Trade-offs between dreams and reality: Agroecological orchard co-design

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Abstract: *Fruit production is among the crops using the most pesticides, affecting both the environment and human health. Previous experimentation have shown the limits of substitution strategies to reduce pesticide use. In this context, the INRA Gotheron experimental station (Drôme, France) aims to redesign a pesticide-free orchard maximizing ecosystem services, especially pest control. To overcome the lack of hindsight and knowledge, a co-design workshop was organized with stakeholders from diverse professional activities and experiences. Four prototypes of fruit tree agroecosystems were designed that combined a range of means to suppress pests and proposed original spatial arrangements and layout.*

The workshop analysis aimed to understand i) which knowledge was brought and by whom, ii) how ideas were elaborated and, iii) the successive steps in the design process. Considering the workshop, the exchanges more than the outputs were source of interest for participants. A fine-grained qualitative approach was adopted and emphasizes the diversity of knowledge brought in by the participants. The ideas finally adopted resulted from negotiations between participants who expressed their support or questioning and suggested alternative or enhanced proposals. Idea elaboration was not a linear process with movements back and forth between exploration and "stabilized" knowledge, between breakthrough and reality, generally ending in trade-offs.

This work opens doors for further research on agroecological design process and knowledge sharing. Besides basic knowledge, the capacity to produce proposals and to envisage trade-offs is a key-element to foster participatory design process.

Keywords: *Agroecology, Fruit agroecosystem, Innovation, Co-design process, Knowledge, Idea elaboration, Expertise*

Introduction

Fruit production is among the crops using the most pesticides, affecting both the quality of the environment and human health. This can be related to both the perennial nature of orchards where some pests and diseases (in short 'pests') can persist across years and to the marketing of fresh fruit paid according to visual criteria; pesticide use is therefore the main tool used to control pests and provide high quality fruit. Decreasing pesticide use and other environmentally unfriendly practices is therefore necessary towards sustainability. Previous experimentation have shown the limits of substitution strategies to reduce pesticide use in orchards (Hill et al., 1999; Simon et al., 2011; Navarrete et al., 2012) but relying on ecological processes to produce fruit and limit or omit the use of inputs is challenging. It requires (i) to consider a range of spatio-temporal interactions within the orchard, namely a multi-layer and perennial complex habitat, but also (ii) to redesign at a supraplot scale the organization of productive and supporting areas, to favor functional biodiversity and maintain soil fertility (Altieri, 1999). In this context, the INRA Gotheron experimental station (Drôme, France) has initiated a project, referred to as 'Z project', to experiment a redesigned pesticide-free orchard maximizing ecosystem services, especially pest and disease control (Haines-Young and Potschin, 2012). It relies on three main principles: (i) the design of a pest suppressive agroecosystem; (ii) the optimization of resource use, e.g. between productive and companion plants, in the experimental area of 8 ha, and (iii) trade-offs between agroecosystem design and feasibility and work conditions. This implies a paradigm shift in agronomic science towards a more comprehensive and integrated approach beyond classical cropping system experiments in orchards (Meynard et al., 2012; Simon et al., 2017). When considering the agroecosystem, the usual study object (i.e., the monoproduction field) is changed for supraplot, multi-production and multi-layer dimensions, and the temporal evolution of species modifies the design of the fruit production area through time. All this implies to identify, collect and organize multi-disciplinary knowledge on the multiple ecological processes, interactions, and feedbacks, i.e. how design and cultural practices affect them and how design affects cultural practices (Altieri, 2004; Duru et al., 2015). To overcome the lack of hindsight and knowledge on such innovative complex perennial agroecosystems, both scientific and technical knowledge as well as experience feedbacks and know-how from various backgrounds are required. This can be achieved though facilitating exchanges among and co-design with stakeholders as advocated by most of the current literature on agroecosystem design (Le Bellec et al., 2012; Malézieux, 2012; Reau et al., 2012; Lefevre et al., 2014; Reynolds et al., 2014; Berthet et al., 2015). Most literature focuses on farmers' participation to design innovative production systems because (i) they have necessary traditional and situated knowledge to share (Malézieux, 2012); (ii) they have additional aims and contexts as regards the agroecosystem design and management (Ingram et al., 2010; Prost et al., 2012); and (iii) they have the capacity to contextualize the understanding of system functioning into farmers' action (Toffolini et al., 2017). Those three aspects should ensure the design of locally-adapted cropping systems and the production of end-users adapted knowledge. The contribution of other actors of the socio-technical system such as advisors, trainers, scientists, sales managers, consumers etc. is also highly relevant to cross contexts and backgrounds for the design of an experimental breakthrough system as is the case at Gotheron (Berthet et al., 2015; Moneyron et al., 2017; Capitaine et al., 2016; Prost et al., 2017). Prost et al. (2017) emphasized the challenge for agricultural and design science to prove that the hybridization of heterogeneous knowledge „*catalyses both the design process and knowledge production*" especially in cases where actors interests and/or points of view may diverge. However, except maybe for landscape design and collective resource management (Etienne et al., 2011; Berthet et al., 2015), studies have seldom analyzed the contributions of a variety of actors and even less participants interactions and the process of knowledge hybridization during a design workshop, at least in agronomy. Vidal et al. (2016) or Valantin-Morison et al. (2016) for instance analyzed the dynamic of knowledge production for agricultural system design but they considered the whole design-evaluation process with several workshops and focused mostly on farmer vs. researcher contributions. In epistemology, Moneyron et al. (2017) analyzed the contribution of a diversity of actors, knowledge and reasoning for the design of agroecological viticulture, here again at the scale of a 14-year research action project mixing interviews, visits, meetings, workshops, training courses and evening meetings. In ergonomic sciences, Barcellini et al. (2015) reported the few studies focusing on the content of the interactions in participatory meetings within a participatory design process of a software that assesses the sustainability of agricultural cropping systems (MASC®) gathering designers and users. However, the elaboration of ideas from the proposal of one participant to the generation of a collectively designed prototype remains undescribed.

