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To cite this version:

Maud Rio, Florent Blondin, Peggy Zwolinski. Investigating Product Designer LCA Preferred Logics and Visualisations. CIRP 2019 - 29th CIRP Design Conference, May 2019, Povoa de Varzim, Portugal. pp.191-196, 10.1016/j.procir.2019.04.293 . hal-02530216

HAL Id: hal-02530216

https://hal.science/hal-02530216v1

Submitted on 7 Apr 2020

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Procedia CIRP 00 (2019) 000–000

www.elsevier.com/locate/procedia

29th CIRP Design 2019 (CIRP Design 2019)

Investigating Product Designer LCA Preferred Logics and Visualisations

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Abstract

Product designers are frequently subject to analyse the environmental lifecycle performance of the product they design through Life Cycle Assessment (LCA) results available to them. The LCA delivers multi-criteria and multi-environmental impact indicators results for improving the design of the product under development at any stage of the design process in any industrial context. Gaining time and precision in this LCA results analysis is crucial for product designers. In this view this research focuses on supporting an efficient matching between a product designer profile and some pre-formalised lifecycle visualisations, called heuristics. To do so this paper investigates product designer's logics in analysing LCA results, as well as their preferred visualisations in the interpretation process. The experimental protocol developed to capture these product-design oriented LCA analysis preferences (logic and visualisation) is presented. Capturing their needs regarding LCA results was the first part of this research, detailed in this paper. The second part is focused on building the visualisations satisfying theses needs. The resulting process of LCA analysis will be then assessed in term of efficiency. The short-term research perspective is to formalise those trajectories heuristics through an interoperable application adapted to the various types of software used in industry based on the LCA methodology. Additional profiles addressed by governmental or enterprise decision makers can be added in the coming years using the same methodology.

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Peer-review under responsibility of the scientific committee of the CIRP Design Conference 2019.

Keywords: Ecodesign; Design to Environment; LCA; Integrated Design; Life Cycle Engineering; Visual Analytics

1. Introduction: Design to Environment failing because of LCA results misintegration

The lifecycle approach is considered as a viable method to identify environmental hotspots in a DtE approach integrating the evolutions required in the industrial society [1]. This research investigates the opportunity and relevance into building-up some efficient visualisations based on singular LCA results' user profiles. Section 1 motivates this research in regard to the frequent LCA results integration failures occurring during the Product Design Process (PDP). Section 2 focuses the research problem on the functions satisfied by the main LCA visualisations and the potentialities offered by alternative visualisations customised for a given profile. The experimental protocol developed to capture these visualisation logic trajectories is presented in Section 3. This protocol includes a survey–Section 4–conducted to capture the product designers and LCA experts needs in visualising LCA results during PDP. Then a second part of this research consists in capturing and assessing the two user profiles' heuristics, introducing to the potential of Visual Analytics tools–in Section 5. The paper concludes in Section 6 to the development of an online-visualisation module interoperable to LCA software supporting pre-defined users profiles to generate an efficient LCA results visualisation for DtE.

Nomenclature

DtE Design to Environment
LCA Life Cycle Assessment methodology from the ISO Standard 14040-44
PDP Product Design Process
VA Visual Analytics

1.1. Research Context: LCA results misinterpretations

LCA results are subject to misunderstanding by industries' actors, such as product designers coming from different expertise. Product designers' LCA results misinterpretation alters the process of integrating a *peer default* environmental parameter into their design practice. Misinterpretation issues have several causes well known by academics [2] and approved by industries in real-life case:

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Peer-review under responsibility of the scientific committee of the CIRP Design Conference 2019.

- Technical failures: LCA tools are unadapted to product designers [3]. LCA results graphic representations are irrelevant for non LCA expert practitioners [4].
- Isolated expertise: environmental experts remain separated from product designer experts judging LCA results prone to too high subjectivity [5].
- Socio-cognitive failure: an insufficient awareness regarding the environmental parameter (eg. lifecycle vision, environmental impacts generation) due to some inappropriate training skills of designers, that bring them reticent to cooperate with the environmental expert [6][7].
- Limited cognitive capacities: inability to interpret the multidisciplinary information contained in LCA, and therefore, a difficulty to identify the links between the lifecycle stakeholders and their tasks to reduce the environmental damage generated [8].

