Agricultural Systems 183 (2020) 102856

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Design of equipment for agroecology: Coupled innovation processes led by farmer-designers

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ARTICLE INFO

Keywords:
Adaptability
Agricultural machinery
Atelier Paysan
Implement
Open-Innovation
Tracking innovations

ABSTRACT

More and more questions are currently being raised as to what the farm equipment of the future ought to be and how it should be designed to best meet contemporary challenges in farming. In Western countries, innovation in agricultural equipment is focused on a dominant model in which the agro-industry designs and patents standardised equipment for farmers. However, today's ambitions for agriculture, with agroecology in the lead, require us to devise farming systems that are adaptable to social and ecological uncertainties, and to recognise and embrace the diversity of situations in which farming is practiced. There has until now been little research on equipment design processes consistent with these principles, and this research helps to fill this gap. To address this issue, we studied the French “Atelier Paysan” R&D organisation, created to support on-farm design of suitable equipment for agroecology. Based on design theories, we analysed three aspects of Atelier Paysan's design activities: specific properties of the equipment designed under its aegis; specific features of the design processes; and roles that Atelier Paysan takes on to enable the design of this equipment. Our results show that all the equipment designed was *appropriate* for the designers' situations and requirements, and *adaptable* to other situations. It emerged from design processes in which the farmers had the support of R&D to design both their own equipment and the cropping systems for which it would be used. We call this the design of *coupled innovations*, and show that farm equipment and cropping systems are designed together during experiments. Lastly, we show that the Atelier Paysan R&D organisation supports these design processes in three ways: it enables farmers to share their experiences of on-farm design; it makes available a set of resources to stimulate farmer-driven design of new equipment; and it brings together designers scattered all over France around a shared ambition for agriculture. This work opens up avenues for research: (i) to explore an alternative to the dominant design, which would rely on *coupled innovation design processes* and allow for the emergence of *appropriate* and *adaptable* equipment that complies with agroecological principles; and (ii) to explore ways of organising open-innovation processes for agroecology, by supporting *farmer-designers*, and thus rethinking the roles of ‘users’ in these processes.

1. Introduction

Advances in agricultural equipment have always played a major role in the evolution of agriculture (e.g. Sigaut, 1989). Questions are increasingly being raised today as to what the farm equipment of the future ought to be, and how it should be designed to best meet contemporary challenges in agriculture (Pisante et al., 2012; Sims and Kienzle, 2015; Bellon Maurel and Huyghe, 2017; Kirui and von Braun, 2018). In Western countries, innovation in agricultural equipment currently focuses on a dominant design (e.g. FAO, 2013; Guillou et al., 2013; Bournigal, 2014), which very largely fits what Mazoyer and Roudart (2006) call the “*motorised mechanisation*” of agriculture that emerged in the mid-20th century. This has evolved into equipment incorporating digital technology, as attested by the frequent references in the literature to such concepts as “*smart farming*” (e.g. Wolfert et al., 2017; Relf-Eckstein et al., 2019), “*agriculture 4.0*” (e.g. Huh and Kim, 2018), “*digital agriculture*” or “*agricultural robotics*” (e.g. Ramin Shamshiri et al., 2018), and stated priorities in government support for

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https://doi.org/10.1016/j.agsy.2020.102856
Received 3 December 2019; Received in revised form 7 May 2020; Accepted 8 May 2020
Available online 22 May 2020

agricultural innovation (e.g. the *Agriculture-Innovation 2025 en France* report includes "*digital agriculture*" and "*robotic agriculture*" as priorities). The challenges for designers of this equipment are to increase "*reliability, efficiency and precision*" (Bournigal, 2014) and to optimise farmers' actions by cutting input wastage, reducing occupational hazards and making equipment more ergonomic. Some authors write about equipment that fosters farmers' "*autonomy*", by which they mean cutting working hours or reconfiguring crop management tasks, which are partly taken over by computerised systems. One emblematic example is precision farming, in which fertiliser or pesticide applications are optimally managed in the field with the aid of spatialised data provided by onboard sensors on the equipment (Lindblom et al., 2016).

Today, most farm equipment is designed by manufacturers that market patented equipment (Fourati-Jamoussi, 2018) built from new materials and intended for large-scale, often international markets. The equipment designed is standardised (Piovan, 2018) for use in the most typical farming systems of the market: farms using chemical inputs on large fields (Onwude et al., 2016). For these firms, the main drivers of innovation are "*customer demand and differentiation from competitors,* (...) *cutting production costs and complying with environmental standards and regulations*" (Bournigal, 2014). From this standpoint, "innovative" is defined by the agro-industry and helps to rejuvenate the market offering.

In most European countries, this entrepreneurial drive in the private sector is accompanied by public sector withdrawal from research (Guillou et al., 2013), and the few scientific studies on the subject mainly concern improving sensors and onboard digital tools for precision agriculture (Bournigal, 2014). Meanwhile in the agronomy literature, articles on support for the design of agricultural systems (e.g. Rapidel et al., 2009; Ronner et al., 2019) regard equipment as a contingent variable and not as objects to be designed – that is, if they mention it at all. This situation reflects the compartmentalisation of research described by Piovan (2018), with research on farm equipment separate from agronomy research.

By contrast, today's ambitions for agriculture, with agroecology in the lead, introduce new challenges such as: recognising the diversity of farmer's situations and expectations (Altieri, 2002); considering uncertainty associated with poorly known agroecological systems (Brugnach et al., 2008); or also developing system approaches and fostering the open-sharing of knowledge, ideas and know-how while redesigning farming systems (Meynard et al., 2012). These issues highlight limitations of the dominant design: how can standardised farm equipment meet the needs and expectations of farmers working in diverse agricultural situations (Nicholls and Altieri, 2018)? How can equipment designed off-farm be made to fit technical systems designed in situ, and cope with the social, ecological or economic uncertainties inherent to eco-friendly systems (Brugnach et al., 2008)? Do patents and digital tools not obstruct the ability of farmers to repair and transform their equipment (Van der Ploeg, 2008)?

