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A Design to Environment Modelling Approach based on Time Variation Networks

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Abstract

Multidisciplinary collaboration from different domains and expertises became a necessity to address the environmental aspects in innovative design decisions and development. Designing to Environment involves overlap of information used and created by the diversity of product design expertises. It remains difficult for product designers and environmental experts to interrelate their respective parameters. This prevents product designers to converge toward environmentally aware design choices. This research therefore investigates the use of time Parameter Network Models to follow the emergence of environmental parameters linkage with product designer expertises' parameters. An industrial cooker hood design process case study explores the co-creation of local environmentally-aware knowledge between product designers based on this parameter linkage. Interesting opportunities are identified to furthermore translate parameter linkage in transformation rules between entities and parameters models. After instantiation such rules would allow dynamic and flexible information exchanges between product designers' and environmental expertises' activities along the design process.

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Keywords: Design to Environment (DtE), Integrated Design, Design Parameter Modelling

1. Introduction to DtE

Designing to Environment (DtE) demands the environmental parameter fully integrated within other parameters to achieve cost, quality, and technical performances of the object designed. Such "object" represents the products, services, and systems in general. In this research the environmental parameter refers to any factor influencing the lifecycle stages of the product or service that generates a positive of negative potential environmental impact.

The main barrier to DtE considered in this research is a deficient or lacking link between product design parameters and the environmental ones. Then if such links (from *local knowledge*) are made dynamically during the Product Design Process (PDP), the second barrier to DtE considered is the capacity of the information system in place to make the environmental expertise be part of the decision process of object under development.

This paper explores the use of the Time Variation Networks [1] to address those two issues together. Section 2 sets research objectives. Section 3 proposes the method applied on a case study illustrated in Section 4. Then Section 5 discusses case study results in regard to the research objectives. Conclusion in Section 6 highlights the added value of this paper and addresses the next research perspectives envisaged in a wider collaborative research program.

2. Research context and objectives: exploring time variation network to support DtE

The PDP is defined in systematic design by the three and overlapping stages of conceptual design, embodiment and detailed design stages [4]. Precise and concrete representations of the product artefact are obtained from design activities [2]. Such representations specify entirely and explicitly the product to be developed. In practice every product lifecycle expert stakeholder (material, industrial, mechanical experts, etc.) [3] produces a singular product representation. Problem solving and building common representations are collaborative activities enabling product designers to meet the deliverables required to produce a product.

In an integrated PDP the contributors intervening at any time during the product life (manufacturing, use, recycling, etc.) have therefore to be present in order to give their specific constraints [5]. The resulting designed object is a compromised representation of the integration of the object lifecycle stake-

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holders' point of view (including expressed knowledge, constraints and specific objectives of each expertise). Design is therefore a cognitive activity building on evolving product designers' knowledge and arguments integrated together [6].

In this research expert's knowledge are considered as *local*, i.e. with a contextual meaning that demonstrates its singular relevance [7]. *Local* environmental expertise knowledge provides a complex multi-criteria, and transversal, product environmental lifecycle view during a DtE process. This *global or transversal* view is hardly translated to product designers' *local scale* of knowledge. Resulting *Design for X—recycling, reusing, remanufacturing, efficiency, etc.* methods (eg. guidelines) may be too generic to be relevant to a *local* product designer. Complementary environmental and product designers expertises' models federation [8] can support a dynamic and bilateral information exchange between those expertise activities. Interoperable systems based on federation are specifically built to take into account the collateral impact of a local product designer's choice on the other expertises' choices linked to the environmental parameters. To do so, the *knowledge transformation* between environmental and product designers expertise (i.e. data models, relations) have to be identified before being useable in IT systems.

A review of the literature showed that the Time Variation Parameter Network Models developed by Kondoh and Kishita [1] offers an interesting support to the *local* expertise representations made during a PDP. An exploratory case study is therefore conducted in this paper to observe the relevance of parameter network models construction in presence of the environmental expertise, in making apparent the integration of local environmental parameters into local product designers expertise own network. The analysis of the resulting parameter network models could be a way to explicit *knowledge transformations* operating at the interfaces of product designer and environmental expertises. From this hypothesis studying the resulting IT system ability to support a DtE process [9], evolving with time spent in that process, will be addressed in further research work.