A product designer needs as early as possible during the PDP an explicit graphical representation of his product LCA to capture the design choices consequences he generates on the product lifecycle [9]. LCA results credibility and legitimacy should be easily and rapidly evaluated by the product designer [6]. A socio-cognitive adapted visualisation should therefore support the followings [10].

- A quick interpretation of the relation between their proper, *i.e. known*, product design parameters and the *unknown* environmental parameters at each product lifecycle step [11].
  Any *reject effects* from actors confronted to graphic results representation differing from their usual working habits, preferences, or socio-cognitive singularities, may therefore be reduced or avoided.
- An explicit product technical functions and environmental criterion interrelations mapping [12].
  An efficient LCA results interpretation in regard to the product designer ability to change his design choices, may therefore be encouraged.

Based on these hypotheses several research Master studies have been conducted at the G-SCOP Laboratory since 2014 to investigate the product designers' LCA results treatment. Results showed that the majority of the product designers were using LCA in their product design projects to produce *gross* data. They were then choosing a relevant graphic for the design task they were assigned to (*i.e.* the viewer), translate the *gross* data graphically, and share them with colleagues. *The hypothesis* of this research is that some adapted IT supports covering the tryptic model-view-controller [13] can support this process of extracting LCA results, treating data, visualising LCA results, to gain efficiency in a DtE purpose–*i.e. control design choices in regard to the environmental consequence*. The following research question is therefore leading this research: **would any invariant sets of representation exist for delivering a relevant LCA results' process for a given user profile?**

2. Research focus: building-up data visualisations adapted for LCA results users

A heuristic is defined in this research as a predefined trajectory of information transferred through a series of visualisations adapted to a user profile. Product designers and LCA experts are chosen as in priority to create the heuristics.

2.1. Data visualisation principles

Visualising LCA results is subject to perception principles affecting interpretations [14] theorised by: **the Gestalt** *i.e. chape, form* principles in psychology–cf. [15] visual motor gestalt test and its clinical use–through a set of rules applied to visual perception based on the principles of figure-ground articulation, proximity, common-fate, similarity, continuity, closure, and past experience; eg. of application to animated visualisations of network data on [16]; **Kandinsky** through the form grammar related to points, lines, and plans; as well as **Bertin's graphic semiology** using visual image propriety to show data order and similarities relations; opening to diagrams, networks and topography [17]. Graphic representation varies through forms, size, value, orientation, color intensity-value-hue, graininess (texture), space dimensions (line, area).

Lectures can be fixed, animated in a defined timespan, and interactive in real time through manipulations [18]. The DataViz catalogues[1] ranks common visualisations used to communicate informations that are used by LCA practitioners to display results and to interpret them [19]. LCA results are displayed in a matrix combining the environmental impacts, such as Global Warming, Water eutrophication, Resources depletion, etc. (in specific units), with the lifecycle stages, including any processes included in the scope. Comparative percentages values can be constructed as meta-data at any stage and for any process considered. Additional statistic calculations are added to asses the relative sensibility of the results to be compared.

2.2. LCA visualisation assets and issues

Discrete, and numerical comparison. LCA results are frequently presented through vertical bars charts, also called histograms. Bars charts are adapted to show discrete, and numerical comparisons across environmental impact indicators or lifecycle stages. For a given environmental impact category, the horizontal axis of the chart would for instance show the lifecycle stage damage contribution represented as a discrete value, scaled on the vertical axis. The bar length equal to the value amount, enabling comparisons between bars. Labelling categories is however restrained to a limited space relatively to the number of bars.

