DEFINING PERMAENGINEERING: NEW PRACTICES FOR STRONG SUSTAINABLE CONTEXTS OF DESIGN

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ABSTRACT

Designers can project their vision of the world into reality and share it. They have, in short, the capability to transmit values and points of view through their products. We believe that engineering culture and tools need to shift from a culture of control to a culture of care. The aim of this paper is to propose and test new engineering practices for strong sustainability. We argue that the role and the shape of engineering in strong sustainability contexts are not explored enough in the scientific literature. We propose therefore a form of strong sustainability practice that we call permaengineering. Permaengineering practices are conceived to be in line with strong sustainability contexts. In other words, permaengineering practices should allow achieving activities upper the social floor and within the planetary boundaries. 4 elements will be studied in permaengineering: the ethics of permaengineering, the goal of the practice, the approach to sustainability, and the expertise needed. Those 4 elements will be tested through an interactive tool embedding perma-engineering principles. A seven-month study was conducted to test this tool.

Keywords: Sustainability, Design engineering, Ethics

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1 INTRODUCTION

Climate change and long-term changes to the Earth system are challenging the way we interact with nature, the way we organise human activities, and the way we consume and produce goods and services. While everyone has a role to play in the coming changes, this study focuses on how engineers can actively participate in this challenge. Engineers have power in the current system because they design and develop products. As designers they can project their vision of the world into reality and share it. In short, they have the ability to communicate values and perspectives through their products (Gero and Kannengiesser, 2004).

The values that are shared by the majority of engineers today are related to the notion of performance, profit and the optimising business as usual activities (Gunckel and Tolbert, 2018). As (Winkelman, 2013) has shown, the value system on which engineering is based is a hindrance to the integration of sustainability in engineering and design activities. To live up to the tasks our societies face (climate change, disruption of biogeochemical cycles, resources depletion, etc.), engineers must rethink their tools and practices to design products in more sustainable ways. Engineers therefore need to move away from incorporating environmental aspects as constraints within a project, and instead change their culture and way of understanding socio-technical problems (Date and Chandrasekharan, 2018). As (Arora *et al.*, 2020), we believe that engineering culture and tools need to shift from a culture of control to a culture of care. "Yet, in a world where problems are increasingly complex and global in nature, technical knowledge is not enough. Engineering also requires empathy, caring, and compassion to develop solutions that are socially responsible and environmentally sustainable (Canney and Bielefeldt, 2015; Hess *et al.*, 2012)" (Gunckel and Tolbert, 2018). The ethics of care enables engineers to better relate their design to the humans and non-humans impacted by the goods produced. Therefore, in this paper we propose a framework for engineering that incorporates the ethics of care for a strong sustainability paradigm.

The aim of this paper is to propose and test a new engineering framework dedicated to strong sustainability contexts. This framework is called *permaengineering*, named after permaculture, an agricultural practice rooted in an ethic of care. Permaengineering should enable engineering activities above the social floor and within the planetary boundaries (Raworth, 2017). We hope that this proposal will open a discussion in the community about the radical changes in values and ethics needed in engineering design to consider engineering for strong sustainability contexts.

Next section focuses on the different types of engineering and justify why engineering in strong sustainability contexts needs to be further investigated. The need for a new type of engineering arises from the urge to adapt human societies to the Anthropocene. We propose to call this new approach permaengineering, a concept that is described in section 3. In the same section, we present the concept and the potentially associated digital tools for permaengineering. Section 4 describes an experiment to understand the adequacy between the use of an interactive artefacts embedding the permaengineering features on one hand, and stakeholders acting for strong sustainability on the other. Section 5 discusses the results of the experiment and the adequacy between the artefact proposed and the permaengineering framework.

