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IDENTIFYING NEEDS FOR NEW ECODESIGN TOOLS WITH THE DSM VALUE BUCKET TOOL - AN EXAMPLE IN THE CONSTRUCTION INDUSTRY

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Abstract

Although a large number of ecodesign tools is available to designers, adoption of these tools still seems limited. This is in part due to an inadequacy between ecodesign tools and designer's expectations. To develop relevant tools, more attention must be paid to designers' needs and usages.
In order to do this, a methodology adapted from innovation management is applied to the specific case of building ecodesign.
To apply this methodology, data is gathered from interviews and case studies. Three dimensions are mapped with the DSM Value Bucket tool: problems encountered by designers, usage situations and existing solutions. As a result, value buckets are identified as major issues happening in important usage situations where current solutions offer little help. These value buckets are opportunities for new ecodesign tool development for the construction sector. Results obtained are compared to those of previous studies and give original insights on needs of building designers concerning ecodesign tools.

Keywords: Ecodesign, Building design, Innovation, Sustainability, User centred design

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1 INTRODUCTION

The construction sector is a major contributor to the environmental impacts of human activities in France. Residential and tertiary buildings accounted for 44% of final energy consumed and 23% of carbon dioxide emitted in France in 2007; in 2008 the construction industry generated almost 75% of the waste produced in mass (Commissariat général au Développement durable, 2009).
Ecodesign can address these environmental issues by "integrating environmental aspects into product design and development" (ISO, 2002). The Eco-design field covers a wide range of practices: methodologies, softwares, specific processes, etc. In this article all these terms will be referred to as "ecodesign tools", following the definition of Baumann et al. (2002): "any systematic means for dealing with environmental issues during the product development process".
Many ecodesign tools exist already. In 2002, more than 150 could be identified in the literature (Baumann et al., 2002). Twelve years later, a more recent systematic literature review based on the same definition revealed the existence of 107 tools and techniques (Antelmi Pigosso et al., 2014).
In the field of building ecodesign, building ecodesign tools can be defined as "all tools minimizing the inherent environmental impacts of a construction" (Gobin, 2011). Through this definition, building ecodesign covers a wide range of objectives and practices and a large number of specific ecodesign tools. In 2004, IEA Annex 31 counted 133 tools of different sorts in 14 countries (IEA Annex 31, 2004). For Building Performance Simulation, a crucial point in building ecodesign, 389 tools were identified in 2010 (Attia et al., 2011).
Despite this abundance of tools available, their implementation still seems scarce (Lindahl, 2006). Hence, a better analysis of designers' requirements is necessary for developing more pertinent and reliable tools (Lofthouse, 2006). The objective of this study is to show how an innovation methodology can help identifying unaddressed or underserved needs in the operational implementation of ecodesign by building designers. Major aspects such as usage contexts, problems and existing tools are analyzed in the study so as to highlight the areas where tools are still missing and thus constitute promising opportunities for new developments. Section 2 presents a review of literature on the barriers to the implementation of ecodesign tools. Section 3 introduces the methodology adopted and demonstrates the innovation principles used and the DSM Value Bucket tool. Section 4 presents the case studies and the results obtained. Section 5 is a discussion of these results.

2 LITERATURE REVIEW

2.1 Barriers to ecodesign implementation

Ecodesign implementation and its underlying barriers were the subject of a large number of research works. Table 1 illustrates a literature review of these works.