3. An Exploratory Research Method to define future work orientation

In a PDP context involving product designers and environmental experts the following method is applied:

- Construct four successive Parameter Network Models [1] during time-successive project reviews.
- Identify the emergence of environmental relations and parameters linking the product entities under development, within the PDP including environmental impact analysis.
- Explore the possibilities of establishing causality links based on Parameter Network Models to build evolutive *transformation knowledge, or rules* between environmental and product designers' expertise models [8] [10].

The research progress is leaded by the following question: which opportunities offer Parameter Network Models to enable the design team learning from the interactions created at the model scale to support DtE processes being the product design processes *per default*?

Answering this question addresses perspectives to prepare a stronger collaborative research program for: the construction of favorable DtE patterns based on capitalised and contextualised knowledge transformation rules, and supports specification (i.e. material and social conditions) for the co-creation of environmentally aware knowledge in integrated design (cf. [12] method).

4. Case study

4.1. Product Design Process context of DtE

The case study is conducted in a context of designing a cooker hood. An environmental expert is in charge of studying and minimising the product lifecycle environmental burden (only carbon footprint and energy consumption impact indicators assessments are presented in this paper). The environmental expert interacts with the other product design expertises during the PDP (including material, mechanical, manufacturing product designers, as well as marketing, ergonomic and safety standards agents).

The PDP involved experts in building their own parameter network model translating their *local* expert view of the existing relations between their parameters concern and the product entities. During the project reviews snapshots of shared *local* experts' views are formalised in four time-successive parameter networks: stage I (before and after lifecycle assessment), II and III of the PDP. They are presented in the following subsections. Iterative streamlined environmental lifecycle analysis are conducted by the environmental expert between the project reviews.

4.2. First parameter network model before LCA results

At the early stage of the PDP the product designers share their own views of the cooker hood to the project manager. Resulting from this *kick-off* meeting the first parameter network model presented on Fig. 1 merges product designers views on the electric motor related parts of the product. Expressions of the cause-consequence (i.e. relations) between product design parameters and the environmental consequence on the product lifecycle design choices, appear around the motor, the lamps, and the air blower components. In the work of Kondoh and Kishita [1], the *parameters* are used to refer both attributes and properties associated with an entity concept (cf. Yoshikawa's general design theory [11]). Fig. 1 captures the design entities (eg. blower) inside the rectangles, the expertise parameters in the oval (eg. air flow debit), as well as relations through hexagones (eg. noise emission should be less than 68 decibels). Changing scale make links become fuzzy (eg. lamps are subject to sound emissions).

The cooker hood first design specification shown on Table1 is formalised by the product manager and shared with the product designers and the environmental expert at the end of the PDP stage I.

From the environmental expert's first glance a few design parameters influencing the environmental lifecycle performance of the cooker hood are identified. For instance, the power consumption during the use stage depends on the type of electric motor chosen to deliver the required function (air flow), the lamps to light up the cooker space, and the electronic de-

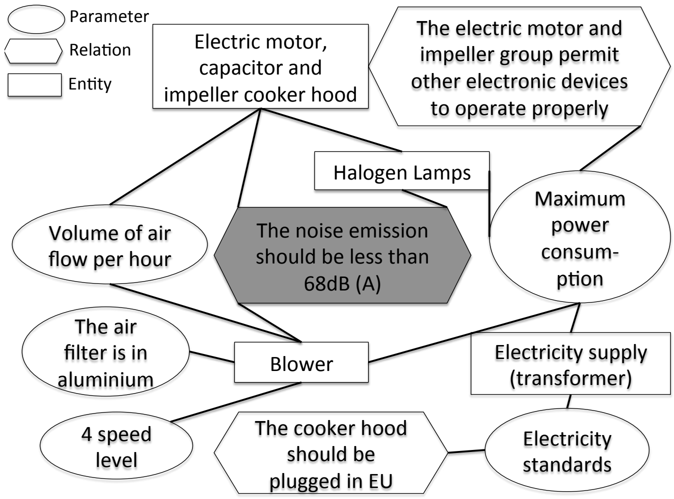

Fig. 1. Cooker hood early design stage parameter network model.

