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THÉORIES ET MÉTHODOLOGIES

SUPPORTING THE DESIGN ACTIVITY OF FARMERS IN TRANSITION TO AGROECOLOGY: TOWARDS AN UNDERSTANDING

SOUTENIR L'ACTIVITÉ DE CONCEPTION DES AGRICULTEURS EN TRANSITION AGROÉCOLOGIQUE

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RÉSUMÉ

Pour faire face aux nombreux défis techniques, environnementaux et sociaux qui s'imposent à elle, l'agriculture doit changer. Parmi les voies possibles, l'agroécologie est une forme d'agriculture qui semble prometteuse. Elle repose sur l'idée de mobiliser les régulations biologiques et écologiques dans les champs pour développer des systèmes agro-alimentaires soutenables. Une telle forme d'agriculture nécessite une transformation du travail des agriculteurs, perçus non plus comme des utilisateurs de solutions clés en main proposées par les acteurs de la R&D mais comme les concepteurs réels de leurs systèmes de production. Mais comment décrire et caractériser cette activité de conception pour permettre de penser la façon de la soutenir ? Dans cet article, nous donnons à voir quels sont les problèmes de conception que les agriculteurs peuvent affronter lorsqu'ils sont engagés dans une transition vers l'agroécologie et quelle activité de conception ils développent pour faire face à de tels problèmes. En mobilisant une méthode appelée Chronique du Changement auprès d'une dizaine d'agriculteurs, nous avons en effet été en mesure de faire émerger certains traits caractéristiques de cette activité. Nous donnons ainsi à voir un aperçu de la diversité des problèmes de conception, en insistant sur leur niveau de structuration variable et les interdépendances qui existent entre ces problèmes, ce qui permet de souligner le caractère systémique de la transformation du travail dans laquelle sont engagés ces agriculteurs. Nous analysons ensuite l'activité de conception déployée par les agriculteurs, par le biais d'une navigation dans les pôles réel, concevable et virtuel

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de leur activité de travail. Nous pointons notamment l'ancrage de cette activité de conception dans le réel de leur activité et l'intérêt d'identifier un pôle « concevable » pour interpréter la façon dont dialoguent le réel et le virtuel dans l'activité des agriculteurs en transition vers l'agroécologie. Enfin, nous discutons des moyens et des défis à relever pour soutenir une telle activité de conception et nous mobilisons notre expérience de la méthode Chronique du Changement pour formuler des points d'attention pour la production d'outils d'aide à la conception des agriculteurs.

Mots-clés : *Ergonomie, agriculteur, transition agroécologique, activité de conception.*

ABSTRACT

Faced with numerous challenges, agriculture needs to change. Agroecology, a way of farming that relies on localized ecological and biological regulations, is a promising option. It requires a transformation of the work of farmers, seen no longer as users of turnkey solutions proposed by R&D actors, but as the actual designers of their production systems. How can this design activity be characterized? This article provides an understanding of the design problems and activity performed by farmers engaged in agroecological transitions and supported by a method called the Chronicle of Change. We provide an overview of the diversity of interrelated and more or less structured design problems facing farmers, showing that agroecological transitions involve a systemic transformation of work. We then analyze at a micro level the farmers' actual design activity, through navigation in the real, designable and virtual dimensions. Finally, we discuss the means and challenges to be taken up to support such a design activity.

Keywords: *Ergonomics, farmer, agroecological transition, design activity.*

I. INTRODUCTION

I.1. Is the transformation of farming to meet the challenges of the agroecological transition a design activity?

Since the Second World War, the development of intensive agriculture, particularly in Western Europe, has increased productivity per hectare and per worker, thus allowing national self-sufficiency in agricultural products, lower food prices, and the release of labor for other economic sectors. This has however had numerous negative effects: decrease in the number of farms and rural jobs, and increase in land concentration and environmental degradation (Stoate *et al.*, 2001; Millennium Ecosystem Assessment, 2005; Emmerson *et al.*, 2016), as well as harmful effects

on agricultural work that lead to higher suicide rates among agricultural workers (Bossard, Santin, & Canu, 2016; Klingelschmidt *et al.*, 2018). Béguin and Pueyo (2011) recently detailed the challenges facing agricultural workers: organizational and relational constraints, environmental and physical constraints, and exposure to biological and chemical agents. Farmers' health is therefore affected, as is that of consumers (INSERM 2013; Waggoner *et al.*, 2013).

Faced with these challenges, many actors, from farmers to institutional actors, agricultural development agents or agricultural researchers, are calling for a profound transformation of agricultural practices (Hill & MacRae, 1996). Many of them are advocating for a transition towards agroecology to develop sustainable agriculture. Agroecology invites us to consider that sustainable agricultural systems would rely more on ecological processes (biological regulation by competition, predation, decomposition of organic matter, recycling of nutrients, etc.) to enhance natural regulations and resilience, and thereby to ensure long-term food security and human and environmental health (Wezel *et al.*, 2009). Agroecological practices can thus be understood through the development of multiple interactions between plants, soils, landscapes, and micro and macro fauna. This makes their effects complex to predict and highly dependent on local situations and dynamics, especially since there is incomplete knowledge of the natural processes involved (Williams, 2011; Duru, Therond & Fares, 2015). Managing these interactions therefore requires the farmers to engage in a learning process and to do things differently (e.g., Mayen, 2013). In this context of agroecological transition, farmers are having to deal with major changes in their work. There is a strong need to better understand the labour issues faced by farmers and to take these into account in the support offered to them. This context raises questions on a whole range of concerns, and more particularly on the diversity of transformations in farmers' work that can be created, provoked or even imposed by this agroecological transition. This question of transformations in farmers' work seems to have received very little attention in the research problems of agronomic disciplines up to now. Conversely, in ergonomics the question of work transformations is central but initially arose in industrial or service contexts. At the crossroads of these two disciplines, ergonomics and agronomy, and in order to focus on the transformations of the farmer's work, we chose to consider the farmer as a major actor in the agroecological transition.