Table 1. Barriers to ecodesign tool implementation

Reference	Method	Main barriers identified
(Lindahl, 2006)	Case-study: one company, 12 interviews	Need for training Unnecessary complexity Lack of follow-up from managers Benefit not clear
(Bovea and Pérez-Belis, 2012)	Literature review	Tool complexity Time required Lack of environmental knowledge
(Le Pochat et al., 2007)	Literature review	Expertise needed Lack of interoperability
(Zhang et al., 2013)	Literature review	No example of a methodology for combining tools along the design process
(Lofthouse, 2006)	Industrial case-study	Unfit language
(Poulikidou et al., 2014)	Multiple case-study: 4 companies, 18 interviews	Cooperation obstacles Communication difficulties Difficulty to access information Complexity of environmental requirements

		Too simplified Too advanced Tools unfit for designers
(Bey et al., 2013)	Internet survey: 80 companies	Finding environmental info No extra resource allocated Too much specialist knowledge required Finding materials/component alternatives

An additional number of barriers to building ecodesign tool deployment can be found in the literature related to construction.

First of all, two professions have a major role in building design: architects and engineers, and their roles are relatively separate (Herbert, 1999). Attia et al. (2011) showed that architects and engineers do not have the same criteria to evaluate Building Performance Simulation software, nonetheless, the vast majority of tools falling into this category are aimed at engineers. Moreover, these tools usually require a lot of data which is not available until design is already well advanced.

A large category of tools dealing with building sustainability is building assessment tools. However, although they provide some guidelines they are not really adequate for design assistance (Ding, 2008).

Another issue is that "building environmental assessment tools are not all commensurable" (Haapio and Viitaniemi, 2008), making thus the comparison of results difficult. Users have to choose carefully among tools, as not all of them return the same result if used on the same building. However, no methodology is available to help them identifying the right tool. Finally, uncertainties on building life span and components life span create issues as designers do not have guidelines to fix these variables which have a major influence on impact assessments (Leroy et al., 2013; Rincón et al., 2013).

2.2 User requirements and Usage Context Based Design

It can be noticed that many of the barriers previously identified stem from the root causes identified by Lofthouse (2006) and Lindahl (2006): poor analysis of designers' requirements resulting in a misalignment between tools and designers' needs and practices. This could be due to the low number of actual implementations of ecodesign tools developed by academics: in 2002, they accounted for about 10% of the 65 papers analysed by Baumann et al. (2002). Baumann et al comment that "references indicate that those involved in the field are more interested in developing a new tool than on studying the use of existing ones and to evaluate them in order to improve them."

As a matter of fact, the analysis of actual usage of tools is scarce. Most studies gather feedback and provide hints: for instance, Poulikidou et al. (2014) show that guidelines are perceived as too vague.

Studies providing actual requirements for ecodesign tools are rare, with mainly the works of Lindahl (2006) and Lofthouse (2006). However, these studies don't mention specific usages where ecodesign tools could provide useful information to reduce environmental impacts of the designed product.

In this line of thought, an emergent trend in design is Usage Context Based Design (UCBD) (He et al., 2012). It is based on both engineering design and marketing approaches, and has been developed in attempts to model usage coverage of products (Wang et al., 2013). UCBD puts extra emphasis on usage analysis and user observation. These principles are at the heart of a radical innovation methodology, Radical Innovation Design® (RID) (Yannou et al., 2013, 2015). RID is a need-seeker innovation methodology which puts emphasis on the analysis of customer needs and unexpressed "pains".

In our work, we postulate that this framework is applicable to ecodesign tool development and can provide developers with precise and robust answers to the following question: "how can we develop tools that can help building designers in reducing the environmental impacts of their products?" The approach consists of analyzing thoroughly the needs and pains of designers in order to identify the shortcomings in the current offer of ecodesign tools.

3 METHOD

One of the tools used in Radical Innovation Design® is called the DSM Value Bucket (DSM VB) Tool. A complete presentation is provided in (Yannou et al., 2015), only a short introduction is given here. This part of RID® methodology will be the only one to be used in this study.

DSM VB is based on Design Structure Matrices (Eppinger and Browning, 2012). It maps three domains:

- A solution domain
- A problems domain
- A usage situations domain

The concept is to cross these domains so as to identify areas of major situations where important problems occur and existing solutions offer little if any help. These areas are called *value buckets*. Figure 1 shows how the tool processes data.