2 STATE OF THE ART: ENGINEERING AND SUSTAINABILITY

The goal of this section is to understand the landscape of engineering for sustainability and identify engineering movements for strong sustainability. Firstly, we explain why the vagueness of some concepts is detrimental to research in engineering for sustainability. In a second time, we present a possible structuring of the landscape of sustainable engineering. Finally, we introduce the concept of empathy and care as a basis for engineering for strong sustainability context.

2.1 Different understanding of sustainability

It is difficult to define engineering for sustainability as sustainability is a contested concept. Furthermore, engineering activities are not generic, and evolve regarding historical, epistemological and geographical areas / periods (Picon, 2004). During our analysis we noted that concepts like "sustainable engineering" remain ambiguous. For instance, (Gagnon et al., 2012) shows that the susstainable design process of engineering depends on 6 characteristics: the structure of the design process, the number of sustainability

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issues covered, the relevance of indicators to define the sustainability of the design process, the accuracy of the analysis tool, the performance of alternative proposals, the integration of all dimensions of sustainability in the decision making. Each dimension is described as 4 levels of achievement (A being low-level of achievement and D a high level of achievement). Thus, it seems that sustainable engineering can vary, from a weak sustainability (low-level) to a stronger sustainability perspective (high level of achievement). We can also note that the focus of Gagnon et al. on design processes impoverishes the theoretical concept of sustainability (Winkelman, 2013). We observe a similar variation in approaches to sustainability in "ecological engineering". Indeed, the practices and tools of ecological engineering are defined according to a spectrum that we consider ranging from a weak to a strong sustainability perspective (we will reuse the image of the spectrum to define a landscape of engineering for sustainability, see Figure 1). For ecological engineering, (Jørgensen and Mitsch, 2020; Mitsch, 2012) define three characteristics: sustainability potential, reliance on self-nature design, conventional engineering investments. Thus, sustainable and ecological engineering are broad families covering a wide range of practices, from weak to strong sustainability perspectives. As these concepts cover different realities, we felt the need to define a landscape of engineering for sustainability more precisely. This will help us to determine whether engineering for strong sustainability contexts is explored in the literature.

2.2 Engineering for sustainability landscape

We started our study from the general framework of engineering families defined by (Seager et al., 2012). This framework describes two kinds of engineering "family" part of the engineering for sustainability landscape: systems engineering (conservative view) and sustainable engineering science (proactive view)1. Both families are described according to different characteristics: attitudes towards technology, understanding of sustainability, ethical position, or the culture of participation in engineering projects. According to Seager et al., the "family" called systems engineering is composed of "engineering within ecological constraints" and "sustainable engineering". In this perspective, sustainability is understood as a constraint integrated in the design process. This approach is well represented in the design society, as most companies are considering environmental issues as additional constraints in the design processes (sometimes integrated in the early phases of the design stages, sometimes only integrated afterwards) for instance with the works of (Bertoni *et al.*, 2018), (Schulte and Hallstedt, 2017), or (Hallstedt, 2015).