Several studies have highlighted alternative processes for farm equipment design. The processes described are always more open, and suggest the need to review the roles of the parties involved. Bellon Maurel and Huyghe (2017), for example, stress the importance of involving the farmer-users at the start of the design process, to enable them to express their needs, and to make it more likely that the design will find a use. Lucas and Gasselin (2016) show that, in the networks of farmers linked to cooperatives for the use of agricultural equipment (CUMA, in France), the sharing of equipment increases the ability to adapt practices in an uncertain environment, and to engage in new and/or diverse practices on a farm by reducing individual investment costs and risks (Lucas et al., 2018). In these situations, the equipment already exists and farmers share its use.

Some articles mention other challenges: "*How can farm equipment that does not yet exist be designed for agricultural systems that do not yet exist either?*" (Bournigal, 2014), or "*Another major obstacle is to be found in the lack of interaction between farm machinery designers, on the one hand, and designers of new cultivation and breeding systems, on the other: a joint working between them is urgently needed.*" (Bellon Maurel and Huyghe, 2017), or yet "*farm equipment can be thought of as resources that do more than just respond to demand, because they foster the establishment of agroecology*" (Piovan, 2018).

Our study is in line with this research trend and aims to contribute to a theorisation of the processes of designing equipment for agroecology. More precisely, the intention is to shed light on features of equipment design processes that are consistent with agroecological principles. With this aim, we use a case study approach, and in so doing we harness theoretical inputs from design sciences and agronomy.

We first present the conceptual framework we have adopted (2), then detail the research method we used (3), present our findings (4), and close with a discussion of the main results (5).

2. Conceptual framework

What is a 'design process'? Various theories of design activities have been proposed in the literature. Many of these are rooted in the proposals of Simon, who in the 1960s introduced what he called a 'science of the artificial' (Simon, 1969). Subsequent work has enriched, discussed and even challenged some of his proposals, notably by introducing new notions and new modelling (e.g. Yoshikawa, 1981; Gero and Kannengiesser, 2008). In this article, we draw on notions and concepts associated with the Concept-Knowledge (CK) theory (Hatchuel and Weil, 2002, 2003, 2009) and the work of Schön (1983). We consider "design" as a process driven by a desire to generate something that does not yet exist. This process is manifest in the actions of one or more designers, in the gradual emergence of a new object, either material or immaterial, and in its integration into physical, social, economic and virtual environments (Papalambros, 2015; Wynn and Clarkson, 2018; Hatchuel et al., 2017).

As mentioned by Hatchuel and Weil (2009), in the course of this process, the *identity of a new object* desired by a designer is defined (Fig. 1), so that its *properties* progressively emerge: its composition, the use that can be made of it, by whom, when, in what conditions, etc. To start a design process, one must formulate a *desirable unknown* (Le Masson et al., 2017). In other words, for the designer, what exists is insufficient and he/she wants something new to emerge (which is desirable), but he/she does not yet know what (it is unknown). The design process is a highly dynamic and collective one (see Fig. 1, Hatchuel and Weil, 2009): a new object is defined over time, through iterations between specifying its properties, acquiring knowledge and negotiating between designers and with other actors. In addition, by introducing the *seeing-moving-seeing* mechanism, Schön (1983) places the situation of action and its materiality at the heart of the design process, and insists on the fact that it is in and through action that a new object emerges. This proposition is based on the observation that one cannot imagine all the dimensions of an object before having acted: only action makes it possible to discover certain dimensions and thus to manage the complexity of the object during its emergence.

Agroecology calls for the redesign of agricultural systems (Meynard et al., 2012), which R&D actors can support, for instance, by generating resources to support change, such as decision support systems, trainings, design support tools (Salembier et al., 2018). However, several authors mention that this project demands an in-depth reconsideration of the design processes. For instance, they raise the following questions: how can systemic interactions and uncertainties in local agro-ecosystems be taken into account during design (Prost et al., 2016; Darnhofer et al., 2010)? How can the ecological and social particularities of each farm be considered during these processes? Or even, what roles should the parties involved take on in order to move towards *social*, *open* and *distributed innovation* processes (Chesbrough et al., 2014; Joly, 2017; Prost et al., 2016), which seem conducive to agroecology? Our work has explored the features of equipment design processes for agroecology in relation to these questions.

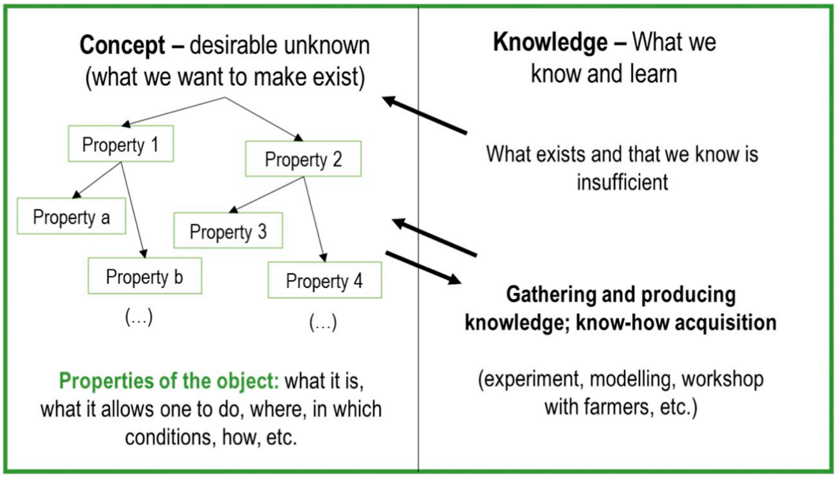

Fig. 1. Modelling of a design process related to the CK theory (adapted from Hatchuel and Weil, 2003). On the left is the space of 'concepts', i.e. a space of the desirable unknown; where the logical status of a design proposal is neither true or false. On the right is the space of 'knowledge', i.e. what we know and what we learn; and where the logical status of a design proposal can be true or false. In the concept space, new designed objects that do not yet exist emerge, by the progressive definition of their properties (which progressively gain a logical status in the knowledge space). The temporality of the design process on the figure is represented from top to bottom. The arrows in the centre illustrate the dialogue that takes place during design between the production of knowledge and the progressive definition of a new object.