To underline farmers' key role in agroecological transitions, some authors have proposed to consider farmers as the real designers of their production systems (Cerf, Guillot, & Olry, 2011; Schiere, Darnhofer, & Duru, 2012; Martin, Martin-Clouaire, & Duru, 2013; Chantre & Cardona, 2014; Coquil, Dedieu, & Beguin, 2017; Prost *et al.*, 2017). The few studies that exist in ergonomics and sociology on how farmers engage in and experience professional transition processes towards agroecology (Chantre, 2011; Chantre & Cardona, 2014; Coquil *et al.*, 2017) confirm the relevance of this "design" angle by illuminating the actual activity of farmers engaged in agroecological transitions. What they show about this activity is consistent with the main characteristics of design activities

(Darses, Détienne, & Visser, 2004). First of all, they underline the imprecise nature of the design solutions to be achieved (What does the notion of agroecology cover?), the complexity of characterizing the initial design problem farmers have to deal with (What should be modified in the current situation to move towards agroecology?) and the difficulty of defining the path between the two (What are the available levers? Which ones have to be invented? How can they be combined?). The authors then highlight the diversity of the paths taken by farmers to specify the design problems and solutions, and to experiment with ways to move from one to the other, all of which are characteristics posed by wicked design problems as identified by Darses *et al.* (2004). More broadly, looking at farmers as designers means recognizing their legitimacy in participating in the construction of their own projects, of course, but also of a project for the future of the agricultural world (Béguin & Pueyo, 2011). These studies however give limited information about farmers' design object. In line with Chizallet, Prost, & Barcellini (2019) and Chizallet (2019), we propose to consider that farmers are the designers of their work systems which encompass all the elements that impact or can be impacted by the work itself. The farmers' work systems are then transverse to biological and technical, socio-economic and family subsystems.

This type of proposition to analyze the farmers engaged in agroecological transitions as designers is an appealing one for ergonomists. First, it allows one to focus on the farmers' work activity in these transitions. Second, it allows one to apply all the knowledge that ergonomics has developed about design activities (e.g., Béguin, 2003; Broberg, Andersen, & Seim, 2011; Barcellini, Van Belleghem, & Daniellou, 2014; Norros, 2014), in order to better understand and support the activity of farmers in transition. Hence, the aim of this article is to explore how the work system design activities of farmers engaged in agroecological transitions can be supported, while developing an understanding of both the issues they have to solve and what they actually do to for that purpose. Our intention is to contribute towards answering the following research questions: How are design problems defined by farmers over time and what are the subsystems involved in defining these problems? And how are these design problems dealt with through farmers' design activity?

I.2. What model of design activity?

If farmers are designers, they are non-professional designers; their design activity is hardly recognized and is almost totally unequipped. This work is implicit for farmers: it is not identified as a task as such, and is intertwined with other types of farming activities. In fact, as underlined by Cerf and Sagory (2004) and Béguin and Pueyo (2011), farmers fulfill several roles on their farm, especially when they are the head of their farm. They are simultaneously workers, managers and designers of their work systems. So, in our opinion, there is a real challenge to think about how farmers' design activity should be supported. In order to support farmers' design activity, we have drawn on research that views design as

a project management process, that is, an iterative process of adjustments between the expression of a will – intention –, driven by decision-makers and designers ("virtual" dimension), and the reality of the work, driven by workers ("real" dimension) (Béguin, 2007; Martin, 2012). The virtual dimension refers to intention and ideality, and provides the impetus. The real dimension reminds us that this ideality has to happen in action. In general, this model seems to assign the virtual dimension to professional designers and the real dimension to workers/users of the designed object. It is then a question of seeing design as an iterative process of adjustments between the expression of a will for a desired future – the intention of decision-makers and designers – and the reality of work carried out by workers (Martin, 2004; Béguin, 2010). In this context of agroecological transition in which farmers are both designers and workers, it is precisely the virtual and the real aspects of the farmers' activity that is of interest to us. Several authors (e.g., Bergamini, 1995; Béguin & Bergamini, 1996; Martin, 2000; Béguin, 2010) explain that these two dimensions evolve in a dynamic of tension during the design process. The real dimension meets the virtual one when a vision of the future is applied in a real or simulated work situation (through tests or experiments). Thus, the results of the action carried out by the workers call into question the representations of the designers/decision makers and make it possible to specify them. These tensions between the real and the virtual reflect a search for feasibility which appears as an intermediary space between the two (Martin, 2000; Béguin, 2004; Daniellou, 2004; Béguin, 2010). The mechanisms at work in this intermediary space are key to the design process. In ergonomics, we go through simulation, mock-ups and intermediate objects (e.g., Daniellou, 2007), but the scale of the design object, the whole work system, makes this complicated in the context of agroecological transitions and points to the need to focus more closely on this intermediary space. We have therefore proposed to consider it as a third dimension to be studied and supported as such, in addition to the dimension of the real and the virtual (Chizallet *et al.*, 2019) within the model presented in Figure 1. This is the "designable": that which could be achieved under the conditions of the real, at the interface between the "real" and the "virtual" (see Figure 1). In the following, we will refer to this model as the "Virtual-Designable-Real" (VDR) framework. We will use it to analyze the design activity that farmers perform to solve their design problems, in order to follow the dialogues they build between the virtual, designable and real.

To support farmers' design activity, we have designed the Chronicle of Change method, which aims to promote a dialogue between the dimensions of virtual, designable and real design.

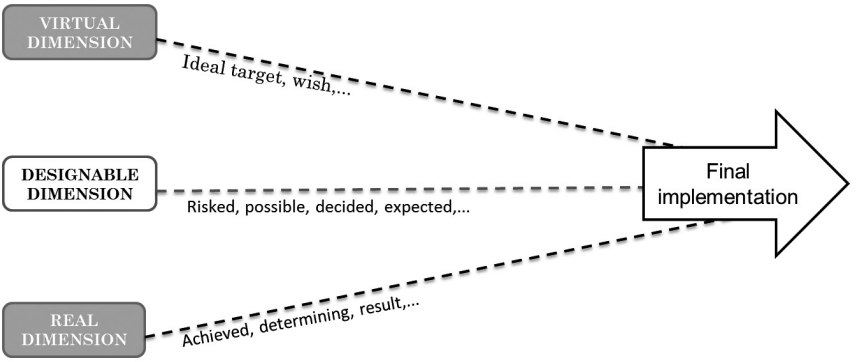

Figure 1. Design seen as project management envisaged in three dimensions: "virtual", "designable" and "real"
(adapted from Martin, 2004; Béguin & Pueyo, 2011; Chizallet *et al.*, 2019).
Figure 1. Le processus de conception considéré comme une conduite de projet, elle-même envisagée comme des itérations entre trois pôles : le "virtuel", le "concevable" et le "réel" (adapté de Martin, 2004 ; Béguin & Pueyo, 2011 ; Chizallet et al., 2019).