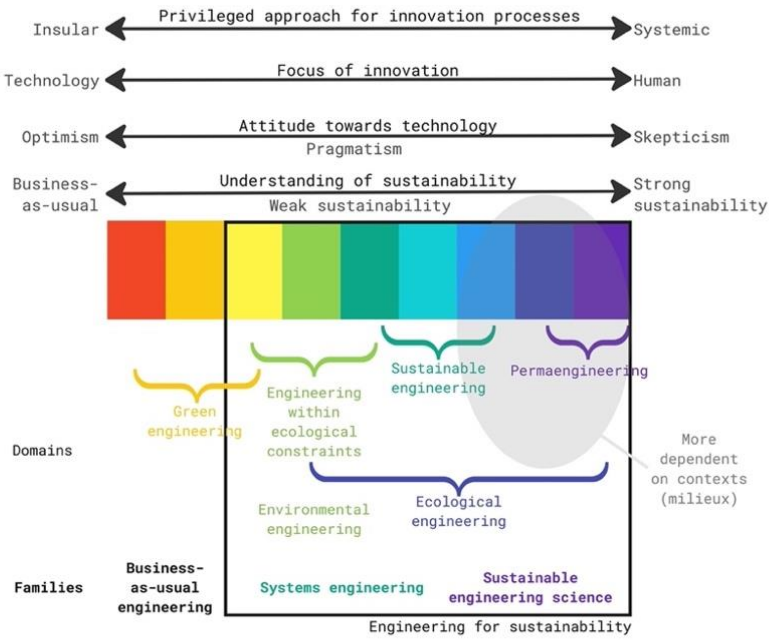

Figure 1: Broad spectrum of engineering for sustainability field

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1 A third family, called 'business-as-usual engineering', is defined by Seager et al. As this family doesn't take sustainability into account, we choose to position it outside the Engineering for Sustainability Landscape in Figure 1.

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We identified that environmental and green engineering were missing from the structure of (Seager et al., 2012), so we added them to Figure 1 to provide a more complete picture of the landscape of engineering for sustainability. "Environmental engineering" is defined as a profession in which science is applied with reason in order to develop the means of economically making use of the materials and forces of nature for the benefits of humanity (Alha *et al.*, 2000). "Green engineering" is the design, marketing and use of processes economically relevant and enabling the minimisation of the pollution and risks for human and environmental health (Kirchhoff, 2003).

Figure 1, designed for this paper, shows engineering activities positioned on a spectrum. Some characteristics coming from Seager helped us to define the attitude towards technology for each one of the engineering families (focus of innovation, attitude towards technology). The characteristic "privileged approach for innovation processes" comes from (Ceschin and Gaziulusoy, 2016) who classified design for sustainability practices from an insular to a systemic perspective.

Weak sustainability is situated on the left side, while engineering practices more rooted into socio-technical approaches are on the right side of the spectrum. The ecological approach of "engineering with ecological constraints" is about protecting nature. Moving to the extreme right side of the diagram, the goal is not anymore to protect nature but to question the distinction between humans and nature. Thus, the word *milieu* will be used to describe the context in which the engineer acts and is part of. This can be related to the proposal of (Bratec, 2020) who suggests that design for sustainability has evolved from a socio-technical system level to a geo-system level, by being situated. A situation of design is situated by the fact it is anchored somewhere, with specific stakeholders and environmental issues. The specificity of the design situation seems an important element which will be part of our proposal.

The formalization of this landscape of engineering for sustainability allows us to conclude that the perspective of strong sustainability is little addressed within the design society. This is the reason why we wish to propose a specific framework for this perspective.

2.3 Considering engineering for strong sustainability

At ICED 2011, (Dewberry, 2011) suggested rethinking the imaginaries around design: "It is vital to understand the need to re-imagine our ways of design thinking and practice, the processes of how to re-imagine and the potential of what we can imagine. We need new language, new concepts and radical change". Since that call, no new imaginary framework for thinking about engineering within a strong sustainability framework has been proposed. Moreover, sustainability is not something innate to engineers. Authors such as (Winkelman, 2013), have argued that is a need for change in the values of engineering. In this paper we want to explore a framework in which traditional engineering values are replaced by values specific to sustainability contexts. By presenting this theoretical framework, we aim to start a discussion on what engineering within planetary boundaries might look like.

We mentioned in the introduction that engineering needs to move towards a culture of care. (Tuomala and Baxter, 2019) have shown that empathy plays a major role in society and in the design of responsive products. We propose that empathy, and more broadly care, can form the basis of an engineering ethic. The definition of the ethics of care is: "Everything we do to maintain, continue and repair 'our world' so that we can live in it as well as possible. This world includes our bodies, ourselves and our environment, all of which we seek to interweave into a complex web that sustains life" (Fischer et al., 1990). At first glance, this may seem abstract. One way of embedding the care ethic in a design practice is through permaculture. Permaculture, permanent agriculture, "is the conscious design and maintenance of agriculturally productive ecosystems which have the diversity, stability, and resilience of natural ecosystems" (Mollison, 1988). Without taking up all the principles of permaculture, we have chosen to draw on the principles surrounding permaculture as a source of imagination (Roux-Rosier et al., 2018) to think about an engineering that is relevant to the challenges of strong sustainability. This is presented in the following section and explains the name of the permaengineering framework.