3. Case description and research method

This exploratory study is based on a single case (Yin, 2003; Siggelkow, 2007). By choosing this method and adopting an inductive research strategy, our aim was to contribute to a theory on the processes of designing equipment for agroecology. Our investigation focuses on a French organisation called Atelier Paysan.

3.1. The case study: Atelier Paysan

Atelier Paysan defines itself as "*a collective of small farmers, employees and agricultural extension organisations*" gathered around the shared objective of "*increasing farmers' autonomy in developing suitable farm equipment for agroecology*" (Atelier Paysan website - https://www.latelierpaysan.org/). The idea of creating Atelier Paysan emerged in 2009 from several observations: (i) the agricultural equipment currently on the market is ill-suited to the particularities of organic farming and is costly, opaque ("black box" systems) and requires expert intervention for repairs; (ii) on farms dotted around France, there exist a number of implements invented and built by farmers themselves to suit their particular organic farming practices, and which are easy to repair, to modify; (iii) this equipment, used only on the farms where it is made, remains invisible to the farming world at large; and (iv) most farmers lack the skills to invent and build equipment that fits their situations.

Atelier Paysan was incorporated as a cooperative (*Société Coopérative d'Intérêt Collectif* - SCIC) in 2014. This status means that users, employees and partners can work together within one company. It allows them to formalise the shared values of their collective ambition for agriculture, such as farmer-driven design, pesticide-free agriculture or agroecological practices. Atelier Paysan is 70% self-financed (from training, margin on equipment sales, private funding, etc.) and 30% funded by government subsidy. In 2020, the Atelier Paysan counts 22 permanent workers and involves occasional volunteers and trainees.

Atelier Paysan organises its work around two overarching themes (Table 1): (i) participative R&D, which includes activities such as innovation tracking, producing 3D technical drawings of equipment and providing support for groups designing their own equipment, and (ii) disseminating farmers' skills and knowledge, which includes organising hands-on training in Do It Yourself (DIY) farm equipment building or running an Internet forum.

Since its creation, the cooperative has increased its audience. Today, more than 1000 implements designed by farmers across France have been recorded, and 670 are registered on the Atelier Paysan map (https://www.latelierpaysan.org/Cartes-des-autoconstructeurs). And, between October 2016 and March 2020, about 260 training courses have been organised across France (e.g. initiation into metal work, training in building one's own implements, learning how to read technical drawings (https://www.latelierpaysan.org/Formations)).

All the farmers engaged in the Atelier Paysan cooperative share the underlying goal, that is, meeting the challenge of contributing to the free circulation of knowledge and know-how to support the emergence of an agroecological agriculture. By participating, the farmers benefit from feedback from other farmers, from their integration into a network of peers sharing the same values, and from the support offered by the Atelier Paysan cooperative. In the rest of the article, we used the term 'farmers' to refer to the farmers involved in the collective dynamic of Atelier Paysan, and the term 'R&D actors' to refer to Atelier Paysan workers and advisors also involved in this dynamic.

3.2. Collecting and analysing data

We used an iterative process to collect and analyse data, and we stopped the collection when we obtained the same results several times and/or when the Atelier Paysan staff confirmed that the results produced seemed to satisfactorily cover the field we wanted to investigate. The material analysed came from various sources: (i) between May

Table 1
The two overarching activities described on the Atelier Paysan website and their associated sub-activities (table drawn up from Atelier Paysan website on 12/01/2019).

Participative research and development	Disseminating farmers' skills and knowledge
Tracking farmers' innovations	Organising hands-on training for building DIY farm equipment
Supporting groups designing appropriate equipment	Bulk ordering of materials and accessories
Drawing up specifications for farm equipment	Disseminating manuals for DIY farm equipment building
Modelling, producing 3D technical drawings	Running a website and Internet forum
Prototyping equipment	
Running experiments	
Publishing open-source equipment building tutorials	
Running a network of DIY farm equipment builders	

2017 and December 2018, we conducted ten interviews with two Atelier Paysan workers and one former worker; (ii) we attended public events where Atelier Paysan staff presented the organisation and its work; (iii) we analysed several dozen written documents, mostly internal documents, such as meeting minutes, project reports or conference papers, (iv) we presented the written results of our work to two of our interviewees, and their critical eye enabled us to enrich, amend and add to the analysis. Our method of data gathering and analysis, in three steps related to our three angles of analysis, was as follows.

1) We looked at the properties of the implements that Atelier Paysan had identified or contributed to designing. We characterised them in terms of what they enabled the farmer to do, how they were made, in what situations, for what uses, with which material.

Given the very varied nature of the information available on each implement, we concentrated on those of which technical drawings had been made (detailed on Atelier Paysan's website) and which had been chosen for dissemination beyond their original designers. This provided us with a homogenous body of documentation, and, including technical drawings that we could refer to in our discussions with the Atelier Paysan workers. The data we analysed were: (i) texts and/or videos accompanying each drawing; (ii) texts describing the particularities of the implements; and (iii) information gleaned from our interviews with the Atelier Paysan workers. A total of 30 implements were analysed using a coding method (Dumez, 2013) whereby the main properties of each implement were categorised based on the following types of question: why was it designed? How was it built? Who used it? In what context? A cross-analysis of the implement properties allowed us to group them into five sub-categories.