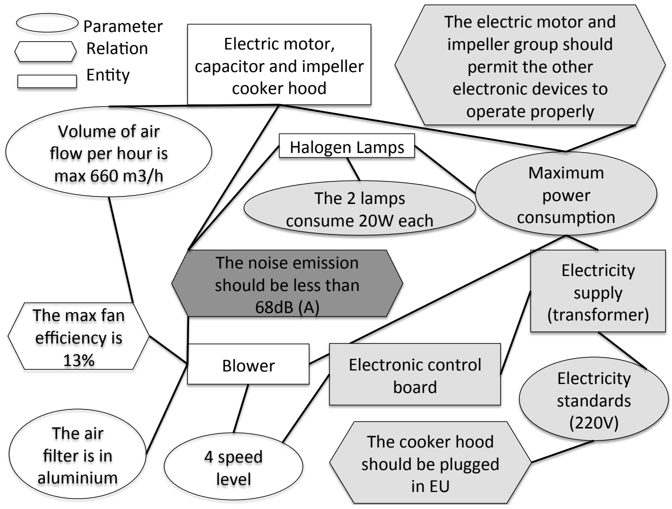

Fig. 2. Parameter network model of the cooker hood at the end of PDP stage I.

Table 1. Early design stage cooker hood specification and design parameters related to the environmental considerations.

Design specifications	Quantity (*Unit*)	Parameters
Maximum air flow	660 *m3/h*	For maximum speed
Maximum power consumption	230 *W*	Electric motor
Speed number	4	Electronics
Noise emissions	68 *dB*	Aspiration and motor
Lighting	2 halogen lamps	Energy consumption
Air filter	one unit	Aluminium

Table 2. Early design stage lifecycle assumptions made to conduct the first streamlined LCA of the cooker hood.

Cooker hood lifecycle	Characteristics
Raw material	Procurement, extraction, transport
Manufacture	Including the majority of components
Transport included	Local and foreign suppliers, distance from manuf.
Transport exclusion	Finished product to the final user
Use	Based on a EuP study on cooker hood users
	Ventilation and lighting devices during 2h per day
Disposal	Recycle household appliances stat. (WEEE, 2002)
Simplification rules	Small parts accounting for less than 1%
	of the total hood weight simplified manuf. models
	of the purchased components (manuf. and mat.)

vices controlled by an electronic board. As the result additional relations, parameters and entities related to environmental concerns–colored in grey, are added in the second Parameter Network Model (Fig. 2) drawn by the project manager during a stage II project review.

4.3. Parameter network model constructions after LCA results

The environmental expert then conducts a streamlined LCA based on the first design specification agreed by product designers at PDP stage I during the product review. The LCA study aimed at (1) identifying the environmental hot spots, and (2) proposing alternative design solutions to reduce the negative environmental impacts of the most critical cooker hood components. The functional unit describes a standard size, steel cooker hood of medium-high category, both in terms of cost and of extraction efficiency, with a maximum air flow of 660 m3/h, a maximum fan efficiency of 17%, an electrical motor consumption of 230W and two 20W lamps. The considered lifetime is 9 years. Assumptions are made for the cooker hood first lifecycle model in collaboration with the product designers, as summerised in Table 2. A third parameter network model (Fig. 3) is built at this moment during the PDP stage II project review with the project manager, merging the product designers and the environmental expertise view on the cooker hood. Black coloured parameters, relations and entities capture the growing environmental concerns in the design team. Based on the lifecycle inventory conducted by the environment expert (Table 2), Table 3 shows the first streamlined environmental impact results conducted on the cooker hood lifecycle model under development. The major environmental impacts are generated during the use stage (around 99% of energy consumption and CO2 eq. emissions). Raw material extraction accounts for about 9% of the total footprint, the other lifecycle stages (eg. transport and end of life disposal) account for less that 1%.