3 PROPOSAL

Our main proposal is composed of 2 subparts: the proposal of the concept of permaengineering and the proposal of an interactive artefact embedding the permaengineering features.

3.1 Permaengineering

We define permaengineering as an activity centred on the principle of collaboration between the stakeholders in an engineering process with the aim of moving towards the sustainability of socio-technical systems. This goal is achieved through four main elements: (1) an ethic of care, (2) a goal of strong sustainability, (3) a socio-technical approach to sustainable problems, (4) an interactional expertise and engineering competencies for sustainability.

The 4 characteristics (ethics, goal, approach, and expertise) are detailed in the following paragraphs:

1) Permaengineering is anchored in the ethics of care. The ethics of care emphasises relationships. Therefore the permaengineer must care about the relationships between the biosphere, the earth's resources, and the technologies that are designed to last in the long term (Gunckel and Tolbert, 2018).

2) The goal of permaengineering activities is to achieve sustainability, understood as respecting the planetary limits (Steffen *et al.*, 2015; Wang-Erlandsson *et al.*, 2022) and enabling human and non-human well-being. Thus, a strong sustainability perspective is the foundation of permaengineering. Strong sustainability means accepting that natural capital cannot be replaced by technical or human capital (Dietz and Neumayer, 2007). This perspective is at odds with the context of a market economy.

3) The approach to solve problems of permaengineering differs from traditional engineering problems. Indeed, sustainability is understood as a wicked problem (Pryshlakivsky and Searcy, 2013). Following this approach, it is easy to understand that permaengineers cannot approach engineering problems as disciplinary problems, but as complex problems.

4) Therefore, the expertise and competencies of permaengineers need to be more related to the management of uncertainty, and to the capability to be in interaction with many specialists and stakeholders. The importance of being in contact with the different actors of a sustainable design project is also underlined by (Sopjani et al., 2017). Interactional expertise can be defined as the ability to understand a domain of expertise without being an expert in it. That is to say, the interactional experts immerse themselves in a field of expertise to understand it, to learn what knowledge and practices are implicit in the field. Thus, interactional expertise allows one to understand several specialised fields, without necessarily having acquired the technical skills and knowledge. Of course, they do not have the same level of expertise as the people specialized in the fields in question. "Through this discursive process, interactional experts demonstrate they can see the world from a specialist's perspective—i.e., proffer authoritative technical judgments, make insider's jokes, and raise devil's advocate questions that revolve around ideas typically known only to specialists in a field." (Seager *et al.*, 2012). In permaengineering practice, this interactional expertise is needed to dive into several fields of specialized expertise to understand a situation, designing desirable (sustainable) and less desirable (with non-intervention) scenarios of the future, and testing strategies to launch a sustainable transition in the dedicated context (to pass from a less desirable scenario to a sustainable one). This interactional expertise requires a strong capacity to collaborate with people with different languages, norms and practices (Collins *et al.*, 2007) Thus, specific competencies of engineering for sustainability are needed. Links between competencies and values have been theorised by (Sterling, 2010) and then (Biberhofer et al., 2019). The competencies of engineering for sustainability have been well defined in the literature in engineering education for sustainability (Quelhas *et al.*, 2019; UNESCO, 2017; Wiek *et al.*, 2011) and are the following: critical thinking, systemic thinking, vision of the future, self-knowledge, normative competence, strategic competence, solve problems, interdisciplinary work.