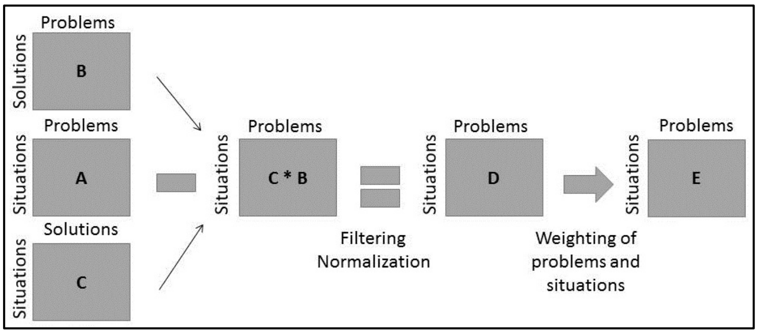

Figure 1. DSM Value Bucket tool workflow

A, B and C are matrices map domains one-to-one:

- Matrix A shows how often problems occur in situations. It is the "ideal performances" matrix.
- Matrix B shows how solutions are relevant to problems.
- Matrix C shows how solutions are relevant in situations.

Matrix C*B is called the "existing solutions performances" matrix. A and C*B are normalized, a scalar filter value f is applied to keep only significant values (filter level is determined by trial and error) for matrix D = A - f.C*B. Matrix D therefore shows the gap between ideal performances and current performances of existing solutions.

All problems and all situations may not be as crucial or frequent, this is why an importance coefficient is associated to each problem and each situation. This way matrix D becomes matrix E, where the value buckets can be identified as the highest values in the matrix.

4 MATERIALS AND RESULTS

4.1 Data gathering

Data gathering was organized in two phases. **A first interview phase** focused on understanding current practices and barriers to ecodesign. It enriched the understanding of the design process and provided elements for the "problems" dimension of the DSM Value Bucket analysis. 19 people from 15 companies were interviewed. Information on the interviewees from this phase are illustrated in table 2.

Table 2. Interviews in phase 2 (F = face-to-face, P = phone)

#	**Company type**	**Size**	**F/P**	**Duration**
1	Environmental engineering consultancy	3-10 p	F	1h15’
2	Carbon impact consultancy	< 3 p	P	1h
3	Urban planning consultancy	> 500 (group)	F	1h15’
4	Environmental engineering consultancy	3-10 p	P	30’
5&6	Real estate development consultancy	3-10 p	F	1h15’
7	Project management assistance consultancy	< 3 p	F	1h15’
8	Research in architecture		F	1h
9	Research in architecture		F	1h
10&11	Architecture practice	3-10 p	F	1h30
12	Local public authority	5000 inhab.	F	1h
13&14	Engineering consultancy (structural and energy eng.)	10-50 p	F	45’
15	Environmental engineering consultancy	10-50 p	F	1h

16	Real estate development	> 500 p	F	1h15’
17&18	Real estate development	> 500 p	F	1h15’
19	Environmental consultancy	10-50 p	P	25’

A case study was then conducted within a French company to gather more precise information on usage situations. Indeed, interviews in various companies with no common history did not produce enough precise information on usage contexts, which depend on company structure, processes, etc.
The company involved is a big French promoter, active in office, residential and commercial buildings. It lays in the > 500 employees category and generates a turnover of over 1 billion euros per year. The choice was opportunistic as one of its employees was interviewed during the first phase. The company had not yet cooperated with the authors’ research institute previous to this study.
The company is very active in sustainable design and has made it a key element of its strategy. It first started to work on carbon accounting. Then it considered impact transfers and therefore turned to Life Cycle Analysis (LCA). It has several pilot programs in building rehabilitation and passive buildings.
Two projects were selected in this company. Both were office buildings in France. One was started in 2010 and delivery is planned for the end of 2014. The other is still in the early design phase. This configuration allowed the association of both feedbacks on the first project and "live data" on the second one. Both projects were followed by the same environmental consultancy. Project managers from the promoter presented the project and their requirements during the interviews. Consultants revealed the problems they had and the methods they used.