To design an agroecological prototype to be experimented at Gotheron, our first hypothesis was thus that a diversity of skills and stakeholders should offer complementary knowledge and comprehensive attention, especially with farmers as key end-users, for experiential knowledge (Baars, 2011) and consideration of farming conditions and socio-economic constraints (Oliver et al., 2012); advisors for the diversity of practices and systems they support; experimenters (i.e., agronomists dealing with experimentation) for technical knowledge and experience of experimental framework; „experts" for accurate and updated knowledge on specific topics; researchers for scientific knowledge and capacity to step back and trainers for experience of knowledge transfer. A participatory workshop was thus organised at Gotheron to try and elicit as much as possible the complementary knowledge of the invited stakeholders. The aim of this paper is to analyze participants' contributions and interactions in the elaboration of design proposals to identify key-elements to foster participatory design process within an agroecological framework.

Materials and Methodology

The workshop session

The studied workshop took place on the experimental station of Gotheron in March 2017 at the beginning of the above-described 'Z project' and aimed to design a first unit of about one hectare in the whole experimental area. It gathered around 30 people (excluding organizers) that were invited to participate on the basis of their expertise, their experience of innovative systems and their willingness to share and debate with other participants. Half a day workshop was organized combining successive sessions: (i) an hour of plenary introduction to present the context, the framework, the design purposes and an overview of previous work of the Gotheron team on perennial agroecosystems; it also permitted to explain the role of the participants and aimed to create a pleasant atmosphere to facilitate participants' expression and exchanges; (ii) one hour and a half dedicated to the design activity in four groups; (iii) one hour for cross restitutions and plenary discussions to collect participants' feedbacks and discuss perspectives.

Stakeholders from diverse professional activities and skills were assigned to four groups and each group produced a prototype. All groups (Fig. 1) included participants with different backgrounds: farmers, advisors, experimenters, researchers and/or trainers, and local resource persons ("Gotheron team") from the experimental station to provide additional details about the context when necessary. Experimenters are technician or engineer agronomists working in experimental stations and whose professional activities are dedicated to the design, implementation and management of experiments mostly in response to operational questions from farmers. For their part, researchers also perform experimentation but rather to test new concepts. The local (INRA Gotheron) and a partner (INRA Ecodeveloppement) research teams collaborating in the project were involved in the progress and facilitation of the session. At each working table, a neutral (external from Gotheron and fruit production) facilitator was in charge of allocating speaking time and prompting the discussion while a rapporteur (familiar with Gotheron and workshop objectives) made intermediary syntheses and an on-live report to register the decisions of the group and their rationale. Experts on specific topics such as genetic resources, biodiversity or plant associations were assigned among the tables to provide each table with knowledge backgrounds on those topics. The discussions were audio-recorded and transcribed afterwards.