The aim of this paper is not only to propose a theoretical framework, but also to propose artefacts that accompany the practice of permaengineering. For this reason, in the next section we try to define tools related to permaengineering. We have chosen to focus on interactive technologies because they are used in many engineering contexts.

3.2 Tools supporting permaengineering activity

What are the characteristics of interactive artefacts for permaengineering activities? To answer this question, we tried to implement the 4 characteristics of permaengineering in an interactive technology already well used in engineering for sustainability activities: Life Cycle Assessment (LCA). A prototype (called ACVnum, represented on Figure 2) based on the LCA method has been designed with the following links with the previous characteristics:

- Ethics: whereas LCA software emphasizes different phases of LCA, our prototype emphasizes the interactions between the different phases (arrows on Figure 2). The LCA norm does

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emphasize on interactions between the different phases of LCA but software dedicated to LCA separates the phases and make the iterative aspect difficult;

- Goal: the goal of the interactive technology is to assess the environmental impact of technical systems (unchanged from regular LCA software);
- Approach to sustainability: the prototype enables non-experts users to touch the complexity of environmental assessment (complexity of processes, how to choose data, environmental indicators, uncertainty of models). This differs from classic LCA software, usually only use by LCA experts;
- Expertise: helping to increase the management of interactional expertise and the competencies of engineering for sustainability.

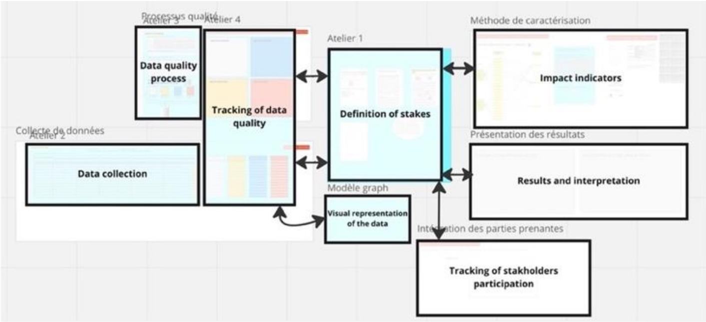

Figure 2: Graphical representation of the different elements of the LCA board "ACVnum" and the links in between the phases of LCA method

This prototype is a first attempt to implement permaengineering features in an interactive tool. We hypothesise that permaengineering activities need to be carried out with specific tools and methods that embed permaengineering features. This prototype has been tested through an experiment described in the next section.

4 METHOD AND RESULTS

This section consists of 2 subsections. The first describes the experiment we carried out in an ecovillage to test the ACVnum prototype. The second describes the results of the experiment.

4.1 Method

The goal of the experiment is to understand the adequacy between the use of an interactive technology embedding the permaengineering features on the one hand and stakeholders acting for strong sustainability on the other. For the strong sustainability context, we have chosen an ecovillage, as its inhabitants are willing to live with very low environmental impact and a high level of well-being. 6 residents of an ecovillage used the LCAnum prototype for 7 months to carry out an LCA of tiny houses.
The focus group was heterogeneous in terms of activities (retired, graphic engineer, researcher, not working), gender and age (25 to 65 years old). All the members of the focus group were residents of the eco-village and volunteered to take part in the focus group. 5 of the 6 had no previous experience in LCA. During each session, the focus group carried out an activity related to the LCA of a tiny house. Each working session was audio recorded and then coded. The researcher who conducted the experiment was present at every stage of the LCA process. All the processes of LCA were done in a collective way. Thus, the members of the focus group had the opportunity to participate in the definition of the tasks of the LCA (definition, functional unit), the data collection, the choice of the calculation method and the impact indicators, and to discuss the results in order to act in the ecovillage.