4.2 Results

4.2.1 Design system

The interviews provided information on how building design is organized. Based on this results, figure 2 shows environment-related information flows during the design of a building.
The role of the environmental consultancy is of prime importance. They are the actor in the system responsible for transforming functional and technical elements into environmental indicators. They also have the best knowledge of how the activity of each member of the design team is connected to the global environmental impact of the building. They guarantee that the environmental dimension is consistently addressed by auditing proposals from the design team. This role is sometimes split between two actors: one contracted with the project owner, who acts as an advisor, audits proposals from the design team and is responsible for the certifications, and one inside the design team in charge of helping architects and engineers in design, e.g. suggesting materials or design choices based on specific analysis.

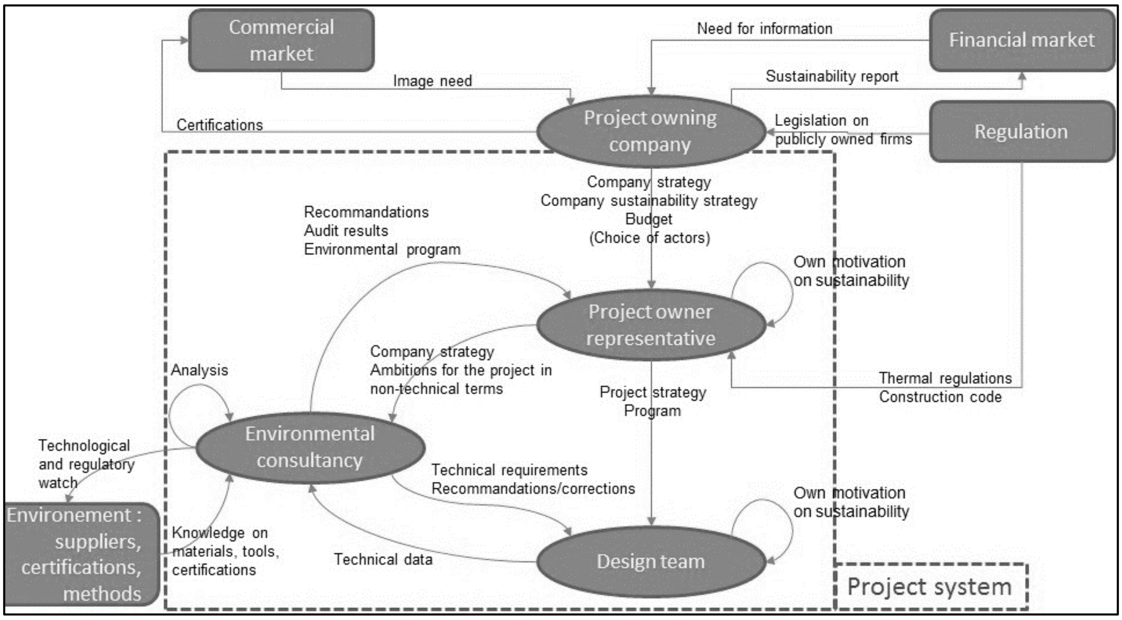

Figure 2. Actors and environment-related information flows in the design system

4.2.2 Problems related to ecodesign

A list of problems preventing the implementation of ecodesign and especially the deployment of ecodesign tools has been identified during interviews. They are classified in table 3.

When interviewees were asked about ecodesign, they only referred to LCA and certifications. In our opinion, LCA is an assessment tool, to be used for the quantification and comparison of the environmental impact of a product or process, whilst ecodesign tools are used to generate new design solutions with a lower environmental impact. Indeed, LCA is a tool with a high degree of evaluation potential but a low degree of recommendation potential (Janin and Bellini, 2011). Nevertheless, this perception is not common in the construction sector, where LCA is seen as the predominant ecodesign tool.