2) We then examined the particularities of the process of equipment design assisted by Atelier Paysan, in order to understand how the equipment' specific properties emerged. Using the “Concept-Knowledge” modelling method (Hatchuel and Weil, 2009), we reconstructed the process by which one particular implement was designed. This was the Buzuk crimper roller (*Rolo Faca Buzuk*) used for growing vegetables through a cover crop mulch on permanent beds. In our retrospective analysis, we sought to track the emergence of the implement's properties and what had fostered and contributed to that throughout the process (e.g. a surprising state of the soil led farmers to rethink crop management and the shape of the implement). We paid particular attention to “who” contributed to the design of the implement. We submitted the intermediate results of our analysis separately to two Atelier Paysan workers.

We analysed the case of the Buzuk crimper roller - the Buzuk project was initiated by Atelier Paysan and funded by the Brittany *département* council from 2014 to 2017 - because of the amount of written material available from various points in the process, such as meeting reports, partial accounts in articles, and the project's internal memos. We were also able to interview two Atelier Paysan workers who had been involved. We asked them questions as to how the process had emerged and where; who had taken part, how and why; how the implement had emerged and how its properties were gradually defined; what resources were harnessed and in what circumstances; and what contributions Atelier Paysan had made.

3) Our third step was to clarify the roles Atelier Paysan takes on to enable such design processes. These may manifest through objects that are designed and disseminated (e.g. Cerf and Meynard, 2006; Klerkx et al., 2012), and methods that Atelier Paysan workers use to foster the process (e.g. Salembier et al., 2018; Agogue et al., 2013). To that end, we used interviews and documentation analysis to: (i) categorise the objects that the Atelier Paysan workers generated and made available to farmers to design their own implements: What were these objects? How did they aim to support farmers in their activity? (e.g. hands-on training in building DIY farm equipment); (ii) identify the methods, such as tracking on-farm innovation, that the Atelier Paysan workers used to generate knowledge and foster design processes.

4. Results

4.1. The specific properties of agricultural equipment at Atelier Paysan

Our study of the range of farm implements at Atelier Paysan showed that they all shared two properties: they were all designed to be appropriate for particular situations (Section 4.1.1.) and they were also all adaptable to situations other than the ones that gave rise to them (4.1.2.)

4.1.1. Appropriate equipment for farmers' particular situations

In contrast with the standardisation of equipment on the market, the Atelier Paysan implements were invented to enable their designers to act effectively in their particular working conditions.

a) Most implements were designed for particular cropping systems, many of which are atypical.
    i. Some of these systems involved reconfiguring layout of crops within a field, which meant changing the way the work was carried out (Table 2). One example of an atypical cropping system is agroforestry, with annual species grown in association with perennial tree crops: the Sandwich tiller was designed for easy tillage near trees (Fig. 2d). Another example is permanent raised bed systems; implements designed for such systems were the Cultiridger (*Culibutte*) and a plastic mulch layer (to cover the soil prior to planting, thus maintaining soil moisture and preventing weed growth).
    ii. Other systems reduced the use of motorised machinery, e.g. by using animal traction. Two implements for animal-powered tillage can be cited: the Neo-Bucher (Fig. 2b) and the Bineuse Néo-Planet.
    iii. There were crop systems involving crops that are rare or unusual in France and for which special implements had been designed (Table 2), such as a hoe for aromatic, medicinal and perfume crops, and a tobacco hoe.
b) Some implements were designed for working in unusual biophysical conditions. The Dahu, for instance, was designed for hoeing vines on slopes, whereas many vineyards in France are on flat or only slightly sloping ground. Other implements were designed to adapt as they went along in response to non-uniform conditions. The Roloflex (Fig. 2a) and Rolo Faca Béton, cover crop rollers for market gardening and vineyard systems, can adapt to the irregularities of uneven ground.
c) Some implements were designed to help farmers cope with the dynamics of cultivated ecosystems, which can be unpredictable, especially in pesticide-free farming (e.g. unexpected evolution of the pest pressure due to weather variations). Atelier Paysan's *Serres Mobiles* (Fig. 2c) were greenhouses that can be moved to avoid cultivating the same piece of ground under a fixed tunnel. By moving the greenhouse, one can advance or extend the cultivation period to extend the crop rotations.

4.1.2. Adaptable equipment

All the implements are adaptable, that is, they can easily be modified for use in situations other than the ones in which they emerged, whether on other farms or new situations on the original farm.

a) Some of the implements designed are “generic bricks” of more complex implements (Table 2); they are parts that can be appended to another implement, to add a particular function. Examples are: Atelier Paysan's quick hitch triangle (the *Triangle d'attelage*, Fig. 3a); a jockey wheel with handle (*Roue de jauge à manivelle*), which serves

Table 2
Specific properties of the implements designed at the Atelier Paysan cooperative, and frequency of occurrence of these properties among the 30 implements studied. In the 4th column, quotations illustrate these properties - excerpts from the Atelier Paysan forum (*), the Atelier Paysan website (**) and from interviews with Atelier Paysan workers (***).