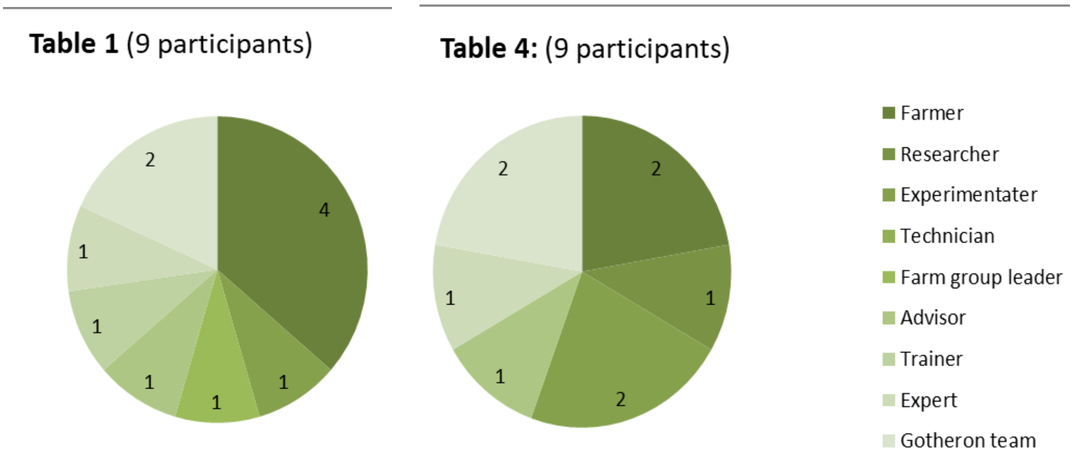

Figure 1: Distribution of the participants according to their professional activity, e.g. Table 1 and 4.

The outputs

Along the workshop, design proposals finally selected by the group (in other words "decisions") were recorded by a rapporteur and could be represented in the form of a model using a homemade layout made of toothpicks and small coloured soft pieces (Playmais®) picked on a ca. 0.5 m² polystyrene board. Final prototypes, combining proposals represented on the model and the ones recorded on the rapporteurs' reports were afterwards numerically modelled in 3D layouts using the software SketchUp© (Fig. 2).

Four prototypes (i.e., one per group) of fruit tree agroecosystems were designed that combined a range of means to suppress pests: this included low-susceptibility fruit tree cultivars, physical barriers, trap plants, pest disruption through plant volatiles and conservation of natural enemies of pests. Many new ideas were brought in by the participants but the originality of the outputs relied above all in the proposed spatial arrangements and layout.

Surprisingly, the outputs of the four tables shared equally into two types of patterns, namely circular and patch spatial arrangements. The analysis of idea elaboration in the design process therefore focused on one prototype within each spatial arrangement group, namely Table 1 and Table 4 prototypes, which were those that most satisfied the contributor participants and also displayed the highest and the lowest number of contributions per participant, respectively (see results section) (Fig. 2).

a) b)

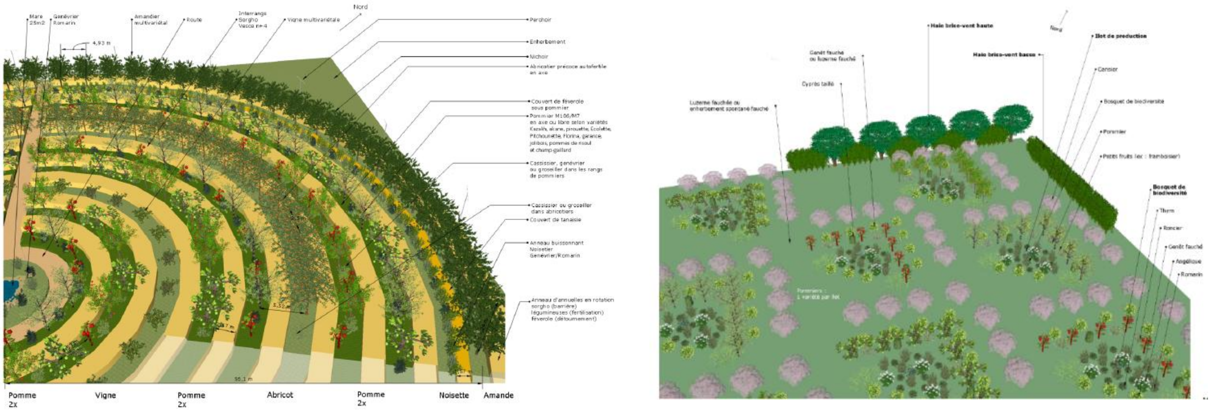

Figure 2: General layout of the prototypes of (a) Table 1, circular spatial arrangement and (b) Table 4, patch spatial arrangement.

Analysis of participants' contributions and idea elaboration

A questionnaire was filled in by the participants during and after the workshop and was used to characterize participants professional activity, experience, fields of expertise, familiarity with workshops, the topics they thought they contributed to („perceived contributions") as well as their motivation to participate and their satisfaction about the prototype they contributed to.