II. SUPPORTING THE DESIGN ACTIVITY OF FARMERS IN TRANSITION TOWARDS AGROECOLOGY

II.1. The Chronicle of Change: a method designed to support the design activity of farmers in transition

To support the design activity of farmers engaged in agroecological transitions, we built a tool called "the Chronicle of Change" (CC; Chizallet, Barcellini, & Prost, 2017) based on the "VDR" framework. As design activity is diffuse and dispersed in farmers' agricultural work, this CC allowed us to organize their working times dedicated to design, in order to stimulate this activity. The CC is based on support that makes it possible to explain and keep track of the difficulties encountered by farmers, the objectives they set themselves, and the resources they mobilize – or would like to mobilize – to conduct a project and thus develop a design activity. It is underpinned by the hypotheses that: (1) talking about objectives makes it possible to clarify farmers' intentions and to initiate discussion on the "virtual" dimension of their activity, (2) talking about the difficulties encountered by farmers in their work situations is a means of discussing the "reality" of their work and addressing the problems that need to be solved, and (3) talking about the resources used, built by farmers, or to be mobilized by farmers, allows an adjustment between the "real" and the "virtual", and thus discussion about the "designable". Thus, the Chronicle of Change makes it possible to represent and keep track of past and ongoing design activity and to generate discussion around it. It is therefore a tool that both highlights the intention, the will for the future that underlies the farmers' design processes and, at the

same time, allows them to adjust their intentions and objectives in an adaptive way, as the "conversation with the situation" (Schön, 1992) takes shape. In this article, we explain how the CC supported the design activity of farmers in a phase of transition towards more agroecological farming practices.

II.2. Description of the use of the Chronicle of Change

The implementation of the Chronicle of Change with farmers is based on three steps. The first is a preliminary step to obtain a global understanding of farmers' work, through an exploratory interview. This step will not be detailed in this article. The second step in the process is a workshop "tracing change until today", from an initial work system identified by farmer(s), to the "current" work system, that is, on the day of the workshop. The work system is understood as all the elements that impact or can be impacted by the farmers' work. In the Chronicle of Change method, the work system identified by farmers is no more precise than this definition, in the sense that the facilitator(s) who lead the method do not intervene to help farmers define it. The question is open: how would you define your working system before the change? This question is deliberately open so that the description they propose of their work system can contribute to the construction of a definition of what a farmer's work system can be, which is rarely defined in the literature (see Chizallet, 2019).

It is the farmer(s) who choose(s) the starting point of the Chronicle of Change, corresponding to a significant and voluntary change for their farm. In this 2-hour workshop, the farmer(s) complete(s) a timeline, presented in Figure 2, with the help of the ergonomist/facilitator. On Post-it® notes, the farmer(s), accompanied by the ergonomist, should indicate the difficulties encountered during the transition, their objectives, and the resources they use in an attempt to solve these difficulties and achieve the objectives. The "Objective–Difficulty–Resource" (ODR) triptych constitutes the common thread for the ergonomist/facilitator to revive discussions between farmers. Following the workshop, the farmers are invited to implement the Chronicle of Change on their farm. They are free to complete it whenever they wish, by adding post-it notes®. A few months later, the Chronicle of Change can be worked on by an ergonomist/facilitator and farmers in two ways: (1) setting up a monthly follow-up to monitor the changes that have been made within the farmers' work system, and thus to analyze and support them (Figure 2), and (2) creating a synthesis, in which case it is a "meeting-synthesis". The farmers and ergonomist/facilitator examine all the aspects of the ODR triptych at that point in time: Are they still relevant? Are the objectives being met? Have they evolved? Are past difficulties still considered as difficulties? The ergonomist/facilitator and farmers update the ODR according to changes that have taken place since the workshop, and record a new ODR triptych. The construction of the Chronicle of Change can continue with new follow-ups and other "meeting-syntheses".

Figure 2. Example of the second step of a Chronicle of Change, with four monthly follow-ups.

Figure 2. Exemple du remplissage de la Chronique du Changement lors de l'atelier "tracer le changement jusqu'à aujourd'hui", puis lors de quatre suivis de la CC.

To illustrate the use of the Chronicle of Change, take an example. An ergonomist worked with two farmers on the Chronicle of Change. Together, they spoke about fighting invasive weeds – a real problem for farmers. These conversations were translated into two "difficulties" post-it notes, "Fight against invasive weeds" and "Wheat harvest because too many invasive grasses", in blue; a "resource" post-it note, "Change of crop rotation", in yellow; and an "objective" post-it note, "Land use", in pink. These post-it notes are shown in Figure 3.

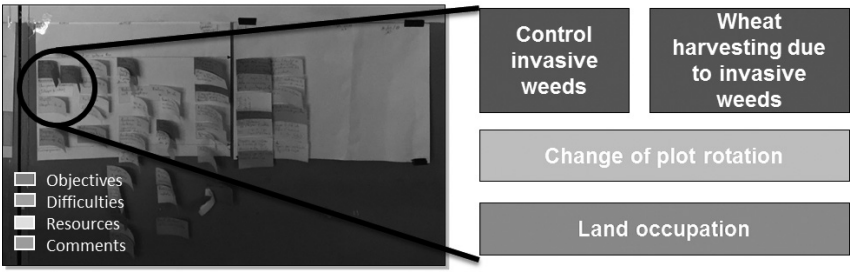

Figure 3. Example of "Objective-Difficulty-Resource" triptych with translation.

Figure 3. Exemple d'un triptyque « Objectif – Difficulté – Ressource » concernant la difficulté des agriculteurs de lutter contre les mauvaises herbes.

Objectives, difficulties and resources are captured from the farmers' point of view. There are no prior categorizations that could have guided the facilitator's questions towards the types of objectives, difficulties and resources of their choice. The ODR tryptic is likely to support design activity in that it allows farmers to navigate in the virtual, the designable and the real, whether in conversations or post-it notes generated by the Chronicle of Change. We believe that farmers' use of the Chronicle of Change, supported by the stakeholder, can additionally reveal design problems encountered by these farmers.