Table 3. Problems related to ecodesign

Category	**Problems**
Goal and scope of the design	Many tools/methods exist: how to choose?
Interpretation of ecodesign results	No priority between impact categories Generating alternatives for comparison is long and costly There is no scale to position one's LCA results i.e. no benchmarks
Cost considerations	LCA is expensive No (affordable) alternatives exist for certain choices
Added value	No customer value to LCA LCA has limited impact on certifications
Other aspects	LCA is not yet a decision making tool LCA is post-design Input data is hard to obtain No incentive People do not understand what the impact categories mean No link with local biodiversity and indoor air quality Hypothesis used for data generation are not clear Many criteria are already considered, environment is only making decision more difficult

For further analysis and computation, seven problems are extracted from the list of table 3:

- Low level of environmental data: not much is known on the environmental impact of the product, or the data is mainly qualitative.
- Low level of technical data: for example, drawings are not available for the analysis.
- Difficulty to compare environment to other criteria: investment cost, maintenance cost, maintenance easiness, functional aspects…
- Difficulty to position the project: there is no reference to which the project can be compared in order to assess if its performance is "good" or "average" or "poor"
- Cost of analysis is too high: existing methods are too expensive
- Delay of analysis is too high: existing methods take too much time compared to projects rhythm
- Difficulty to compare options: when multicriteria methods are used and no priorities are set, or when results are not able to distinguish options for instance.

Some of these issues may already be solved by existing tools, but these problems are directly extracted from feedback of interviewed practitioners and are based on their operational practice.

4.2.3 Usage situations

Six usage situations were identified during the case studies. They concern the environmentally conscious design and choice of:

- Program, i.e. the requirements for the building to be designed
- Sketches, when an architectural concept is chosen among proposals of different architects
- Choice of constructive systems: timber, steel, concrete frame
- Façade concept
- HVAC system architecture
- Finishing touches, i.e. internal elements like doors or carpeting materials

"Environmentally conscious design and choice" means an informed decision, including environmental impact as a criterion even if the best option from the environmental point of view is not the one retained.

4.3 DSM Value Bucket Tool analysis

Five tools are selected for the analysis:

- Complete LCA (ISO, 2006; The EeBGuide Project, 2012)
- Screening LCA, a simplified LCA for early stages, focusing on the main contributors and "likely to be based on generic assumptions" (The EeBGuide Project, 2012)
- Quality Function Deployment for Environment (QFDE) (Masui et al., 2003), a modified QFD methodology including environmental aspects
- Ecodesign Pilot (Vienna TU, Institute for Engineering Design, 2012; Wimmer and Züst, 2001), a generic tool to identify ecodesign strategies using checklists
- A guide by the reference French institute on building sustainability (Nibel and Valicourt, 2012). This is a step-by-step guide for the management of the sustainability aspects of a construction project, from feasibility stages to delivery and exploitation.

The objective is to cover a wide scope of tools, from evaluation to recommendation ones (Janin and Bellini, 2011), and from passive to interactive ones (IEA Annex 31, 2004). The two first tools are evaluation tools. LCA and screening LCA are included because LCA proved to be well-known during the interviews. QFDE is a popular approach for integrating environmental requirements (Bovea and Pérez-Belis, 2012). EcoDesign Pilot is an interactive set of checklists (Janin and Bellini, 2011). The guide is a passive collection of guidelines and good practices.

These five ecodesign tools, the problems listed in section 4.2.2 and the usage situations listed in section 4.2.3 are the rows and columns of matrices A, B and C of the DSM Value Bucket tool.

The scale for filling the matrices is: (0) No/Never (1) Very few (2) A few/rarely (3) Some/sometimes (4) Many/Often. For instance, in matrix B, tools * problems, LCA scores "1" for the problem "Low level of environmental data" as LCA requires a lot of data and is therefore very little relevant to this issue.