From the transcripts, we first codified the types of contributions for quantitative analysis. This codification was adapted (see correspondence on Figure 4) for the qualitative analysis of participants' interactions. Depending on the context, a query may be: (i) to ask for clarification in which case it helps facilitate the discussion, (ii) to ask for information background in which case it emphasizes lacks of knowledge, and (iii) to put a proposal into question in which case it forces the group to reconsider the proposal. The final classification included six main types:

- Technical proposals: concrete design suggestions by participants
- Positive contributions : arguments to support or approbation in favour of a proposal
- Negative contributions: arguments to disapprove or to reconsider a proposal

- Information background and lacks of knowledge: to explain mechanisms and/or ecological processes or provide references related to one proposal, or to note lack of information
- Facilitation contributions: clarification requests, contextual information (about Gotheron objectives, pedo-climatic and biotic context, design constraints and room for manoeuvre), workshop instructions or punctual syntheses to prompt the discussion
- Spatial layout: final proposals (decisions) reported on the homemade layout and registered by the rapporteur.

Moreover, proposals were categorized according to the topic addressed: biodiversity, global spatial organization (i.e., general design), orchard management (i.e., cultural practices), fruit tree association (i.e., other than apple tree), soil fertility, genetic resources (i.e., cultivar and rootstock), commercialization and animal introduction. This categorization was used to analyze the topics participants contributed to according to their field(s) of expertise (from the questionnaire) and professional activity. Effective vs. perceived contributions by the participants were also analysed using the feedbacks of the participants collected on the questionnaires. Quantitative and descriptive data were managed using Excel software.

To analyze more accurately participants' interactions and ideas' elaboration in Tables 1 and 4, participants' contributions were finally organized along linear axes using a fishbone diagram under Xmind open-source software. Discussions were cut into ideas (one fish = one idea) and the types of contributions were distinguished by colours and represented by bones separating, above the backbone, the proposals and positive contributions and, below, neutral (mostly facilitation) and negative ones (Fig. 3).

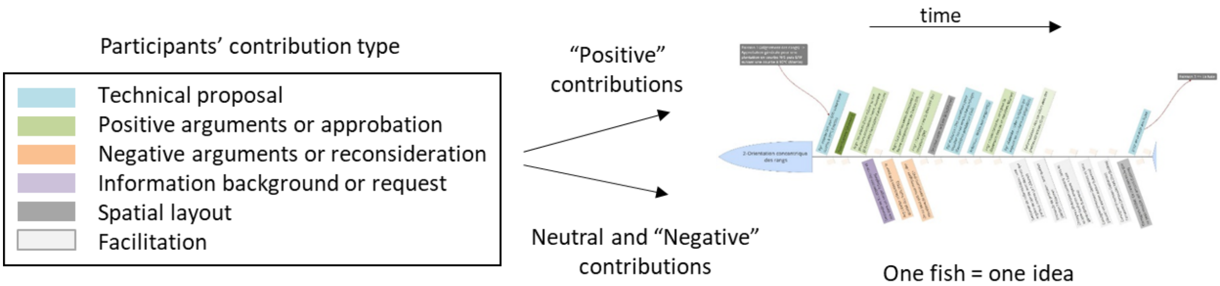

Figure 3: Organization of participants' contributions representing the elaboration of an idea along a horizontal axis shaped as a fishbone.

The length and shape of the fish directly attests to the participants' support (i.e., more upper bones) or reconsideration (i.e., more lower bones) of each proposal and the time (i.e., the number of bones) necessary to develop it with elaborated or alternative proposals suggested by participants. The succession of ideas in the whole workshop consisted in a "shoal of fish". It was cross-checked with the final prototypes and decision reports to identify adopted, rejected, bypassed or transformed ideas (see Fig. 6).

Results

The analysis aimed to understand i) which knowledge was brought and by whom; ii) how ideas were elaborated and; iii) the successive steps in the design process.

What was brought and who brought it?

A total of 2516 contributions were categorized across the four tables with an average 627 contributions per table, and a range from 422 contributions at Table 4 to 848 at Table 1. Each participant contributed in average 53.5 times during the design activity but this number differed greatly among participants (from 4 to 176), tables (from 53 to 106) and professional activities. Farmers participated the most with at least 50 contributions per participant.

The analysis of the type of contributions according to the professional activities (Fig. 4) emphasized four main results. First, few references and processes were used to reinforce arguments or provide information background. Second, the contributions of participants were related neither specifically to their occupational category, nor to their expected field of expertise only (data not shown). Third, all the participants facilitated the discussion asking questions, suggesting instructions and asking for validation to progress in the design. Fourth, the contributions of the facilitator and the representative of the Gotheron team were important to provide contextual information and validate ideas. In addition, the proportion of negative arguments was disconnected from the satisfaction of the participants about the prototype they contributed to (data not shown).