II.3. Case studies

This CC was tested with several farmers who were the managers of their farms (not agricultural workers) on 10 different farms in France. In this article, we chose to focus on two illustrative case studies detailed in Table 1.

TABLE 1. Characterization of the two case studies
TABLEAU 1. Caractérisation des deux cas d'étude : les agriculteurs X et L céréaliers et l'agriculteur N éleveur bovin

	Farmers X and L	**Farmer N**
Type of agroecological transition	They are in the process of conversion to organic farming while maintaining no-tillage crop production, which is a technical challenge (Lefèvre, 2013).	He is in the process of transition to an autonomous system that limits the purchase of inputs on the farm and puts the cows back on the grass.
Motivation of the transition	These choices are mainly motivated by ethical and ecological reasons (preserving the life of the soil by reducing its disturbance), as well as purpose (regaining meaning in the farming profession) and economic considerations (being able to get paid).	This transition to a low-input grassland system goes through several stages that the farmer describes: an awareness after a poor grain harvest in 2010, after which he dismissed his grain technician; the establishment of multi-species meadows in autumn 2013, constituting for him the "real start"; and in the fall of 2018, his decision to stop fattening his male calves and to plant corn silage to make more grass. This transition was primarily motivated by significant economic difficulties.
Type of production	Grain farmers – The farm consists of 200 hectares of wheat, maize, barley, oats, faba beans and soybeans.	Cattle farmer: The farm consists of 80ha of which 63% is grassland, with 50 cows and a breeder-fattener system.
Summary of the history of the farm before the transition	Before being associated with farmer L, X was associated with his cousin. Following the retirement of the cousin, farmers X and L had been associated since 2013 to practise a conventional no-till farming. They had begun the conversion to organic farming in October 2014.	He first joined the family farm in 2008, with a conventional system with very little grass, and then took over his uncle's farm alone in 2010.

Salary situation of the farm	These farmers have no employees. They sometimes call on the help of neighboring farmers.	N works alone on the farm. However, N frequently helps his brother out on his farm, and his brother in turn helps him out as well.
Number of interviews conducted with CC taken into account in this article	Six meetings (initial CC, four follow-ups, and synthesis) were held with these farmers over the course of a year.	Two meetings (initial CC and one follow-up) were held with this farmer and the ergonomist, as well as a CIVAM (center for initiatives to promote agriculture and the rural environment) facilitator.

The second case has a particularity since the intervention with farmer N is done jointly with a facilitator from the CIVAM (center for initiatives to promote agriculture and the rural environment). CIVAM facilitators usually support farmers with the technical changes in agroecological transition, using original facilitation methods often based on collective interaction. The facilitators who accompanied us in the implementation of the Chronicle of Change were in a process of accompanying farmers in agroecological transition, with an approach focused on work transformations. As part of this research-intervention, the facilitators discovered and tested with the ergonomist and sometimes alone, the Chronicle of Change as a method of individually accompanying farmers. The collective dimension of the design activity supported by use of the Chronicle of Change (two farmers in the first case study, an ergonomist and a CIVAM facilitator in the second one), is not studied in this article.

II.4. Data analysis

All the meetings were transcribed and segmented in order to reveal the main design problems the farmers deal with. This segmentation was made possible by a detailed analysis of farmers' objectives, difficulties and resources, which showed a "coherent whole" in which each element informed, challenged or explained a problem in the farmer's design. This intrinsic definition of design problems from farmers' verbatim was then supplemented by using the description of the dimensions of farmers' work system (Chizallet, 2019): biological and technical, social, economic, family, and directly related to the farmer's internal conditions (knowledge, skills, health, history, etc.). This is to better understand the design problems and to better situate them within the work system designed by the farmer(s). The definition of dimensions of farmers' work is presented in Table 2.

TABLE 2. Definition of dimensions of farmers' work
TABLEAU 2. Définition des dimensions du système de travail des agriculteurs : les dimensions biologique et technique, sociale, économique, familiale et relative aux conditions internes de l'agriculteur

Work subsystem	Definition
Biological and technical	refers to the natural environment exploited by the farmer as well as the methods, tools and materials available to exploit natural resources
Social	includes the farmer's (non-family) social relationships, market or non-market
Economic	corresponds to the characteristics of the farmer's financial system
Family	corresponds to the household and the distant family who may impact the farmer's work
Worker's internal conditions	corresponds to the internal and personal characteristics of the farmer (knowledge, skills, health, condition, history, experience, age, motivation, decision-making ability, etc.)

Data from the interviews were analyzed from complete transcripts of audio records, which were iteratively coded for the various dimensions, relying on different markers that were identified during an inductive process. The list of markers finally compiled is presented in Table 3.

TABLE 3. Coding scheme for Virtual-Designable-Real dimensions
TABLEAU 3. Schéma de codage des pôles identifiés de l'activité de conception : le « virtuel », le « concevable » et le « réel »

Design dimension	Definition	Description of the markers used	Examples
Virtual	Objectives targeted by the workers, desire for the future	Time orientation marker: - Objective, goal, wish, aim, etc. - Verbs: to like, to aim, to seek, etc. - Verb tense: future	*"The objective is to make the soil live, to make it turn, to make it work."*
Designable	The "possibilities" to be designed, requiring the farmer to know or to seek to know the conditions of the real	- Temporal orientation marker: tense of verbs (future conditional, past conditional, future) and marks of past alternatives (past alternatives, bifurcations that presented other possibilities and that could have led to another present) - Marks of necessity: obligation, necessity, forecast of an evolution of the situation and what will necessarily happen	*"We could, yes, if we do nothing, really face a no-harvest situation, an inability to harvest."*

		- Marks of possibilities and impossibilities: expression of an expectation, possibility or impossibility concerning a situation, an event or an action (e.g., "I can") - Marks of conditions, contingencies: condition or contingency considered in the future situation, disjunctive alternatives for an achievement, to initiate actions (e.g., "if") - Links with choices (it allows you to, you are sure to be able to, leading to)	
Real	What actually exists: a worker's work situation, elements that make up or impact this situation; more generally an observable fact or event	Marker of the temporal orientation: - Tense of verbs (past tense, present tense) - Markers of the present tense (already, there, today, etc.) - Reference to the calendar (seasons, years, dates, days, weeks, months)	*Farmers talk about wheat bunt: "I saw some in an experiment in a field that had been artificially inoculated, the bunt had been brought in and counts had been done."*

III. RESULTS

III.1. What types of design problems, reported in the Chronicle of Change, do farmers have to deal with?