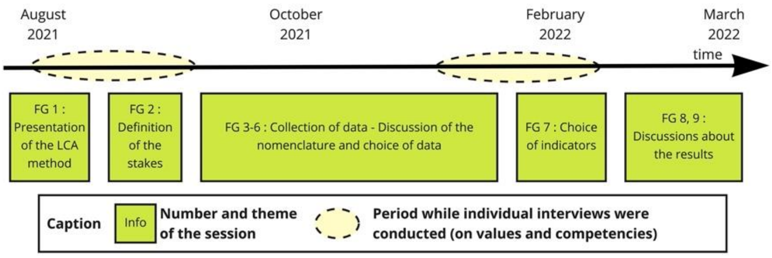

Figure 3: Data collection over a seven-months period of experiment on ACVnum users

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Three types of data were collected:

- Qualitative data on values supported by the inhabitants (individual interview conducted with the method "motivational interviewing" to understand the deep motivations of inhabitants in their life);
- Qualitative data on engineering competencies for sustainability of inhabitants. Through an individual interview, participants filled in a grid of competencies (engineering competencies for sustainability from (Quelhas *et al.*, 2019)) and for each competence they explained how they acquired it. 5 levels were suggested and the discussion on each level was recorded);
- Qualitative data on working sessions on ACVnum tool (9 sessions of the focus group, the aim of each session is described on Figure 3).

The treatment of the data was done through a qualitative coding, identifying moments in the LCA process were inhabitants face difficulties to cope with the LCA process.

4.2 Results

4.2.1 Results of value-oriented interviews

In all the interviews, it is possible to find a kind of mixture between the values held by the individuals and the values of the ecovillage. This is logical given that the individuals present in the ecovillage joined the project because they are in line with the values of the project. Four main values have been identified in the individual interviews. The four values and the link with ACVnum are presented here:

- Autonomy of the members in their choices: autonomy is understood by the inhabitants as being responsible for the choices made and being aware of the biases/values underlying our choices (inhabitant 1). For some inhabitants, it also means that the inhabitants are able to carry out a project from start to finish with the internal competences (inhabitant 2 and 4). This autonomy should not be confused with a desire for isolation/withdrawal from society (all inhabitants). On the contrary, the ecovillage has a strong will to anchor itself with local actors. In that sense, the ACVnum prototype was a first step to enable inhabitants to be better understand LCA process (uncertainty of data for instance) and being more autonomous in the conduct of a LCA.
- Involvement in a collective dynamic: each inhabitant described the fact that they did not see themselves looking for answers to the ecological crisis alone (all focus group members). Thus, in the proposed LCA approach, involvement must be collective (involving members within the ecovillage and potential indirect stakeholders).
- Transparency: The inhabitants expressed this value when they talked about the Oasis' governance system. Access to information related to the technical system, to data, to LCA results, tends towards a form of transparency. However, as the prototype does not include a calculation engine, the inhabitants were not able to build the model of the tiny house themselves on software and then launch the calculations (done on the ACVnum prototype without being able to launch the calculations). This transparency was undermined by the data system linked to the LCAs (data that was not accessible, paid for or not easily understandable).
- Co-responsibility (all members of the focus group): "So there is the notion of the common, of what is common. We are not concerned with the notion of individualistic interest, even if we are in the business of taking care of humans. It's more the idea of being at the service of what makes humanity and what makes life in its biodiversity." (inhabitant 1). This co-responsibility hasn't been taken into account during the design phase of the ACVnum prototype and is a limit to our experiment.

Also, the notion of care was touch by some inhabitants: "Benevolence in fact, communicating in a different way, being in relation with others in a different way. That was my entry point into the eco-village." (inhabitant 3) or " The ecovillage has objectives, a vision of where it wants to go, with what human posture it wants to go. And I think the question is how an engineer can fit into that, how he can transform himself." (inhabitant 2) or " "taking care of humans, taking care of humanity, in the service of what makes life" (inhabitant 1).