Generic properties	Detailed properties	Number of implements	Quotations
Equipment appropriate for farmers' particular situations	Designed for particular cropping systems	16/30	"This weeder is designed to work as close as possible to the perfume, medicinal and aromatic plants without damaging them."** "[*Cultibutte*] It allows the work on the mounds and in permanent beds (…). It is designed to shape or maintain the mounds."** "[*Drill roller*] The drill roller is an implement for drilling through plastic mulch for sowing or transplanting. This implement is very modular. It is possible to choose the number of rows and the spacing between plants."**
	Designed for working in unusual biophysical conditions	5/30	"[*Dahu*] The two pairs of discs can be oriented independently to direct the soil where necessary according to the slope and to avoid the risks of erosion. The '*boudibinage*' stars (which allow weeding as close as possible to the plants), are mounted on three adjustable axles that allow to adapt to the topography of the terrain. The aft gauge wheel is fitted with a large disc serving as a 'rudder' to keep the *Dahu* in the middle of the row, despite the slopes and the thrust of the discs."** "[*Vibroplanche à étoiles*] is an implement for soil refinement on permanent raised beds: it prepares the soil for rolling in case of the presence of crop residues on the raised bed."** "This *Faca roller* is adapted to the slightly sloping soils of mechanizable vineyards."***
	Designed to cope with the dynamics of agro- ecosystems	12/30	"*Mobile greenhouses* have two main agronomic advantages: cultivation anticipation/ extension and soil regeneration. Its insertion in a cultivation plan makes it possible not to overexploit a single plot under a fixed tunnel."** "The articulation of the *Quick hitch triangle* makes it possible to optimise work (…) when the micro topography is not homogeneous (bumps and hollows)."**
Adaptable equipment	Generic bricks of more complex implements	8/30	"[*Jockey wheel with handle*] This module is transposable to most agricultural implements and allows adjusting the implement's working depth. Very useful on implements whose height adjustment often needs to be changed."** "[*Tractor tool bar*] Vegetable lifter, plastic lifter, weed harrow, hoeing and ridging elements (…) this versatile and easy to use support allows you to equip yourself with many indispensable implements at a lower cost."** "[*Aggrozouk*] is a lightweight pedal-operated tool carrier with electric power assistance, which allows light agricultural implements to be hitched in the prone position."**
	Implement made using scrap materials	30/30	"[*Market gardening hoe*] The construction of this implement is very simple, two wheelbarrow arms recovered from the rubbish dump, 4 small welds to attach them together (…) holes to install a bicycle wheel (also from the rubbish dump), and other holes to put the screws that hold the handle of the implement."* "[*Puncher roller*] The frame can be made using scrap metal, such as old polytunnel poles."**

to precisely adjust tillage depth; a tractor tool bar (Fig. 3c); and finger hoes (*Etoiles de binage*) that can be attached to another implement as accessories for hoeing in particular places.

b) All the implements were designed by farmers and made using simple procedures, often from scrap materials, which cut costs and contributed to recycling (Table 2). They are easy to reproduce and dismantle and a farmer can easily be trained to acquire the basic technical knowledge and skills to build, maintain and repair them. These properties make them easy to adapt to new situations (e.g. other farm, when facing hazards) and facilitate learning (farmers can tinker with them themselves, at low cost). For example, the Rolo Faca Béton, designed for controlling vegetation between vine rows, is simple and easy to make and reproduce: "*Each small roller is weighted with concrete, the formwork being included as an integral part of the implement. This increases the weight of each roller by a third*" (excerpt from Atelier Paysan's website). The market gardening hoe (*Houe maraîchère*, Fig. 3b) was made entirely from recycled materials.

4.2. Features of design processes: coupled innovations, multiple designers and in-situ iterative design

To describe specific features of the Atelier Paysan design process, we analysed the case of the Buzuk crimper roller (Fig. 1). We have broken down the design process into two stages.

4.2.1. Stage 1: Elicit a design project for coupling a cropping system with an implement

4.2.1.1. Define a common goal for a change in farming practices. The project brought together partners with complementary expertise: 7 farmers and 2 agricultural advisors, who had knowledge of local agricultural conditions and could explain design expectations at the level of each farm and the region, and Atelier Paysan workers, who had expertise in agricultural equipment engineering (e.g. computer modelling, equipment construction). Trades and competencies guided the allocation of some tasks during the process, for instance, technical drawings were made by the Atelier Paysan workers, and the farmers did the more manual fieldwork. But all decisions and assessments were discussed collectively. From the start of the project, the partners were in agreement on the following objectives: (i) vegetable growing; (ii) exploring ways to maintain soil fertility; and (iii) reducing the time spent on crop husbandry tasks and the need for inputs (fuel, plastic mulch). To stimulate their explorations, the partners organised an information watch. Very soon, in connection with various initiatives the partners knew about (e.g. a raised bed project Atelier Paysan was involved in; experiments by the *Maraichage sur Sols Vivants* association), the collective was drawn to the concepts of "*vegetable growing on living soil*", "*conservation farming*" and "*seeding through a cover crop mulch*". In light of their various skills, preferences and aims, the partners gradually narrowed their exploration to a combination of a cropping system and implements that would enable farmers to: (i) sow a cover crop requiring