Variables were obtained as follows:

- Matrix A, usage situations * problems, was filled by the interviewed environmental experts met during the case study. A meeting with three consultants was organized to validate the list of steps considered. Then two of them filled matrix A independently from each other (the response of the third interviewee could not be obtained). The question they were asked was: "based on your experience as an environmental consultant, how present is the following problem in this usage situation?" Then mean values were computed.
- Matrix B, tools * problems, and C, usage situations * tools, are based on literature analysis of the tools evaluated.
- Weighting coefficients are set to 1 for both problems and usage situations.
- The filter is set to 0,5, its default value (Yannou et al., 2015).

Figure 3 shows the data flow. To ease the reading, matrix E is reproduced in figure 4.

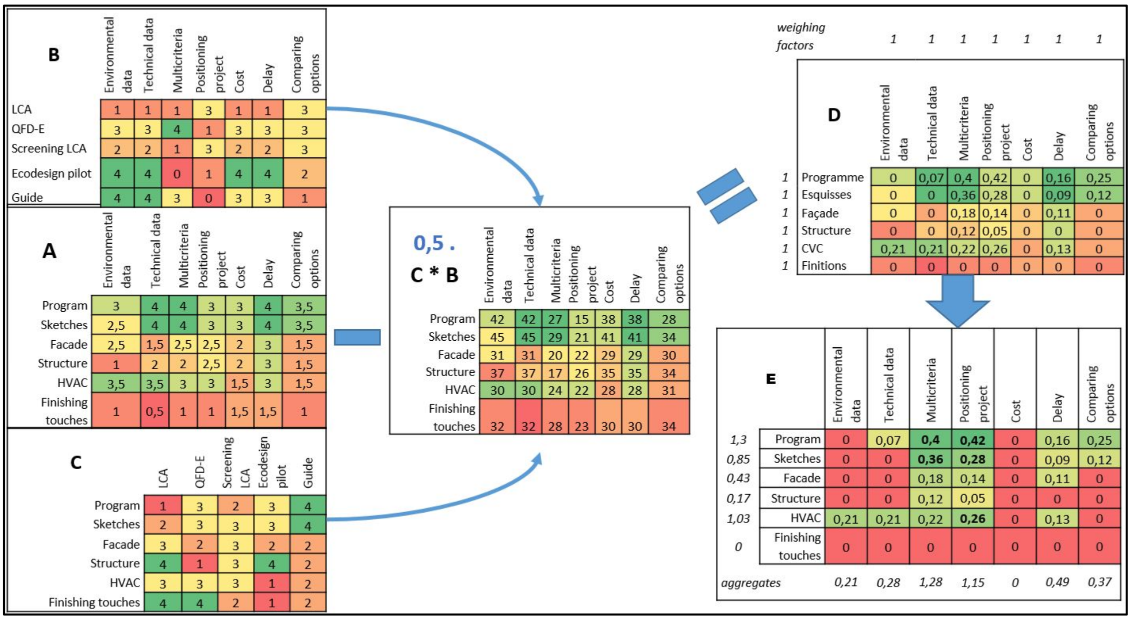

Figure 3. DSM Value Bucket treatment of data

	E	Environmental data	Technical data	Multicriteria	Positioning project	Cost	Delay	Comparing options
1,3	**Program**	0	0,07	**0,4**	**0,42**	0	0,16	0,25
0,85	**Sketches**	0	0	**0,36**	**0,28**	0	0,09	0,12
0,43	**Facade**	0	0	0,18	0,14	0	0,11	0
0,17	**Structure**	0	0	0,12	0,05	0	0	0
1,03	**HVAC**	0,21	0,21	0,22	**0,26**	0	0,13	0
0	**Finishing touches**	0	0	0	0	0	0	0
aggregates		*0,21*	*0,28*	*1,28*	*1,15*	*0*	*0,49*	*0,37*

Figure 4. Results of DSM Value Bucket Tool (matrix E)