III.1.1. Farmers X and L: isolated farmers who have some technical and social support

Table 4 shows some of the design problems encountered by farmers X and L in connection with their decision to convert to organic farming. After having decided to partner, the two farmers faced major economic difficulties, linked to a fluctuation in selling prices in conventional agriculture. As prices in organic farming are more stable, this was a driving force behind their conversion to organic farming. They also faced ethical difficulties: they no longer felt comfortably applying chemicals to their crops and their work no longer seemed meaningful. However, while the

conversion to organic farming solved some problems, it also brought new ones to light. The cessation of chemical use led to a major weed problem for which the farmers were not trained (biological and technical problems). It was then necessary for them to acquire new tools and to learn how to use them according to the weather conditions. In addition, farmers found themselves isolated because they were the only ones to practice no-till organic farming in their area (social dimension). They were trying to remedy this situation, for example by meeting other farmers from other regions of France, in particular to help them choose the equipment to weed their plots.

TABLE 4. Design problems faced by farmers X and L
TABLEAU 4. Les problèmes de conception rencontrés par les agriculteurs X et L, relatifs aux dimensions du système de travail des agriculteurs

Work subsystem	**Design problems**	**Description**
Biological and technical subsystem	Control weeds	Weed control is a big challenge in agroecology: X and L have had several dirty harvests (with economic impact). Their strategy is to do mechanical weeding, which requires the use of new tools and trial/error.
	The sort of harvested products	X and L want to sort harvested products to be self-sufficient in seed. However, the sorting they are currently doing is not working well: there are a lot of broken grains and their crop remains dirty.
Economic subsystem	Address profitability problem (2013-2015)	X and L made the choice to switch to organic farming in part for economic reasons: they no longer paid themselves wages.
	Limit the cost of accounting	X and L used an accountant to manage the accounting of their farm. They considered doing some of the accounting themselves.
Social subsystem	Be less isolated	These farmers were the only ones in their area to practice organic farming combined with "no-till". They were looking for contact with other farmers who practiced the same agriculture.
Family subsystem	Rarely mentioned	Family was rarely mentioned in the interviews as a problem. On the contrary, it was a source of support.
Worker's internal conditions	Respect their values	X and L switched to organic farming in order to be aligned with their values, such as respecting the environment (having a healthy soil, not using chemicals), health (their own and consumers' health), and finding meaning again in the farming profession, which they had lost.

III.1.2. Farmer N: an isolated farmer trying to uphold his values and to cope with his family's skepticism and economic issues

Table 5 synthesizes design problems expressed by farmer N during the two meetings. N is facing family as well as economic difficulties, which isolate him. First, the choice he made of moving toward a more agroecological agriculture is opposed by others members of his family [4]: his mother, brother and uncle disagree with his choice. Moreover, his in-laws want him to diversify the activity of the farm (to create a restaurant and educational workshops). This farmer is thus caught between his own values and aspirations, and his family's projects. Second, he must solve financial problems that result from the agricultural model he wants to move away from. A conflictual situation has arisen with his bank, which generates tensions with the family (his wife). With regard to the social dimensions, in addition to family and neighborhood problems, N is concerned about preserving his physical health and making his work meaningful again. Finally, N expresses technical problems related to the development of the skills necessary to implement more agroecological practices: for example, how to "cure" calves with essential oils.

TABLE 5. Design problems faced by farmer N
TABLEAU 5. Les problèmes de conception rencontrés par l'agriculteur N, relatifs aux dimensions du système de travail des agriculteurs

Work subsystem	**Design problems**	**Description**
Biological and technical subsystem	Try to set up a specific type of cropping	He is concerned about succeeding in harvesting "something", in setting up a specific type of crop (multi-species grasslands).
	Develop a strategy to deal with his fragmented farmland	The farmland is very fragmented, which is a problem for getting the cattle out.
	Ensure the health of his cattle	Several calves that were sick from birth died. The implementation of a new health protocol using essential oils, instead of antibiotics, has failed. He has to stabilize the protocol.
	Develop a *technical* strategy to move toward organic farming	He wants to move to organic farming but does not know where and how to get proper advice.
Economic subsystem	Cope with former economic issues	Past economic choices (2010-2014) still have some consequences and contribute to the mismatch "*between social, family issues and economic profit*".

4. In France, farms are more often "family businesses".

Social subsystem	Acknowledge his agricultural practices in the neighborhood	The neighbors' opinion is a major difficulty for N. Discussion with his neighbors – sometimes also friends – often turns into conflict.
Family subsystem	Acknowledge his own values "against" family and neighborhood ones	To cope with family and neighborhood judgments.
Worker's internal conditions	Protect his health	N is concerned by his health (psychological and physical) as his father (farmer) died early; and he wants to enjoy himself again at work.

III.1.3. A diversity of interdependent design problems, designed on various spatial, temporal and complexity scales

The analysis of the design problems expressed reveals that farmers have to deal with a diversity of design problems when engaged in agroecological transition, from "biological and technical problems" which may be the more obvious ones, to economic and social problems, more broadly. In other words, the design problems encountered by farmers affect all of the farmer's work subsystems. All these problems are interdependent, as shown by the intricacies of family, health and economic issues in the case of N, for instance.

References to subsystems of work made by farmers also make it possible to report differences in situations between the two case studies presented in this article. We can see for instance that X and L are less isolated and get more support – technical, social, family and maybe economic – than N. This may be a crucial point: given the diversity and complexity of design problems, farmers need not only technical but also economic, social and family support. Thus, beyond the diversity of the work subsystems to which farmers refer, the design problems do not involve the same level of difficulty. For example, some technical problems may be well-defined, while the design problem "to face economic difficulties" requires a structuring of the sub-problems to be delineated and addressed. Design problems can thus be addressed on different scales. First of all, a complexity scale, and we could ask ourselves: does a design problem have a higher level of complexity in terms of the number of work subsystems it involves? We also think that these design problems are to be understood on a spatio-temporal scale. The results show that the families of farmers X and L are much less present in explaining their design problems than is the family of farmer N. This could be justified by a spatio-temporal scale. Farmer N lives with his family on the farm, next to his brother's farm. In addition, the farm is located in a small village in which other members of his family reside. As a result, the family of N is certainly more involved in the design activity of farmer N. Conversely, farmer L lives 40 km from the farm and X only a few kilometers away. In X and L's interviews, X talks more easily about his family than does L: for example, he talks about his wife's opinion about projects for the

farm, as well as about neighboring farmers who are members of his family. In this example, the temporal aspect is to be understood in the sense of "making history", for farmer N took over the farm of his uncle, who is now retired. His uncles and his father were all farmers, so the farm has a family history, initially rooted in conventional practices that farmer N is trying to change. Some design problems are therefore also to be understood as rooted in a history that goes beyond the farmer's current difficulties. However, the temporal aspect is also to be understood in relation to a calendar: When did the design problem start? When was it resolved? How long did it last? How long has it been going on and why? And so on.