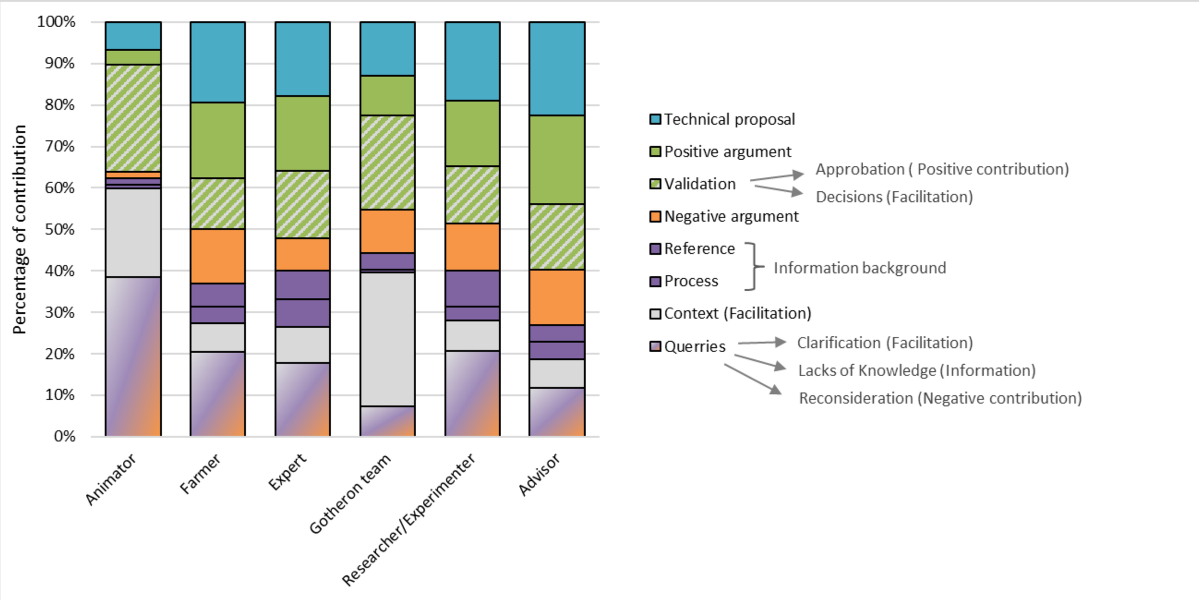

Figure 4: Distribution of the types of contributions according to professional activities (pooled data from the four tables). Correspondence with the categorisation used in the qualitative analysis (above described fish, see Fig. 3) is indicated in the legend.

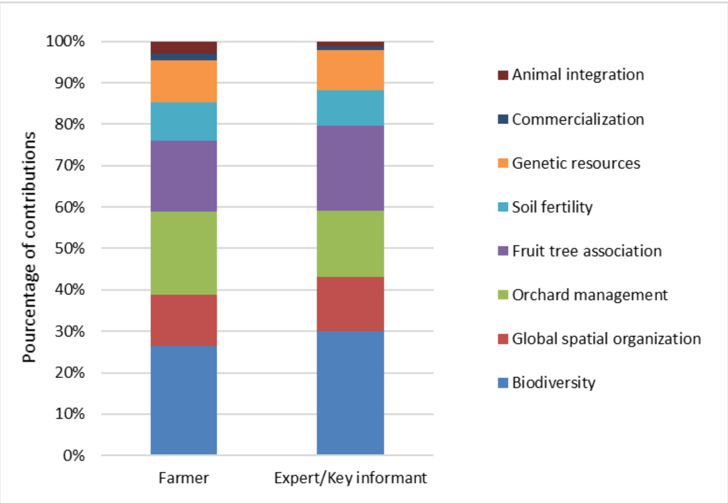

Figure 5: Distribution of the topics addressed by contributions according to professional activities (pooled data from the four tables).

The analysis of addressed topics from the transcribed contributions, participants' perceived contributions and fields of expertise collected from the questionnaire emphasized that biodiversity, orchard management and genetic resources were the three topics on which participants contributed the most in agreement with their field of expertise. In contrast, soil fertility and plant protection knowledge was underused, while spatial design and plant associations were topics participants contributed to outside of the fields of expertise they indicated in the questionnaire. Contributions' distribution among topics was very similar whatever the participant professional activity (Fig. 5). Regarding tables, Tables 1 to 3 matched the same proportion of biodiversity contributions (20-25%) whereas Table 4 proposed more biodiversity contributions (35%) to add agroecological infrastructures, companion plant or ecosystem mimicry design elements. Table 4 also discussed more about fruit tree mixture compared to Table 1. Since final prototypes of both tables displayed a similar level of diversification, this implies that Table 4 needed more time and interactions to address these topics.

How did ideas emerge, took shape and were adopted (or not)?

Our initial hypotheses concerning the construction of ideas were: (i) the idea starts with a proposal followed by a justification; (ii) the idea is corroborated or supported by references; (iii) the idea is challenged and then (iv) reconfirmed. The final step (v) should be the realization of the idea on the spatial layout or on the rapporteur report. From our analysis, the process of the construction of ideas was nevertheless more complicated and displayed multiple patterns.