Bars Charts are displayed through various sub-categories in a complex LCA, potentially dealing with a dozen of environmental impact categories for the chosen environmental impact

[1] Commercial websites: search by functions or list, e.g. on: https://datavizcatalogue.com, accessed on February 2019

calculation method, as well as detailing lifecycle unit categories and processes modeled in the study. In addition, LCA scenarios are meant to be compared together, and some sensitivity analysis are required to evaluate the scientific relevance of an ISO 14 040 standard study. A Multi-set Bar Chart therefore better captures the distribution patterns and the relationships between scenarios. It is mainly used to plot side-by-side two or more data series (scenarios), grouped together under a lifecycle stage for instance, on the horizontal axis. A Candlestick Chart would rather display a result interval obtained from a mathematic calculation (e.g. in statistics, Monte Carlo analysis).

The notion of proportion would rather be brought by Stacked Bar Graphs, in which bars are segmented of multiple datasets. A lifecycle stage is for instance divided into smaller unit categories, displaying the relationship of each singular part on the total amount. Heterogeneous baseline values complicate any comparison to make. Choosing a percentage Stack Bars Graph therefore enables to plot the percentage of each value the total amount in each group in a relative perspective.

Relationships, interdependence: systemic vision. A Bars Chart may fail in delivering the systemic dimension of LCA: relationships, dependance between items and sub-items, are rather related to the Tree Diagram in LCAs. The sources of an impact can be identified in a reverse manner. Zooming to a desired degree of detail supports a system-based analysis. In addition flow quantities' variations can be made visible with the Sankey Diagram features. The Sankey Diagram–rather used in Mass Flow Analysis (MFA)–displays some flow magnitudes through lines or arrows width. Lines or arrows can be split or combined together at each node of the tree, or at each stage of the process modeled in a gate-to-gate environmental impact analysis for instance.

In [20] usual LCA visualisations are evaluated through their capacity to address the multiple impact categories, the contribution of lifecycle phases and of the system elements, the trade-offs, the spatial effects, as well as the decision implication they procure. Heat maps widely used in biological sciences are originally introduced by the authors to display LCA results on the totality of those criteria–except the spacial one–together. This research results shows that (1) other scientific domain (eg. biology) can bring new visualisations, and (2) that there is no consensus on the number of visualisations required to cover the main LCA results facets (x separate visualisation in different orders *vs.* one merging all aspects).

Therefore, to summarise this subsection, visual information has the power to convert multi-criteria LCA results in easy to understand graphics to a certain limit of complexity. Fig.1 synthesises some common graphs used to satisfy a given function, and some functional alternative. A visualisation can also deliver some implicite functions. The cognitive load involved by the person in charge of the data treatment charged in the chosen visualisation is a major assessment criterion to consider to choose an efficient visualisation.

2.3. Problem statement: matching users' profile needs to pre-defined visualisations

LCA results are displayed in a very limited number of graph. In regard to the power of data visualisation there is an opportunity of gaining efficiency in the LCA results understanding. A majority of LCA graph representations could be therefore ensured by other charts covering similar functions, and offering additional ones, *cf.* Fig.1

Problem statement: analysing LCA results is a complex task requiring several steps ensuring distinct functions. The **hypothesis** made is that a series of successive steps supported by complementary data visualisations would draw a relevant trajectory for a given profile. Heuristic may be pre-defined based on customised data visualisations.

Function	**Main LCA graphs**	**Alternatives**	*Illustration*
Discrete Numerical comparaison	Multi-set Stacked Bar Radar	Bullet Radial Column Nightingale Rose	
Ranges	Candlestick Error Bars	Box and Whisker & Violin Plot	
Relationships Hierarchy	Trees Diagrams	Parallel, CoordinatePlot, Dendrogram Sunburst Diagram	
Proportions	Pie Chart	Tree Map Circle Packing Marimekko Chart	
Flows	Sankey diagrams	Flow map Parallel Sets	

Fig. 1: Product designers needs visualisation

2.4. Research output evaluation: combining mental effort and visualisation efficiency to assess heuristics

The product designers and LCA experts related needs in analysing LCA results should be firstly identified. Then the visualisation effectiveness to support a given user task can be calculated by his time to respond, and his accuracy in answering to this need. However in the complex task of LCA results analysis the cognitive load is a factor of high impact. A same graph can deliver the same information while generating a higher cognitif process. Mental effort and visualisation efficiency should be combined. This research therefore proposes to measure the heuristic effectiveness by integrating the cognitive load involved in each visualisation treatment, based on [21].