III.1.4. A systemic approach to the design problem that is structured over time

Our analysis of all the design problems has shown their diversity and the fact that they involve several work subsystems. We propose to now focus on a longitudinal analysis of one design problem to analyze how it developed and how it unfolds over time. In the example we have chosen, farmer N expressed a problem concerning the economic subsystem: dealing with former economic issues. Figure 4 shows how the events experienced and projected by the farmer, reported in the Chronicle of Change, can be described chronologically.

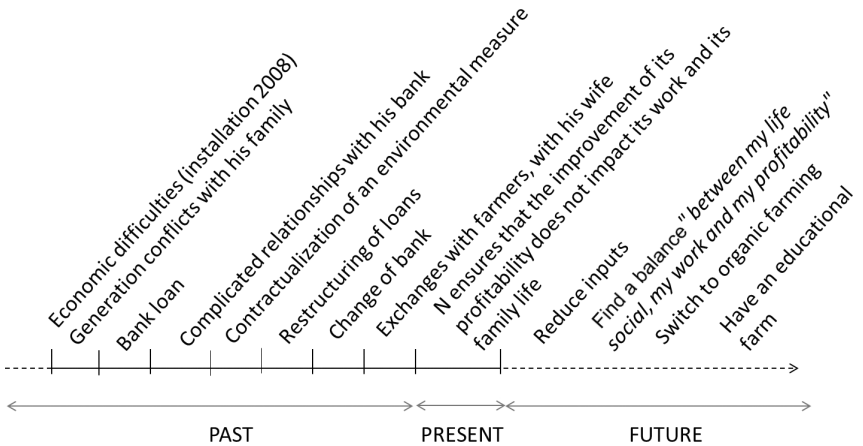

Figure 4. Tracing the design problem related to the economic subsystem of farmer N.
Figure 4. Traçage dans le temps du problème de conception, faire face aux anciennes difficultés économiques, liées au sous-système économique de l'agriculteur N.

The design problem presented here was triggered by economic difficulties and generational conflicts, which the farmer encountered shortly after his arrival on the farm, as his family members were all farmers. The initial situation of this process thus combined the economic and family subsystems. This figure shows moreover that a situation projected by the farmer relates to the economic, social and family subsystem, and to the farmer's internal conditions. Here, farmer N's objective of finding a

balance "*between [his] social life, [his] work and [his] profitability*" seems to have been built on an accumulation of events affecting diverse work subsystems, and expands on his initial formulation of the design problem. In fact, it is precisely because of his economic difficulties that farmer N has recourse to various financial mechanisms such as a bank loan, the restructuring of all his loans, and aid, and we also note that relations are strained between him and his bank, which prompts him to change banks. But the accumulation of these experiences exclusively related to the socio-economic subsystem is not sufficient to explain N's objective of finding a balance "*between [his] social life, [his] work and [his] profitability*". It is actually his relationships with agricultural actors and with his wife that trigger the formalization of this objective. Moreover, to continue with this example, we note that three other projected situations are exclusively of a biological and technical nature – a subsystem that was not present in past events. These projected situations also respond to the economic difficulties encountered by farmer N. It would then seem that the farmer resolved his farm's economic difficulties in two stages: initially, in the urgency of the situation, he preferred the economic solutions. It was only after that, that the farmer considered other technical solutions, requiring more time, through his projected situations: reducing his inputs, transitioning to organic farming, and possibly setting up an educational farm.

Finally, while we think that the categories of work subsystems proposed by Chizallet (2019) are to be understood with permeable boundaries, we agree with the result that the subsystems are articulated to one another, and more precisely impact one another. This reinforces the idea that a systemic approach is necessary for the researchers to better understand farmers' design activity.

Beyond this first understanding of the nature of farmers' design problems, a key question is then what they actually do to deal with these different problems. We tackle this question by describing how farmers navigate through the virtual, designable and real dimensions of design activity.

III.2. Forms of VCR dialogs which structure the definition of design problems

The aim of this section is to better understand how a design problem is addressed during the use of the Chronicle of Change and, more specifically, how it is structured through farmers' design activity in the use of the Chronicle of Change. This type of navigation involves thorough work on the data, which is why we have chosen to present a detailed example showing the type of analysis that can be built, and the mechanisms of interaction between dimensions that appear. Thus, our analysis focuses on the design problem of "sorting the harvested crops" of farmers X and L. To be more precise, this design problem is based on discussions between farmers about sorting, storage and selling prices. We have taken an excerpt from the interview to illustrate it. Figure 5 shows the order of the discussions during the use of the Chronicle of Change, between the

two farmers and the ergonomist. Figure 5 shows the dialogues between the different mobilizations of the dimensions of VCR by the farmers in their verbal exchanges. It makes it possible to account for the complexity of the forms of dialogues that are played out between the virtual, designable, and real dimensions of the farmers' design process. It shows how, through the exchanges involved in the construction of the design problem, farmers X and L navigate the three dimensions of the dialogic model of design. The forms of dialogue between the real and the virtual and between the virtual and the designable are present in equivalent proportions.