(i) Ideas were always the result of a succession of proposals with evolved, alternative and trade-offs depending on participants' support or reconsideration.

(ii) Proposals were generally not supported by only one participant but by the group, i.e., negotiations involved all participants who expressed their support adding mostly arguments such as additional services provided. In comparison, references to processes were little used except for companion plants supported in both tables by scientific, empiric and theoretical references.

(iii) Ideas rarely got directly a consensus, but were more or less criticized as emphasized by the alternation of upper and lower bones. Negotiation was an important process to balance positive and negative arguments, to provide alternative proposals and find trade-offs.

(iv) Collective validation was most of the time implicit, except in a few case when the facilitator asked all participants to express their points of view on one specific proposal. In most cases, an idea ended when a participant (including the facilitator) switched to another idea without others needing to go back to the previous idea. On the contrary, participants may go back to previous ideas despite facilitators' attempts to move to another subject, as observed for Table 1 with several round trips to integrate or not hazelnut in the outside row.

(v) The spatial layout was here a useful tool as well as the intermediary syntheses performed by the rapporteur to record validated ideas.

The fishbone analysis also highlighted the topics with the highest lacks of knowledge. In our cases, it concerned the effects of companion plants or of species or cultivar associations on pest dynamics.

General design process

Regarding the design process (Fig. 6), the length of the fish and the number of bones indicate that some ideas were more than others matter of debate, while some ideas were relatively rapidly adopted. The fish related to the implementation of a hedgerow at Table 4 (see Fish 3 in Fig. 6) and of a pond at Table 1 (result not shown) were relatively short with a majority of upper bones. In contrast, the arrangements and composition of the ring-row (Table 1) or the cultivars to be mixed within the islets (Table 4, Fish 8 in Fig. 6) were longer fish with more questioning or negative arguments. In those cases, the debate (and the fish) finished when trade-offs were found, that combined both pest control and fruit production.