5 DISCUSSION

5.1 Opportunities for building ecodesign tool development

According to the results, opportunities for future ecodesign tool development would address:

1. Positioning project environmental performance when writing requirements, i.e. evaluating the harshness of requirements and how stringent they are on environmental performance.
2. Developing multicriteria assessment for program, i.e. ways to assess how the specification of a certain requirement can impact on all dimensions of the project performance (e.g. how specifying environmental certifications can impact on cost).
3. Developing multicriteria assessment for sketches, i.e. ways to assess how functionality, cost, delays and environmental impacts as well as other criteria balance each other in early phases.
4. Positioning project at the sketches stage.
5. Positioning project for HVAC design.

In a more general way, "multi criteria" and "positioning project"' are the two columns with the highest sum of values, and for lines the list is first program, then HVAC, then sketches.

Some of these results are confirmed by previous analyses. The need to move towards multicriteria evaluation and sustainability concepts has been identified regularly (Cole, 2005; Ding, 2008; Haapio and Viitaniemi, 2008). This result is also in line with some conclusions of an international conference on LCA and Construction (Lasvaux et al., 2014) which stated the needs to:

- "Improve the interpretation of results by developing benchmarks to compare buildings from localized average types or best practice."

- "Develop decision-making tools and methods for construction stakeholders."

These elements are quite similar to "comparing options", "multicriteria" and "positioning project". However, our conclusions are more precise as they spot specific steps in the process when designers need to be provided with these methodologies by mapping issues to usage situations.

Another part of the results sheds new light on the needs of ecodesign tools. Lack of environmental data is recurrently identified as a barrier to environmental assessment, LCA and ecodesign, including during interviews in this study. However, after computation it is here rated very low. The same is true for technical data. Although these results would need confirmation from more interviewees, yet they still point out the fact that data is not the main concern, whether it is of environmental or technical nature.

Regarding this last point, the present study shows that the perception of ecodesign tools in the French construction sector seems to be limited to LCA whereas the suitability of LCA for design activities is controversial (Millet et al., 2007). LCA generates a lot of information with regard to the impacts of projects, but currently organisations are not capable to manage this information and act on it. Tools are needed to bridge this gap: transform data and raw information into meaningful information which is useful for multi-dimensional decision-making.

Given the preceding, a major question is still non-answered: for whom should these tools be designed? Figure 2 shows the central role of the environmental engineering consultancy in the management of environment-related information and models in the project. Tools should therefore address their needs as a priority, as they are the ones handling the environmental dimension across all other disciplines (structural engineering, HVAC engineering, architectural design, certifications and environmental communication, etc.). Our interviews show that French environmental consulting firms are currently more focused on environmental assessment and certification, but they are shifting more and more to ecodesign. Therefore, there might be an opportunity to co-develop tools in collaboration with them. Although they do not make decisions themselves in the project, yet they are often expected to provide decision-makers with weighing and multicriteria methods.

From the methodological point of view, this study shows how the use of the DSM VB tool can give new insights on designers' needs concerning ecodesign tools. The analysis confirms some trends but also puts forward new problems of interest for ecodesign tools developers.

5.2 Limits and future works

This study is based on interviews of French professionals and two case studies in one company.

However, the company involved is a large company, and ecodesign implementation dynamics may be different in a SME. Indeed, Le Pochat et al. (2007) showed that SMEs have specificities, which our first phase of interviews confirmed. Opportunities identified are pertinent in the context of the considered company, but more analysis is still needed if more generic opportunities are to be spotted. More values need to be gathered for matrix A, through a survey of practitioners for instance.

Besides, only a few tools are analysed in this study. A more extensive review of tools would make the analysis more robust and provide harder evidence to justify development opportunities.

Finally, methodological aspects need to be investigated to make the DSM Value Bucket analysis more robust. Indeed, qualitative entry for the matrices may introduce bias because of different raters. Furthermore, taking the average of entries for Matrix A will hide discrepancies between values.

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