The project manager following up on the project formalises the third parameter network model (Fig. 3). New links and relations appear between the product entities and the expertise parameters having an influence on the environmental hotspots during the cooker hood use stage. For instance, the noise emissions depends on the blower, but also on the electric motor, and the halogen lamps.

The first streamlined LCA results and the relations established between the product entities through the third parameter network model helps the environmental expert to build some alternative design scenarios. The resulting comparative LCA on alternative lifecycle scenario shows a reduction of energy consumption during the use stage, while maintaining product design expectations in terms of functional performance and lifespan (a second LCA is performed). The alternative lifecycle design scenario focuses on the electronic devices: the electric motor, the lighting components and related end of life treatments (compliance to Electronic and Electric devices Waste European directive - WEEE). Based on these results expressed by the environmental expert during the PDP stage III project review, a fourth Parameter Network Model (Fig. 4) is established. Environmentally concerned guidelines appear in the relations hexagons linking expertises parameters and design entities to-

Table 3. Extraction of streamlined LCA early design stage results of the cooker hood: energy consumption and CO2 emissions.

Cooker hood lifecycle stages Streamlied software used	Energy consumption (%) Granta MI©	CO2 (%)
Raw material extraction	9.7	9.5
Manufacture	0.6	0.8
Transport	0.8	1
Use	88.8	88.7
Disposal	0.1	0.1
End of Life recovery	*-907 MJ*	*-43.8 Kg CO2eq*

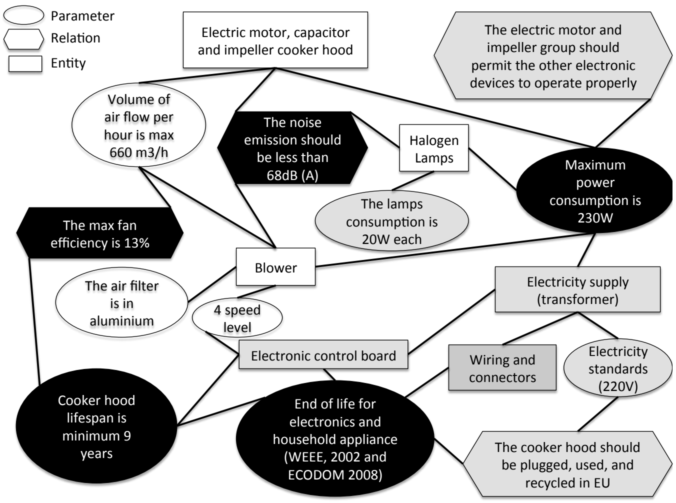

Fig. 3. Parameter network model of the cooker hood after streamlined LCA results during PDP stage II

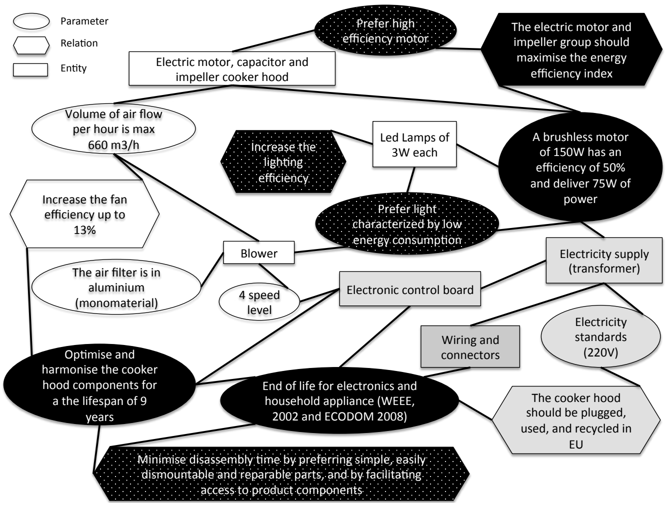

Fig. 4. Parameter network model of the cooker hood at stage III of PDP with environmental guidelines appearing from LCA results treatment

Table 4. Example of model transformation rules capitalised through Parameter Network Models.

Transformation rules, eg.	Characteristics
Calculation rules	Predefined formulas and parameters *Links between entities concerned*
Energy consumption and conservation	Energy formula *Link to models containing electronics eg.: in PLM and BOM*
Frequencies, effect, etc.	User scenario

gether.