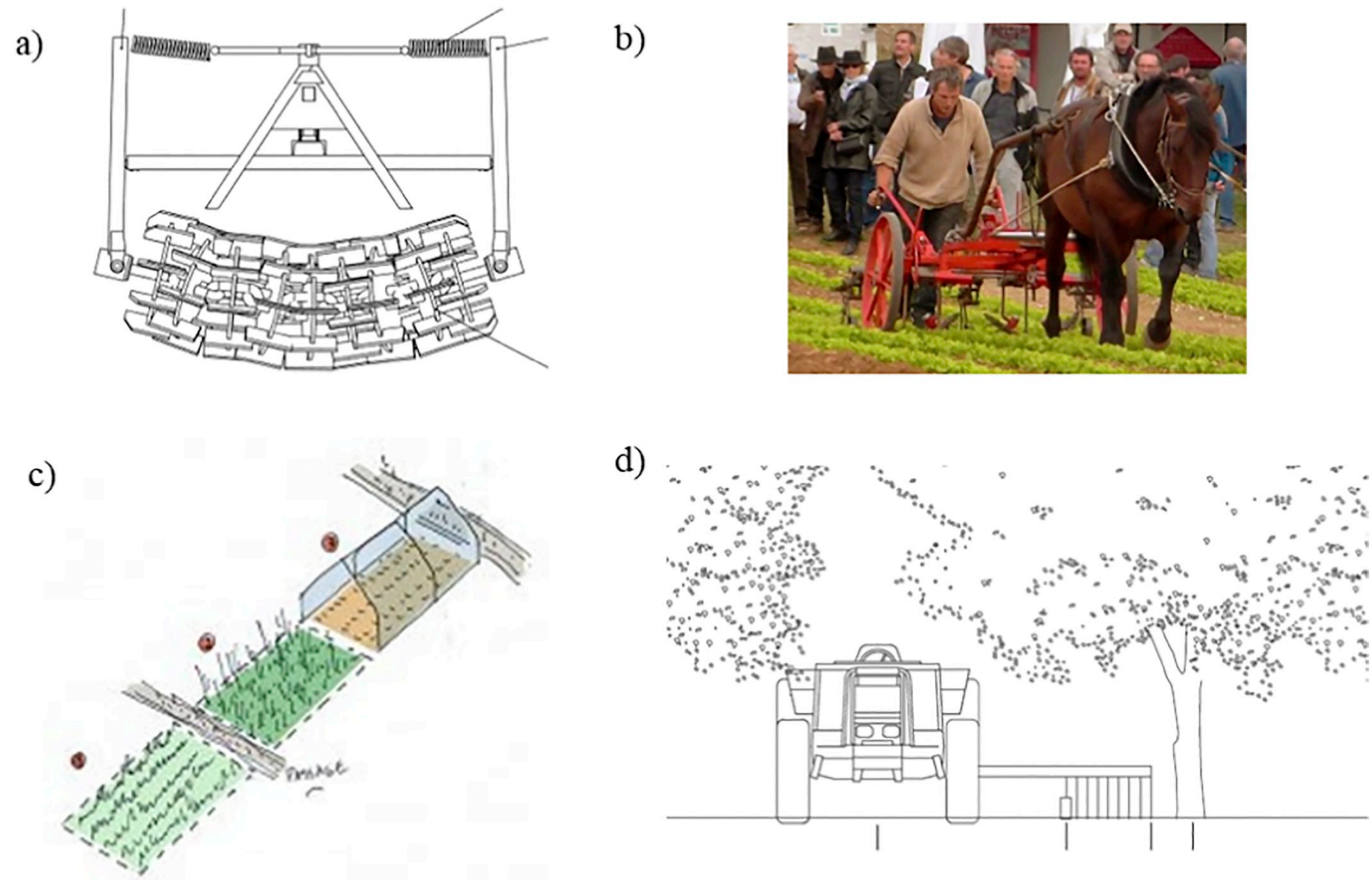

Fig. 2. Pictures and drawings presenting implements appropriate to particular situations: a) a Rolofex; b) a Neo bucher; c) a movable greenhouse; and d) a Sandwich tillage implement (from https://www.latelierpaysan.org/).

little tillage; (ii) sow the next crop directly through a mulch formed by the killed cover crop; and, for some of the farmers, (iii) use permanent raised beds.

4.2.1.2. Make a preliminary definition of a desirable cropping system. The collective had few references for the three techniques (introducing a cover crop, direct sowing, permanent raised beds) and how to combine them for vegetable cropping in their local region (Finistère, Brittany). The partners were familiar with the agronomic processes concerned - e.g. direct sowing fosters the biological life of the soil - but they asked themselves, for each farm's situation, "*What varieties that grow well in Finistère can be used in the cover crop mix? What Plan B could we use if the cover crop fails to grow? How can we manage a cover crop on permanent raised beds, depending on the season? What implements should we use for direct sowing of the main crop? How does the choice of cover crop affect the direct sowing and growth of the main crop? What are the risks?"*, and so on. The collective explorations and the acquisition of new knowledge resulted in the formulation of some general choices for crop management and for including a cover crop in the rotation, on which all the farmers were in agreement (e.g. varieties sown, dates, technical operations).

4.2.1.3. Make a preliminary definition of a desirable implement. Whenever they discussed a crop management task, the partners asked themselves what implements already existed for the job. Very soon they realised there was no implement for flattening a cover crop on raised beds so that

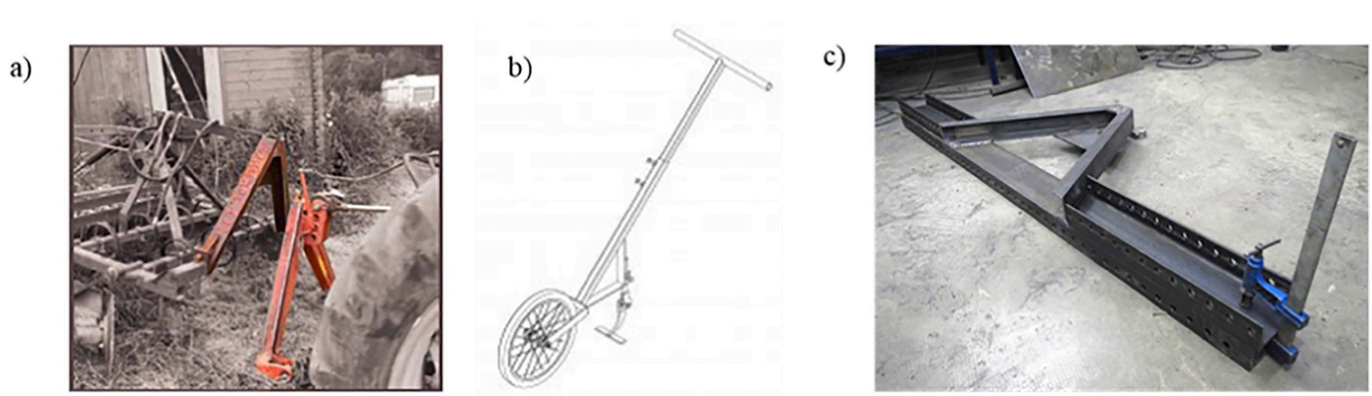

Fig. 3. Pictures and drawings presenting adaptable implements: a) a quick hitch triangle; b) a market gardening hoe; and c) a tractor tool bar (from https://www.latelierpaysan.org/).