4.2.2 Results of competencies for sustainability

All the members had to position themselves in relation to the engineering competencies for sustainability. In fact, our grid of competencies suited the members of the focus group with an engineering background, while the others had difficulty identifying the perimeters of each

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competence. All the inhabitants positioned themselves at fairly high levels on each skill because their experience in the ecovillage mobilized all of the competencies in the grid. Furthermore, the results of the questionnaire show that the use of our prototype ACVnum by the members of the focus group did not raise a link between the competencies and this tool. At least, it wasn't mentioned in the interviews. The ACVnum prototype is therefore not consolidated in terms of learning comptencies.

4.2.3 Results about the LCA process carried out by the focus group

The LCA approach is a request from the inhabitants of the eco-village. In the long term, the inhabitants' objective is to use an environmental analysis approach to prove that their adopted lifestyle has a low environmental impact ("it's not just a matter of showing but of proving" (inhabitant). Three elements have been identified through the LCA process: (1) A difficulty of the inhabitants to master certain fields of competence: minimum mastery of industrial processes (example of exchanges: "The polypropylene rainscreen, it is not fair to say that it is granulated, it is rather a tarpaulin.", "do you have the rock wool process independently of the materials?", "it seems to me that plant fibres are used more like flax to reduce the [environmental] impact. By extrusion, injection or thermo-moulding?"). As the group was heterogeneous, the participation of the inhabitants in the exchanges fluctuated greatly according to the topics. This was also the case for the understanding of environmental impact categories (for the choice of environmental indicators and calculation methods). Thus, the inhabitants felt they needed an external expert to help them conducting the process. (2) Difficulty for residents to understand data uncertainty: a lot of data were missing. Also, as the data were described in English (non-native language), it was difficult for half of the group to understand the scope of the data and the relevance for the tiny house. Some members of the focus group could not understand the data they had. (3) The participants' difficulty in understanding the environmental indicators prevented them from relating the environmental impacts they were given in the results to the industrial processes required for the tiny house.

5 DISCUSSION

5.1 Interpretation

As the researchers were involved in the ecovillage, they were in relation with the members and observing at the same time, which led to close links with focus group members. We are thus close to an interpretive epistemology. This epistemology implies that our conclusions are not universal, but very specific to our study. If we go back to the 4 elements of permaengineering (ethics, goal, approach and expertise), here are some conclusions we can formulate from our study:

- Ethics: The care ethic is relevant to stakeholder expectations in a strong sustainability context. However, it is not clear how well the ACVnum prototype meets this ethic (it enables collaboration, but does it ensure that collaboration is done in a careful way?).
- Goal: the ACVnum prototype enables an environmental assessment but does not link the results with the planetary boundaries.
- Approach to sustainability: participants were already understanding sustainability as a wicked issue, and it seems that the LCA process didn't change this perspective (complexity of sustainability problems were recalled by inhabitants during the discussions on the results for instance). The prototype challenged the inhabitants in the management of uncertainty (related to data issues).
- Expertise: an expertise in industrial processes or environmental indictors is not needed but a minimum is required. It is only through this minimum that interactional expertise can be developed.

5.2 Limitations and future works

One of the limits of our experiment is that we could not conclude on the 8 competencies of engineering for sustainability. Indeed, we didn't collect enough data to measure the progress made by members of the focus group through the LCA process. Better data collection should be done on engineering competencies for sustainability. Another limit was that the subject of tiny houses was not relevant for all the members of the focus group. Thus, different level of involvement has been observed, linked to the interest to the subject (and the understanding of LCA aspects).

6 CONCLUSION

The ACVnum helped us to pragmatically explore a first attempt to practice permaengineering. We can conclude that ACVnum does not necessarily correspond to a permaengineering tool/method. We offer two possible explanations: ACVnum doesn't embed enough of the values/practices of permaengineering, or the interviews didn't manage to output the values and practices of permaengineering. Further interactive or non-interactive artefacts need to be designed by the community to begin to better understand the tools and methods of a permaengineering perspective.

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