4.4. Knowledge transformation rules captured through Network Parameters Models

Figures 1 to 4 show the emergence of correlations between environmental and other product designers parameters during the PDP. Such cause-consequence links are clarified during project review. Models are shared in an explicit way between the product designers and the environmental expert. Parameter Network Models are therefore able to (A) capture the inner complexity of multi-expertise dependance. And (B) project reviews offer spaces to share this intrinsic parameters interdependency knowledge between stakeholders.

(A) can improve collaboration: anticipated models of links can be made between multi-expertise parameters to facilitate the information exchange between the expert activities manipulating parameters specifying the product entities. Such *transformation rules* (cf. Table 4) can be expressed in meta-models to support (when instantiation occurs) bilateral and flexible data exchanges between different software (different data format, syntaxes and grammar). Links are defined but, they are only used if informations are present locally. The information is transmitted from a local activity to another to be interpreted in local semantics, which is necessary to perform DtE. This local model federation is different from mappings based on Knowledge case Base Reasonings (KBR). In KBR the context is also contextualised. However the information exchange is rarely bilateral which hardly supports Agile PDP information exchanges required in DtE.

However an information transmitted in a flexible and dynamic manner (evolving iteratively) does not guarantee the creation of a local *environmentally-aware* knowledge. Is (B) sufficient to support the environmentally aware knowledge to be created in a contextual and flexible manner between product designers? A sufficient space is necessary to find the relevant amount of expertise transfer during those project reviews.

5. Discussion for environmental and product design expertise knowledge sharing in DTE

Four time-successive parameter networks are presented in this case study. Their post-description highlights some new environmental parameters and relations between new and existing parameters and entities, that have been introduced by the PDP stakeholders.

However one of the concept of parameter networks in [1] is to offer a representation of every knowledge by a set of relations among parameters. In this case study such knowledge is represented by relations among entities which slightly differs from the original parameter networks models proposed. An extension of this case study will be conducted avoiding direct links between relation node and entity node to furthermore address the time variation aspects captured in such models during the PDP.

Numerical data treatments can be conducted to extract the number of parameter, relations and nodes at different moments of the PDP to study its evolution [1]. Based on similar data

Table 5. Case study Time successive Parameter Network Models characteristics evolution identified.

Parameter Networks Models Characteristics	PDP Stage I, I bis, II and III cf. related Fig.
Number of design entities	4, 5, 6, 6
linked to environmental performance	*increasing, stabilising*
eg. of design components detailed	wiring and connectors
Number of parameters	4, 6, 8, 9
including linked to environment	*increasing*
eg. of considerations	energy efficient motor and lights
Number of relations	2, 4, 4, 5
including environmentally oriented	*inexistent, explicating, recommending*
eg. of recommendations	end-of-life disassembly guidelines

treatments of the four successive parameter network models, three product design stages are identified in Table 5. The number of design entities linked to the environmental performance of the product under development increases, and then stabilises. Accordingly the number of environmental parameters increases during the PDP. For instance the energy efficiency is an environmental performance targeted that is aligned to the electronic devices (entities) chosen. While the number of relations between entities and the environmental parameters are increasing, relations are also gaining meaning to the expertises concerned in the PDP. By contrast to usual ecodesign guidelines the appearing recommendations are integrated within experts parameters, explicitly inked to design entities.

This evolution shows the capacity of such local environmentally related parameters, and contextualised, knowledge to emerge during the PDP. The Parameter Network Models are a way to create this local knowledge during project reviews where interactions between product designers and the environmental expert can occur.

A first level of analysis of the evolution of the parameter network shows that the motor on which electronics devices depends on, is a central parameter. New relations are created around this central parameter from the design stage II, to the design stage III. A mathematical analysis about the degree of centrality of the electronic parameters would be required to better explore the time variation parameter network capacity to highlight important design components regarding the product environmental performance.

In conclusion of this case study the environmental expertise has found its place into the decisional process of the product or service under development by being contextualised and dynamically linked to the other parameters, and at the right scale. The representation of interdependencies of expertises in the form of a parameter network model provides an excellent foundation for the implementation of IT tools supporting the exchange and transformation of expert knowledge, as well as the facilitation of decision making.

