In Product Lifecycle Management for Society (pp. 220–228).

De Oliveira, J. L., Pires, F., & Medeiros, C. B. (1997). An environment for modeling and design of geographic applications. GeoInformatica, 1(1), 29–58.

Fenves, S. J. (2001). Core Product Model for Representing Design Information. Citeseer.

Fenves, S. J., Foufou, S., Bock, C., & Sriram, R. D. (2008). CPM2: a core model for product data. Journal of Computing and Information Science in Engineering, 8(1), 14501.

Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., Suh, S. (2009). Recent developments in Life Cycle Assessment. Journal of Environmental Management, 91(1), 1–21.

Gero, J. S., & Kannengiesser, U. (2004). The situated function–behaviour–structure framework. Design Studies, 25(4), 373–391.

Hart, a., Clift, R., Riddlestone, S., & Buntin, J. (2005). Use of Life Cycle Assessment to Develop Industrial Ecologies—A Case Study. Process Safety and Environmental Protection, 83(4), 359–363.

Iochpe, C. (1999). Specifying analysis patterns for geographic databases on the basis of a conceptual framework. In Proceedings of the 7th ACM international symposium on Advances in geographic information systems (pp. 7–13).

Jarupathirun, S., & Zahedi, F. (2005). GIS as spatial decision support systems. Geographic Information Systems in Business. Idea Group Publishing, Hersey, PA, USA, 151–174.

Meyers, J. (1999). GIS in the utilities. Geographical Information Systems: Management Issues and Applications, 2, 801–818.

Mutel, C. L., & Hellweg, S. (2009). Regionalized life cycle assessment: computational methodology and application to inventory databases. Environmental Science & Technology, 43(15), 5797–803.

Mutel, C. L., Pfister, S., & Hellweg, S. (2012). GIS-based regionalized life cycle assessment: how big is small enough? Methodology and case study of electricity generation. Environmental Science & Technology, 46(2), 1096–103.

Niemann, J., Tichkiewitch, S., & Westkämper, E. (2008). Design of sustainable product life cycles.

Noël, F., Roucoules, L., & Teissandier, D. (2006). Specification of product modelling concepts dedicated to information sharing in a collaborative design context. Advances in Integrated Design and Manufacturing in Mechanical Engineering, 135.

Péti, M. (2012). A territorial understanding of sustainability in public development. Environmental Impact Assessment Review, 32(1), 61–73.

Sudarsan, R., Fenves, S. J., Sriram, R. D., & Wang, F. (2005). A product information modeling framework for product lifecycle management. Computer-Aided Design, 37(13), 1399–1411.

Vadoudi, K., Allais, R., Reyes, T., & Troussier, N. (2014). Sustainable Product Lifecycle Management and Territoriality: New structure for PLM. In PLM International Conference (p. 10).

ACKNOWLEDMENT

We would like to thank Florian Bratec for his cooperation concerning the GIS software.