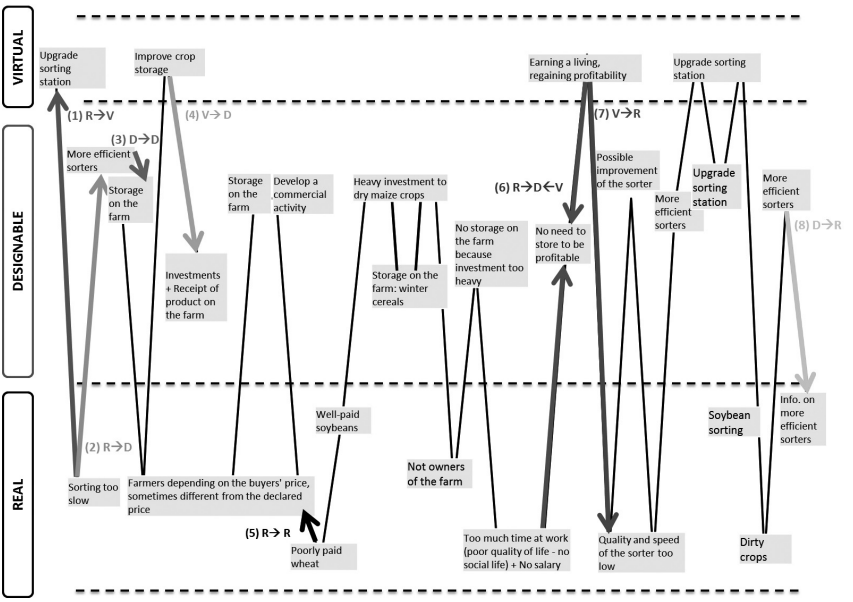

Figure 5. Navigation in the Virtual-Designable-Real dimensions for "sorting the harvested crops".

Figure 5. Navigation entre les trois dimensions identifiées de l'activité de conception : le "virtuel", le "concevable" et le "réel", concernant le tri des récoltes.

Figure 5 shows the iterations between the different dimensions of the design activity, in the farmers' attempt to develop strategies regarding: sorting harvested crops, storage, and sales price control. It also makes it possible to report on the forms of dialogue that are played out between the virtual, designable and real dimensions of the design process, in all the complexity of the farmers' discussions. These forms of dialogue are developed by farmers X and L in their attempt to develop strategies for crop sorting, storage and sales price control. The commentary on this figure follows the chronological order of farmers' discussions and highlights each new form of dialogue that appears (not all forms of dialogue

are therefore systematically listed, only the new forms that appear throughout the story).

(1) The first objective expressed, the improvement of the sorting station, is linked to the idea that farmers can use their crops as seed for subsequent crops. This objective is put into dialogue with the real dimension. In this case, we are talking about an elaboration of the virtual from the real; in blue **(1) R→V** in Figure 5. In fact, farmers use a sorter belonging to their agricultural equipment cooperative, which has a low flow and thus impacts their work (real). This causes them to formulate their objective of improving their sorting station.
(2) Farmers' observation that sorting process is too slow (real) leads them to discuss the fact that there are more efficient sorters (designable). This is a form of dialogue about the elaboration of the designable from the real; in green **(2) R→D** in Figure 5.
(3) In addition, the possibility of having a more efficient sorter (designable) would allow X and L to store their harvests on the farm (designable), thus highlighting a form of dialogue within the designable dimension; in red **(3) D→D** in the figure 5. This would be a way of being less dependent on buyers than they are today (real).
(4) The objective of improving the storage of crops is formulated (virtual); however it would require significant financial and time investment, as well as the development of the farm, to allow the reception of crops (designable). We note here a form of dialogue of elaboration of the designable by the virtual; in orange **(4) V→D**. X and L then seek other ways to no longer be dependent on prices set by buyers (real), such as the development of a commercial activity (designable).
(5) This dependence on buyers' prices (real) seems really heavy for X and L who then describe an experience with a crop they considered to have been poorly paid (real). Here we see a wheat-related difficulty that adds to the weight of buyer price dependence for X and L. In this case we speak of a form of dialogue of amplification of the real; in black: **(5) R→R**.
(6) Farmers' assessment of the remuneration they received for wheat led them to ponder the question of storing their crops on the farm (designable) in order to have the choice to sell their crop or not to a crop buyer, and possibly to wait for better offers. In discussing this, the farmers explain that this might be possible but only for winter cereals that are harvested at 15% moisture. Spring cereals require the installation of drying stations on the farm (designable), which is hardly feasible for farmers X and L, given the fact that they do not own the premises (real). They therefore decide not to store their crops on the farm (designable). This decision is then linked to the excessive time they spend on the farm and the fact that farmers do not get paid properly (real). They feel that they do not need to store their crops to get back to profitability (virtual). This is a form of dialogue focusing the virtual and the real on the designable; in purple **(6) R→D←V**.

(7) Discussions carry on about the sorter, the flow of which they consider too slow to meet their needs, and which they deem to be of poor quality (real), while aiming to restore profitability (virtual): dialogue of elaboration of the real from the virtual, illustrated in brown **(7) V→R**. They also have the opportunity to buy another sorter with the CUMA (cooperative for the use of agricultural equipment) or even to buy a second-hand more efficient one (designable). The farmers then mention their objective to improve the sorting station (virtual), also as a "possible" designable that can respond to dirty harvesting difficulties (real) that they have for example encountered when sorting soybean crops containing broken grains and weed debris (real).

(8) Finally, farmers again mention the fact that there are more efficient sorters for sorting (designable). This is when farmer L explains that he has done research on the internet concerning used sorters (real). We read here a dialogue of elaboration of the real from the designable; in yellow: **(8) D→R** in Figure 5.

In this case, we note a preponderance of dialogue between the real and the designable. The fact that the designable is powered by reality refers, for example, to known mechanisms for comparing design solutions with reality. It would then be possible to envisage that the real difficulties and possible solutions could feed on one another. We believe that naming this third dimension makes it possible to claim the importance of what is happening at the interface of the real and the virtual, not only to better understand how farmers specify their design problem, but also to explore possible solutions. Without claiming to be exhaustive, several forms of dialogue are noted here. While some forms make it possible to grasp the convergence proposed by the dialogical model of the design (the tension between the real and the virtual allows a convergence of the two dimensions), others raise questions about this convergence in the context of the agroecological transition. The results highlight the complexity of these dialogues, which do not seem to systematically steer one dimension towards another. In the example of farmers X and L, which deals with "sorting the harvested crops", we find dialogues of expansion or amplification within the same dimension that evoke not a "precision" of the virtual through reality, but an exploration and thus an expansion of these dimensions. We have thus identified: a form of dialogue within the designable dimension and an amplification of the real. Thus, these different forms of dialogue highlight the complexity for farmers to design their working system. In addition, they offer perspectives for the researcher to question the movement (convergence, expansion, amplification, and perhaps even divergence) of the design process of farmers in agroecological transition.