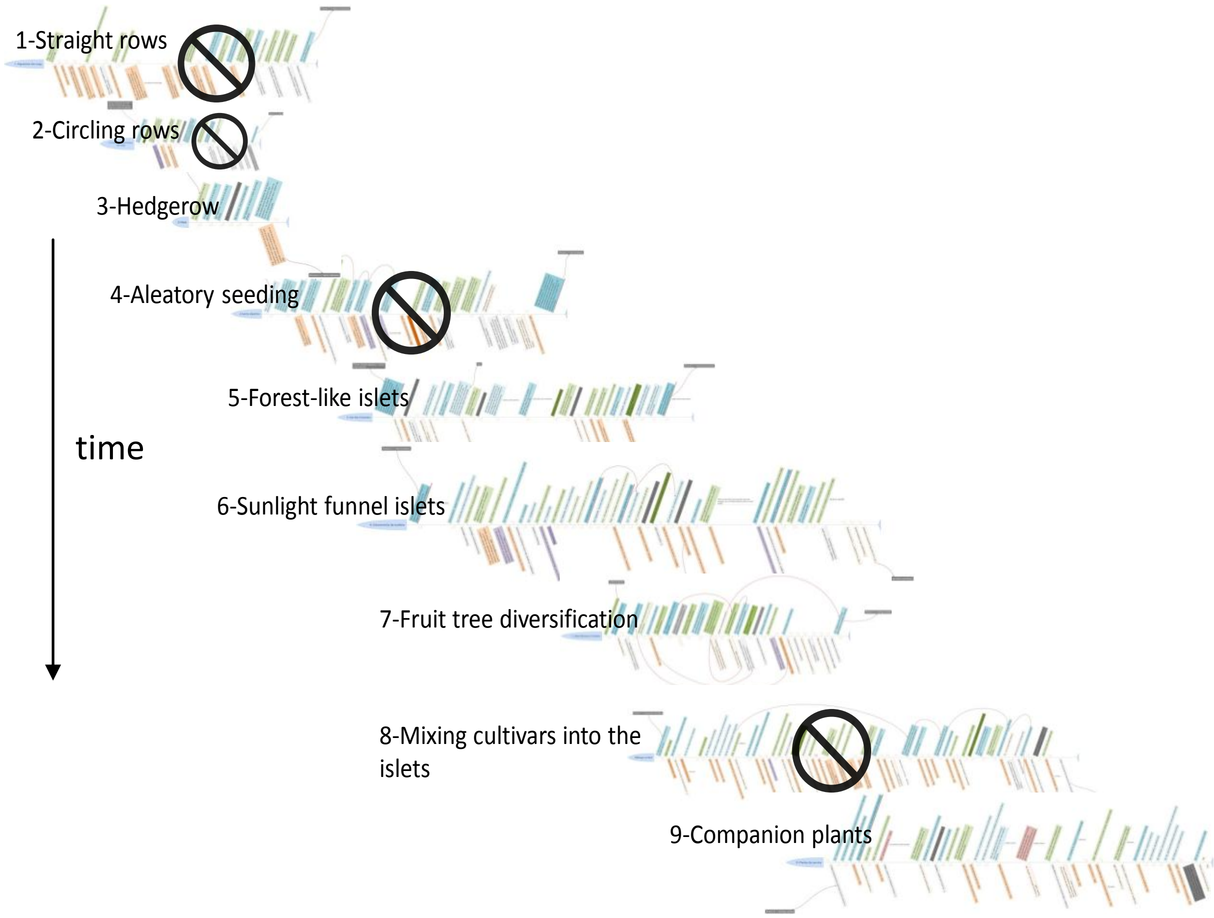

Figure 6: Successive steps in the design process: the shoal of fish at Table 4. Nine ideas were discussed. Prohibiting direction signs correspond to non-selected rejected ideas, i.e., that were registered neither in the rapporteurs' reports nor on the models. Overlapping proposals or ideas are not represented for clarity. Fish legend is presented at Fig. 3.

Some ideas were merely rejected. Table 4 was especially interesting because the group introduced several ideas that were not adopted because proposals were too much 'out of the box' or did not suit Gotheron requirements (Fig. 6). Random sowing of fruit tree seeds to select the hardiest trees was for instance rejected after a long debate on feasibility and time issues. Other reasons for rejection across tables were: the potential attraction of pests (e.g., peach hosting the oriental moth *Cydia molesta* or walnut tree hosting codling moth *Cydia pomonella*); the lack of knowledge on the effect of companion plants (e.g., repellent effect of plant volatiles of blackcurrant bushes on flying pests).

Ideas were generally enriched, e.g. constructive critics were useful to insure multi-services plant selection such as species that combine wind protection, fruit production, pest control and supporting biodiversity, especially at Table 1 with the proposal of almond trees and hazelnut bushes. Surprisingly, operational constraints were little evoked except for harvest operations or ground cover management.

Another statement is the overlap between ideas and between proposals. Species diversification was at the core of the design process and constantly recalled in the discussion as well as design aspects. In contrast, apple production was relatively little and lately addressed at both tables, limiting the discussion on cultivars choice. Such overlap entails and explains the difficulty faced by the facilitators of both tables to organize the discussions. Despite facilitators' regulation, the discussions could continue or quickly go back to previous not "finished" topics. However, facilitators played a decisive role to advance the process asking for details and clarifications and inviting participants to change topics once they felt consensus was achieved.

Finally, the two design processes at Tables 1 and 4 started discussing the row arrangements and adopted spatial arrangements that combined plant and wind protection and ensured accessibility to the trees. They then adopted a spatial design process moving roughly from the outside to the inside of the prototype, i.e. from the surrounding hedgerows to the plant composition of the islets (Table 4) or from the surrounding to the inner rows (Table 1).

Discussion

The four 1.5 hour parallel sessions in the workshop permitted to collect a substantial dataset used to analyze contributions and the design process. Despite some few exceptions (e.g., participants who did not contribute much), contributions were numerous and diverse in terms of topics and category, and each group achieved a consistent fruit tree agroecological prototype. Concerning the topics, socio-economic aspects (commercial) and soil fertility were little addressed. We were in an early step of the system design process and the workshop focussed on pest suppressive design. Arguments clearly focused on the services the proposals must provide in a quest to combine pest control, fruit productivity, biodiversity conservation and feasibility. Our analysis also identified important lacks of knowledge, e.g. on companion plant and plant associations, what was already noticed by Valantin-Morison et al. (2016) for the design of low-input rapeseed cultivation practices. This calls for future research and partnership to integrate knowledge on interactions among plants, among plants and animals and plant community.

The need for heterogeneous knowledge to design agroecological perennial agroecosystems was confirmed by the diversity of the categories and topics describing participants' contributions. Information backgrounds, i.e. references and processes, were nevertheless little used compared to proposals, arguments and questionings: participants were familiar with concrete proposals rather than concepts (processes) whatever their background. From our results, the heterogeneity of both the category and the topics of participants' contributions did not come from the professional activity (Fig. 4, 5) whereas the negotiation between participants, their capacity to generate and explore ideas and trade-off findings seemed crucial for our design performance. Profiles such as the ones suggested by Barcellini et al. (2015) may be used to describe forms of participation to the design process. In our study, animators and Gotheron team were participants that distinguished themselves from the others: they particularly fitted the "*project leader*" profile, i.e. with an interactive and group driver involvement facilitating ideas' progression and decision making in correspondence with the role they were assigned. "*Boundary spanners*" and "*super experts*" profiles could also be used to better describe at the individual scale participants' contributing profile in our case study. From our analysis, a new profile could be proposed as a "t*rade off agent*" in capacity to reach trade-offs from different points of view. Finally, in line with our findings, the epistemological analysis of participants' perspectives, practices, positions, and reasoning by Moneyron et al. (2017) demonstrated the interest of having different points of view. The latter authors advocate that the lack of contradictory contributions may lead to heuristic poverty and that dissensus, rather than consensus, can be no longer an obstacle but become a resource for research and agroecological changes. Our results confirm the benefits of "negative" contributions, i.e. proposals' critics and reconsideration, in the process of idea elaboration.