6. Conclusion

The three value added outputs of the paper's discussion are: Parameter Network Models can be used during the product design process to (1-) follow the emergence of environmental parameters linkage between other product designer expertises parameters; (2-) co-create local environmentally-aware knowledge between product designers; and (3-) to translate transformation rules between entities and parameters models that after instantiation would allow dynamic and flexible information exchanges between product designers' and environmental expertises' activities.

Medium term research collaboration perpectives stands on the opportunity brought by the Parameter Network Model approach to helps transforming the complexity of design decisions and designers' interactions into the space of connected graphs, mathematical objects. Such objects can be exploited efficiently programmatically thanks to the vast and powerful set of algorithms of graph theory, one of the oldest mathematical disciplines. This provides the foundation for the design and implementation of IT-tools supporting decision making and knowledge transformation in design projects that require complex stakeholder interactions.

A further key lever provided by such networks is related to impact estimation. In competitive industrial environments, decision makers as well as designer are first and foremost interested by the impact of design choices on both the designed product, service, or system, as well as the underlying organisation. In case of DtE, design decisions affecting environmental parameters are certainly in the primary focus of such considerations. Questions such as *what is the environmental impact (operational, tactical, strategic "cost") of replacing material X by material Y?* can be addressed in a clear analytical and transparent way. In addition such information can be expressed in the convenient form of known algorithms from the graph theory.

Exploring the dynamic evolution of a parameter network over time (i.e. the duration of the design process) offers the possibility of analysing the efficiency and effectiveness of introducing and modifying environmental design parameters at specific points of time (i.e. stages) of the design process. Researching for instance both decision and organisation patterns related to particular environmental parameters and product categories, or patterns which facilitate the planning of expert interactions as well as their collaborative decision making are interesting perspectives addressed in medium term research planed in the following of this work.

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References

[1] Kondoh Sh, Kishita Y, Recording the design thought process as time variation in parameter network, In CIRP Annals, Vol. 65, Issue 1, 2016. p. 197-200

[2] Visser W, Design: one, but in different forms, In Design Studies, Vol. 30, Issue 3, 2009 p. 187-223

[3] Michelin F, Vallet F, Reyes T, Eynard B, Duong Vl, Integration of Environmental Criteria in the Co-Design Process: Case Study of the Client/supplier Relationship in the French Mechanical Industry. in ICED 2014.

[4] Pahl G, Beitz W. Engineering Design a Systematic Approach. Springer; 1996.
[5] Tichkiewitch S, Veron M, Methodology and Product Model for Integrated Design Using a Multiview System, In CIRP Annals, Vol. 46, Issue 1, 1997 p. 81-84,
[6] Prudhomme G, Pourroy P, Lund K. An Empirical Study of Engineering Knowledge Dynamics in a Design Situation. Journal of Design Research, 6(3) 2007 p. 333-58.
[7] Prudhomme G, Boujut JF, Pourroy F. 2005. Activite de Conception et Instrumentation de La Dynamique Des Connaissances Locales. in Ingenierie des connaissances, edited by R. Teulier, J. Charlet, and P. Tchounikine. Harmattan, p. 413-36 .
[8] Rio M, Reyes T, Roucoules L, FESTivE: an information system method to improve product designers and environmental experts information exchanges, In Journal of Cleaner Production, Vol. 83, 2014, p 329-340
[9] Rio M, Riel A, Brissaud D, Design to Environment: Information Model Characteristics, In Procedia CIRP, Vol. 60, 2017, p. 494-499
[10] Domingo L, Rio M, Linking Use Stage Life Cycle Inventories with Product Design Models of Usage, In Procedia CIRP, Vol. 48, 2016, p. 342-347
[11] Yoshikawa H, Uehara K, Design Theory for CAD/CAM Integration, In CIRP Annals, Vol. 34, Issue 1, 1985, p. 173-178
[12] Baouch Y. Ameliorer les demarches d?ecoconception en prenant en compte les connaissances locales. PhD thesis of Univ. Grenoble Alpes, 2016.