IV. DISCUSSION AND CONCLUSIONS

IV.1. An improved understanding of farmers' transition processes

Our exploration of the design activity developed by farmers engaged in agroecological transitions highlights several aspects of this activity.

First, we highlighted the diversity and interdependence of the design problems that farmers encounter. Farmers seem to be engaged in a time-structured systemic transformation that raises the question of whether they combine routine and non-routine design problems, involving multiple dimensions and levels of abstraction as found in Gero's (2000) work. The scope of this design activity reflects the scope of the changes required if sustainable development is to be achieved (Seppänen, 2002; Zink, 2014; Thatcher & Yeow, 2016). It supports the claim that agroecology requires redesign and in particular a profound redesign of farmers' work, in all its dimensions, beyond simply improving current agricultural practices or replacing them with equivalent practices (Hill & MacRae, 1996). Following the line of these authors, our research work could also be viewed from the perspective of innovative design, i.e. without the technical or scientific knowledge available. This strengthens farmers' ability and legitimacy to set up design projects. In fact they are the most able to integrate the full diversity of design problems in all their dimensions (socio-economic, family, biological and technical, relating to the farmer's internal conditions), which in turn raises the question of how to support these actors. The fact of considering work transformations in these design projects, as ergonomics proposes, seems to us to be an integrative proposal that can give a real place to farmers as designers within the agroecological transition. Following these proposals, farmers could actually be a force for reflection and proposals on three levels: (1) virtual, i.e. what can be desired in a real agroecological transition, (2) real, i.e. they are the rapporteur of a reality of work, and (3) designable, i.e. they explore the different possibilities offered, or closed, by the agroecological transition.

Second, our analyses of the virtual-designable-real dimensions of farming provide an original perspective on the design processes in which farmers are engaged during agroecological transitions. Carried out at a micro level and focusing on farmers' activities, these analyses complement existing studies on farmers' transitions towards agroecology (e.g., Lamine, 2011; Chantre & Cardona, 2014; Coquil, Béguin & Dedieu, 2014) or research carried out at macro levels (e.g., Geels & Schot, 2007; Brédart & Stassart, 2017). They highlight the diachronic, process-oriented nature of farmers' design activity. The results show a real dynamic of this activity, over time. One perspective of this work would be to focus our attention on the types of dialogue identified between VDR: are there any closures and recurrences in the mechanisms applied by farmers to change their practices, in accordance with what is known of design processes (e.g., Stempfle & Badke-Schaub, 2002; Cross, 2007; Visser, 2009)? These iterations are part of a dynamic that is driven by the farmers' trajectory and their objectives, which are not defined once and for all, and evolve as farmers evolve in their work and are confronted with actual work situations, in a "conversation" with these situations (Schön,

1992). Giving visibility and support to these dynamics, over a longer term, is a challenge to be taken up to support farmers in their change of practices.

IV.2. Some key elements in the support of the design activity of farmers engaged in agroecological transitions

Through our different results, we highlighted the complexity of the design activity of farmers engaged in agroecological transitions. This called for a reflective method to make farmers' design activity less implicit for them.

This is consistent with all the studies that point out the importance of tracking design processes and building a memory of these processes, which is a major issue in collective design activities (e.g., Détienne, 2006). It has been discussed extensively, notably with the notion of design rationale (e.g., Moran & Carroll, 1996) as a way to improve learning and knowledge management in firms (e.g., Matta, Ribière, Corby, Lewkowicz & Zacklad, 2001). Here, we understand the need for a reflective method more as a way to support non-professional designers (Manzini, 2015) and allow them to be more efficient in an activity with which they are unfamiliar. In this sense, the Chronicle of Change provides an easy way of keeping a memory of the design process and then of maintaining awareness of that process on farms. It is easily used by the farmers and encourages them to reflect from time to time on the transformation of their activities. Through simple categories (describing objectives, difficulties, resources), it allows them to explore and articulate "real", "designable" and "virtual" dimensions of their activity.

Finally, we think that formulating their problems and discussing them with others, the farmers learn to defend their choices and build new knowledge about their situations. This would then be a strength of the CC, which could be intended for collective use (with at the very least a farmer and a facilitator). Accordingly, we posit that the use of the CC fosters collective deliberation on design problems – crucial to solving such problems (e.g., Bucciarelli, 1988; Détienne, 2006) – in which the artifact is discussed with other farmers or facilitators. This is a perspective that we would like to develop for this work.

IV.3. The Chronicle of Change: a tool supporting design activity whose appropriation by other stakeholders has yet to be developed

Throughout the workshops or follow-ups, the farmers largely expressed a need for support in their transitions towards agroecology from a work point of view. The choice we have made to meet this request is to consider the farmers as designers of their own work systems. The CC has proven to be an efficient tool to put the farmers in this role. It not only

supports a systemic exploration of farmers' design problems, but also makes different scales of complexity and of space and time visible and makes it possible to structure these scales. It therefore provides a framework and specifies the design problems to deal with. Finally, in view of the results presented in this article, we think that the Chronicle of Change method may be one resource to support farmers in their role as designers. To generalize our results beyond the two case studies mentioned in this article, this method is currently being discussed with various agricultural advisors. The idea was that it could become a tool which agricultural advisors could use with farmers engaged in agroecological transitions. To date, it has been used primarily by a network of facilitators from the CIVAM (center for initiatives to promote agriculture and the rural environment) involved in a sustainable agriculture network, as shown in the case of farmer N who uses the CC with the ergonomist and a facilitator from this network. Such an appropriation requires that the method be further specified. Aside from the artifact itself, the CC relies on a way of questioning farmers by constantly returning to their real activity, to their experiences, and to actual examples, all of which are familiar to ergonomists but sometimes less so to technical advisors. The profound transformations linked to agroecological transitions therefore concern not only the work of farmers but also that of those who support them (agricultural research, agricultural development networks, advisory services, etc.). The question of transferability to other agricultural actors thus raises the question of the collective dimension of the design, and therefore the ability of the CC to support collective debates. These collective debates can then be understood not only between farmers belonging to the same farm (farmers X and L here), but also between the farmer(s) and the intervener(s). Analyzing the role of the CC in an activity of collective design of a working system is an avenue that would be worth pursuing.

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