According to Meynard (2016), it is not possible to specify in advance the knowledge and the required skills for innovative design. Such breakthrough design in fact refers to a process of exploring new "possibilities" to meet new expectations that are not completely defined at the beginning but become clearer as the designed object takes shape. As stated by Hatchuel et al. (2013), the rationality of design keeps the logic of intention but accepts the undecidability of its target; it aims at exploring the unknown, and it is adapted to the exploitation of the emergent. Yet, its ontology can be explained to make the complex clearer. To investigate the actual content of participatory design meetings, Barcellini et al. (2015) and Labatut et al. (2009) defined for instance three levels of abstraction to model the evolving representations during the phases in the design process of the artefact designed - in this case the software to assess cropping system sustainability - from more abstract representations to more physical-concrete ones. These levels of abstraction were not used for this study, but their implementation in our case study would certainly confirm how the operational, functional and conceptual dimensions are intertwined. The spatial layout was a useful tool to foster operational contributions. The functional level was constantly used to argue propositions according to the defined purposes, in our case the multi-functionality of the agroecosystem. Finally, the conceptual level was expressed through many interrogations and contextual information given by the facilitators or the Gotheron team.

Fishbone diagram was a useful tool to globally analyze the "design path" (Hatchuel et al., 2013) and the hybridization process of heterogeneous knowledge, i.e. (i) to describe the complex succession of new, alternative, trade-off proposals, positive and negative arguments; (ii) to distinguish the different steps and ideas discussed; and (iii) to identify lacks of knowledge and debates. This representation was proposed from the analysis of a one-day workshop session but four parallel tables were analyzed and the overall structure of the 'fishbone' can be considered as quite generic. This representation was yet time consuming because it required post categorization of all the contributions; if useful for research purposes, further developments are required to develop it for a direct use during workshops. It would then allow the participants to weight directly positive and negative arguments and may help them validate ideas before moving to a new one. Conversely, it must not be too formal to avoid affecting negatively creativity and the dynamics of exchanges. It was also sometimes difficult to distinguish a "fish" from another, which is symptomatic of the design of diversified and complex systems where components are strongly interrelated. The representation of interactions between fishes were attempted but rapidly abandoned for the sake of clarity. The representation should therefore be developed to better integrate interferences between design elements.

Finally, the prototypes designed during the workshop were analyzed from reports and layouts and discussed among the Gotheron team. Some proposals were adopted (e.g., circular shape with a central pond from Tables 1 and 3, fruit species diversity from Table 1) in a deconstructing then rebuilding approach that occurred along series of internal meetings. Through proposals, exchanges during and around the workshop, analyses of contributions and idea elaboration, this workshop can therefore be considered as a turning point in the design of the first experimental prototype in the project. Even if prototypes of the workshop were far from being adapted and adopted as they were, it was a decisive moment because a prospect became concrete (dream became reality) and also got collective support. As emphasized by Prost et al. (2017) on collective design processes, „*it is not only an object that is designed but also the activities of all those who take part in the design*". If the direct users of the design were here the Gotheron team, all the participants of this workshop were potential users of the knowledge the experimentation will produce. The Gotheron team is fully aware of this contribution; in the on-going project, the workshop participants were informed of the further design process, and they will be regularly invited, as well as other stakeholders, to exchange about the experimentation and the evaluation of the finalized prototype and to develop further design activities.

Conclusion

This study is the first one that analyzes precisely how ideas are elaborated during a workshop session to design a complex agroecosystem: it considers required knowledge, its heterogeneity and the way it hybridizes in final proposals through a dynamics of exchanges. It highlights key elements in the co-design process of agroecological systems that were already pointed out by other authors (e.g., workshop group composition, participant profiles effect, knowledge heterogeneity, facilitation, exploratory dimensions etc.) or very little developed (e.g., knowledge hybridization along idea elaboration, capacity to achieve trade-offs, overlapping dimensions in the whole design process). Finally, this work opens avenues to understand processes at stake during co-design workshops, and to improve the organization, facilitation and capitalisation of such activities to support an agroecological transition still in its beginning.

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