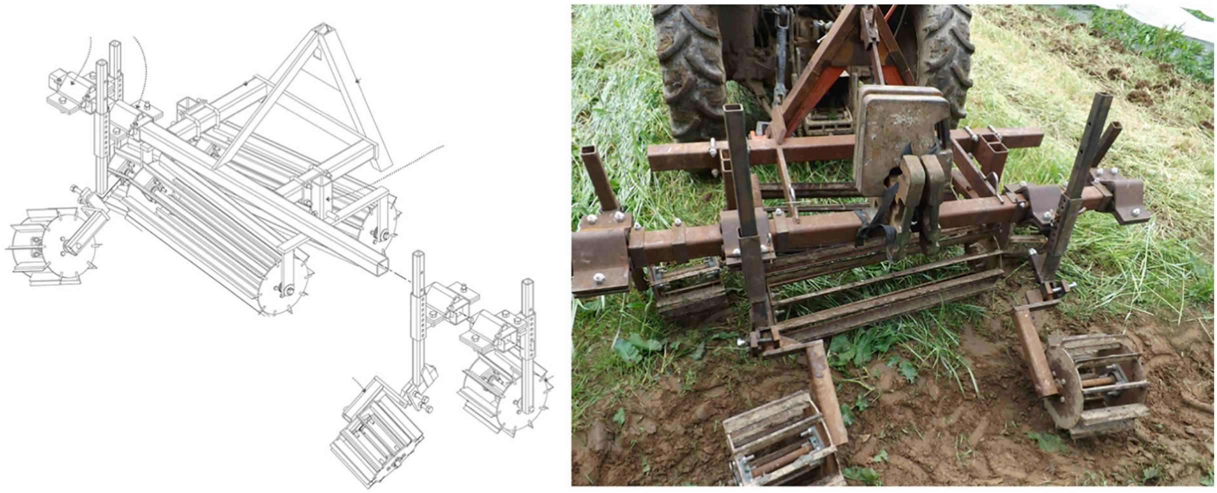

Fig. 4. Illustrations of the Buzuk crimper roller Version 2: (a) from the technical drawing produced using the SolidWorks computer-aided design software; (b) photo of the completed implement (from Atelier Paysan's website). The Buzuk crimper roller consists of six rollers with chopping blades. Its purpose is to flatten a cover crop and break the stems, on a raised bed (top and sides of bed, and alongside). The roller is effective if, after rolling, the cover crop is flattened and the next crop can be sown directly.