3. Proposal: capturing and assessing profiles' visualisations

An experimental protocol lasting 18 months has been developed to capture the product design oriented LCA analysis visualisations and logics preferences, and assess the process efficiency, for the product designers, and LCA experts.

Part One: profile selection based on a creativity session conducted by an expert comity composed of researchers in

product design, as well as, consultant in ecodesign: elaboration of two personae identified as the key actors for interpreting LCA results. Product designers and LCA experts personae have been built. **Profile needs**: elaboration of a list of LCA results' needs based on a creativity session, and a literature review; then, selection of the main needs by survey 1.

Part Two: **visualisations generation:** for answering to personae' needs, assessing visualisation efficiency with a creativity session and a survey 2. **Heuristics trial**: based on long interviews from the detection of survey 2 invariants and irregularities. **Demonstrator**: development of an operational web application to generate efficient visualisations specific to the personae. The **Validation of the research results** is based on feedbacks and measurements of the global efficiency of LCA results treatments using the demonstrator.

4. Part One case study: identifying the personae needs

4.1. Building-up survey 1: LCA results functional requirements

The aim of survey 1 was to identify and hierarchise the needs of each personae visualising LCA results.

First, a list of potentiel needs have been generated from a literature review [7][3] [6][23][24] [27]. **A product designer** creates his own value scale, or hierarchy between impact indicators, to be able to classify the functional structure of the product under development for each environmental impact indicator he chooses [22]. He may evaluate for instance, the environmental impact of a material ratio chosen for a component (component material mass / total product mass). He needs to access to high quality level environmental information, precisely linked to his design choices, and limited in quantity [8]. As a designer needs to make some design improvements prioritisation. His analysis may require some creativity support and decision making aid [10][26]. A value scale can be imposed to him for addressing legislative or regulatory aspects [30]. Comparing the environmental impact of his product to a similar functional product, a reference product for instance, could be required [25]. He needs to find the environmental impacts: generated by the specific material flow chosen in his product component [4], as well as, associated to each technical functions satisfied by design solutions [12]. Evaluating the credibility and the legitimacy of the LCA results he analysis should be eased [9].

A LCA expert either internal or external to the company, needs to communicate LCA results to people having a lower expertise than he has [11]. He addresses the complexity behind LCA [28], and build results accessible at a macro, meso, or micro scale [29] to fit the LCA goal and scope.

Second, an alpha test of survey 1 with a small batch of product designers, and LCA practitioners has been conducted leading to: clarifying questions, reducing time spent in answering, trying all answer trajectories possibilities, designing survey for an efficient results collection, and data treatments process. These needs have been translated into functions required by LCA results visualisations, ranked into main categories.

4.2. Conducting survey 1: capturing main LCA results functional requirements per target personae

The online survey 1 was spread nationally in France from Nov-December 2018. Respondents have been targeted using LCA, product design and engineering practitioners' networks: from industries, engineering organisations, consultancy agencies, as well as academic researchers. Results have been collected automatically.

The online interviewee had first to select his familiarity with LCA (high/intermediate/low). Then he had to present the organisation he was part of, and his role in this organisation (open answer). In case of unfamiliarity with LCA, the interviewee was directed to a video from the french environment and energy management agency–ADEME presenting LCA, and exit the survey. In other cases the interviewee had to select the personae profile he was the closest to. Product designer and LCA expert personae were respectively linked to the preferred list of LCA results functional requirements presented in the subsection 4.1. Any other profile exit the survey. The interviewee had then to select the three main needs encountered in this list of LCA results potential functions. He had the possibility to prioritise his selections in order of importance.

4.3. Survey 1 results: preferred LCA results functional requirements per personae

The Survey 1 captures about 90 answers of respondents included in the survey targets. The results are presented in Table 1 for product designer needs and Table 2 for LCA experts. Around 25% of interviewees were product designers and the rest LCA experts involved in PDP. A workshop has been conducted to analyse survey's results and converge to two main needs for both profiles. The *involved actors* were researchers in product design and ecodesign. Results show that the two target expressed different needs, which means that the personae have been correctly treated distinctly through the survey process.

Table 1: Survey 1 results: Product designers LCA Results visualisation needs

Product designers visualisation expressed needs	**%**
To identify where the impacts come from	36
To know where I need to put the efforts to make a significant difference	29
To choose components with consciousness	7
To choose processes with consciousness	7
To know the environmental impact of each product technical functions	7
To evaluate the credibility of a LCA	7
To compare the product to the same product range average	7

Fig. 2 illustrates Data Visualisation assets in presenting Table 1 content. Each bubble presents a need expressed in keywords quickly readable. The bubble size varies proportionally to the percentage values associated to each need. Bubbles have separate degree of grey to be differentiated in sub-categories. The three right side ones expressed in the same grey intensity are close in meanings: choosing best design, process, and component satisfying functional requirements.

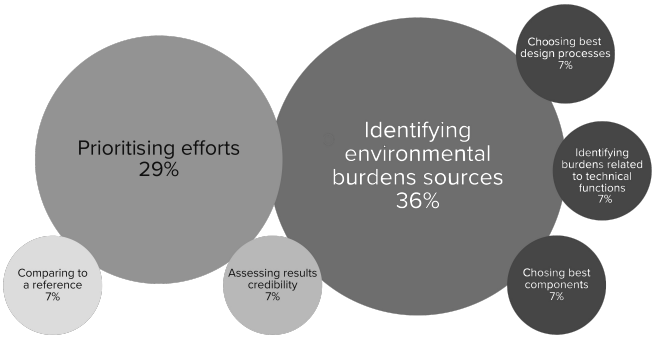

Fig. 2: Product designers needs visualisation

Product designers clearly expressed LCA results as required to help them identifying the environmental burden sources of the product they are designing. They want to be able to prioritise their efforts.

Table 2: Survey 1 results from LCA experts LCA Results captured visualisation needs

LCA experts visualisation expressed needs	**%**
To check the coherence of the hypothesis taken in the LCA	29
To identify on which life cycle steps the product is environmentally efficient (or inefficient)	23
To extend LCA databases	13
To check the coherence of the LCA with some norms and related PCR	10
To know on which impact indicators the product is efficient or inefficient	10
To check the results coherence with other LCA similar goals and scopes	3
To create new LCA models (LCI, impact indicators, etc.)	3
To check the coherence of the LCA scenario taken	3

5. Part Two: capturing preferred profiles' visualisations

5.1. Data visualisation in VA: a powerful support for LCA

The Data Visualisation (sub-section 2.1), is indeed part of the Visual Analytics (VA) among other sub-disciplines [31] [32], such as the **analytical reasoning technics** aiming at generating ideas and understanding them to support planning and decision making; the **visual representations and interaction technics** to view, explore and understand large amount of information at once by using human perception and cognition sciences; the **data representations and transformations** converting all type of conflicting and dynamic data in ways to support visualisation and analysis; and, the **production, presentation and dissemination technics** to support communication of the information or the results in the appropriate context to different types of viewers. VA therefore combines information visualisation technics with computational transformation, and with data technics analysis. Efficient human cognitive capabilities for LCA results visualisation would therefore be facilitated with such a tool by:

- amplifying cognitive sensors, *eg.: expanding product designers working memory using visual interfaces between their IT environment and the LCA software results.*
- reducing search/lost; *eg.: using a small space to represent the large amount of data embodied in LCA results.*
- enhancing the pattern recognition; *eg.: organisation of lifecycle product data in a similar pattern than the Computed Aided Design tree structure used.*
- supporting easy reasoning; *eg.: using preferred diagrams to induce cause-effect linkage between the product designer's parameters and their environmental impact consequences.*
- providing interactive medium; *eg.: interactive graphics with manipulable parameter values to support the product lifecycle scenario comparisons and identify hot spots, to generate sensitivity analysis.*

This powerful potential of VA tools bridging *" (1) data-driven approaches for lifecycle data collection, modeling, simulation, and analysis, (2) creation of computer-supported, interactive visual interfaces for presenting lifecycle data, and (3) application of domain knowledge from sustainable lifecycle design"* is detailed in [33] significative review. VA considerably surpass this research project perimeter. A reasonable scale to operate to measure the effectiveness of some heuristics on the two targeted users is therefore a priority. This requires measuring the effect of the user process, much involving his cognitive load as mentioned by [21], as well as the IT support procuring the user's reasoning space within a dedicated environment. A creativity session has therefore been conducted at the G-SCOP lab to prospect about the complexity of generating efficient visualisations satisfying Survey 1 target users needs with researchers in design, not necessary familiar with LCA.

5.2. Prospecting heuristics complexity and associated potentials: feedback from a creativity session

The goal of this workshop was to put researchers in a position of generating their preferred visualisation of LCA results from the one of another colleague to fulfill a need. Two LCA results standard bar charts were provided in a context of redesigning a jacket generating less environmental damages. The LCA visualisation need written at the front page was *to understand efforts to be made by identifying the environmental damage sources*. A data visualisations catalogue was given to the researcher to help them choose a preferred alternative visualisation. The researcher had to draw this new visualisation and give it to another colleague while hiding the initial visualisation. This process was reiterated 3 times. At the end, the visualisations slew was unfolded to display the 4 stages heuristic that had been co-constructed. This heuristic served as a basis to discuss about the criteria to criticise their effectiveness.

This study was very limited: in size, in participants profiles (researchers), in its informal format, etc. Results cannot be generalised. However some observations made during the experiments and on the visualisations obtained bring new parameters to consider in the next project steps. Participants fa-

miliar with bar charts would rather add complexity to the chart to combine different functions together, rather than change the type of graph. A higher LCA results treatment cognitive load was endurable, due to a familiar pattern recognition based on habits and LCA related knowledge capitalised. Icons were used in proposed visualisations to ease lifecycle stage representation or to find out design parameters, such as the product component. Icons were also used as a medium for answering to *where should I concentrate my efforts, and which associated intensity?* through a podium, or a lever. Finding alternatives to catch notions of relative quantities and being able to compare environmental impact generated by the product components have emerged as a constant. Each visualisation that failed in translating some fundamental LCA results notions, such as lifecycle stages, quantities, components, consistently reduced the quantity of information displayed by the next visualisation, lost for the other one following. Participants notified the trouble caused by the resulting lack of information in written remarks next to their draw. This shows the complementarity of visualisations, willing to catch some information but forgetting others, therefore, the necessity to support a series of customised visualisation. Measuring time, accuracy, and effort in using a given heuristic have appeared to be required parameters to measure the visualisations efficiency, in regard to the visual complexity and the LCA results treatment objective complexity of the profile task.

6. Conclusion

This paper addresses the challenge of identifying some invariant parameters for delivering an efficient set of LCA visualisations for a given profile. Product designers and LCA experts have been chosen as the two-first profiles. Their respective LCA visualisation needs have been identified in a survey gathering 90 targeted participants advices. The second part of this research project is to formalise those heuristics through an interoperable application adapted to the various types of standard based LCA software used in entreprise, and to conduct surveys to assess their efficiency. Additional profiles addressed by governmental or enterprise decision makers can be added in the coming years using the same research methodology.

Acknowledgements

This research is supported by the EcoSD network and the ADEME. Product designers and LCA communities mobilisation for surveys and workshops has been much appreciated.

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