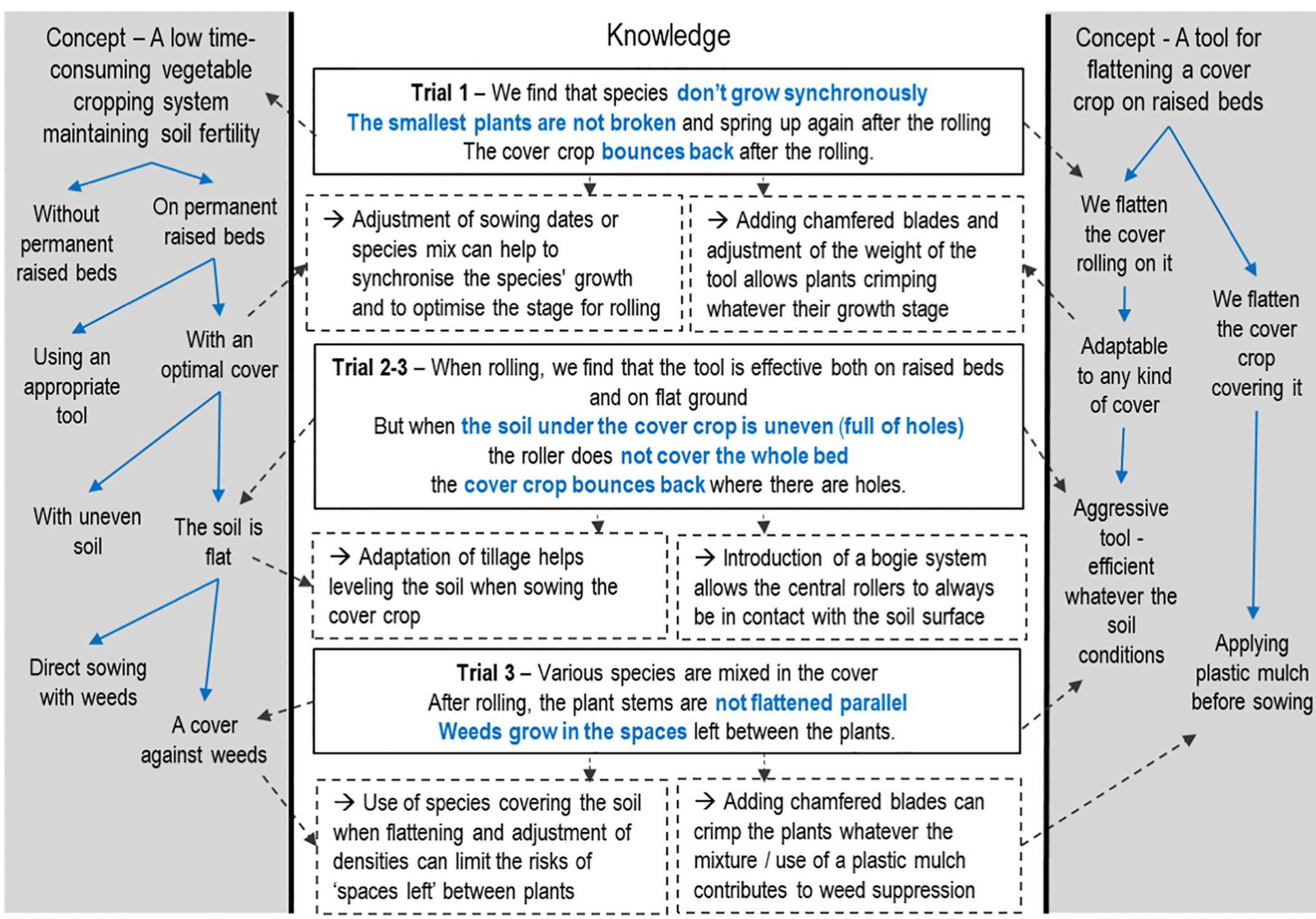

Fig. 5. CK model illustrating joint emergence of an implement and a cropping system, designed by the collective involved in the Buzuk project, and detailing different situations during trials in farmers' fields. Left and right of the figure (grey rectangles) are the concepts spaces where we observe the gradual definition (blue arrows) of the "implement" concept (right) and "cropping system" concept (left), in connection with the information acquired on the agroecosystem during trials. In the central space, the knowledge produced in the trials, and which stimulated the design of the two objects, is described. In this space, the rectangles refer to the indicators collected during the experiment and that foster the exploration of knowledge on new design proposals (dotted rectangles). The temporality of the design process goes from top to bottom in the figure. Blue bold type in the central space refers to the indicators. The dotted arrows show the interactions between knowledge and concepts throughout the process. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the main crop can be sown directly. They noted the specifications of the crimper roller, which already existed for open field systems with grain or oil crops. This implement consists of a central roller to which are welded horizontal blades; it flattens and crimps the vegetation, so that it will wither and die on the ground. The collective's challenge was to make sure the cover crop was sufficiently damaged to remain lying on the raised bed, covering the soil and preventing weed growth in the main crop. Several options were considered when it came to imagining the new implement, which they called the Buzuk crimper roller. The Atelier Paysan workers transformed the ideas collectively explored into technical drawings (Fig. 4). These drawings were amended each time a modification of the implement was proposed. Prototypes of the implement were made at collective working sessions, with assistance from Atelier Paysan. There was a new working session every time the implement had to be modified. The farmers were thus able to familiarise themselves with implement building operations and could acquire skills to be autonomous in their repair and re-design. "*The major difficulty with the Faca roller is encountered on the sides of the permanent raised beds. (...) Fixed rollers pass on the top of the permanent bed. Of the 2 options considered, the one with the small roller in the centre is preferred, for its better balance. (...) When discussing this with Joseph this morning, we thought that it might be better to be able to adjust the height of the rollers on the sides (...) and he told me about the systems, sometimes used with Cress fingers, using rubber (...) Let's see after tests if there are risks of jamming in the axes of the rollers*" (from a Buzuk project report). But once the implement had been made, there were still many unknowns as to how it would behave in different situations, and in interaction with the imagined cropping system (crop species, sowing dates, farmers' expectations etc.).

4.2.2. Stage 2 - continue the design of the "cropping system – implement" combination during trials on different farms

The next step – involving all the partners – was to continue collective design of the implement and the cropping system during trials in farmers' fields, observing, interpreting and assessing interactions between the prototype of the implement, field conditions and the cropping systems.

These trials were run in a variety of field conditions, such as clayey or loam soils, different previous crops, different crops after the cover crop. Their implementation was always monitored by several partners who gradually acquired some indicators which helped (a) to trigger technical operations and follow their implementation (e.g. in what soil conditions is it best to use the implement?) and (b) to assess the results the farmers were seeking after rolling, that would cause them to deem the operation successful. Fig. 5 shows that these indicators enabled the design process of coupled innovation of implements and cropping systems to advance.

1. Acquiring indicators to trigger technical operations and follow their implementation

Whatever the species in the mix - such as rye/vetch, crimson clover, sorghum, radish, forage pea - the implement prototype successfully flattened the vegetation several times. One major difficulty was to achieve a mix in which all the species grew synchronously; otherwise, rolling would be less effective because the stems of the smallest plants would not be damaged and they would spring up again. This observation led farmers to look for 'optimal covers for rolling' and caused some of them to stop using vetch in their mix, as its behaviour was too unpredictable.

Field trials and observations also confirmed that the implement could be used effectively on raised beds as well as flat ground - in both cases the cover crop did not come up - so validating the design elements introduced for that purpose.

A levelled soil quickly proved to be a determining factor for the implement's effectiveness. In several field trials it was found that the soil under the cover crops was "*irregular, not flat*" or "*had ruts*", or "*the central roller was not working the whole bed*", "*the cover crop stood up again, or there were holes*" (from a Buzuk project report). In view of these problems, the collective considered possible action to take before applying the roller, such as tillage to level the soil when sowing the cover crop, or altering the implement's design to adapt it to such situations, for example "*Installation of a bogie system for fixing the central rollers: articulated joints allow the two central rollers to always be in contact with the soil surface, whatever the angle of the implement's chassis*" (from a Buzuk project report).

The group's representation of what the ideal state of the cover crop would be for applying the roller was refined over the course of the trials. The height, composition, density, growth stage and so on of each variety all played a part. To maximise chances of choosing the right cover crop, the collective thought about adjusting the sowing date and the rolling date: "*Season by season we delayed rolling the rye a little more; we realised clearly that June was the most effective time*" (from a Buzuk project report). They also considered making the implement more "aggressive"; in the end they added chamfered blades that crimped the plants more efficiently, whatever their growth stage.

2. Acquiring indicators to assess the results after rolling

The trials showed that after the cover crop had been flattened and crimped, there were areas of bare soil, not covered by the flattened crop, where weeds could grow. This led the group to reconsider the sowing density and to choose combinations of species that covered the ground better once flattened. They found that some species that produce a lot of aerial biomass did not cover the ground well once flattened (e.g. sunflower). Unforeseen events like the lodging of some varieties also favoured weed growth: after the roller had passed, the plant stems were not lying parallel but were leaving spaces where weeds could grow. These observations led the collective to consider, in some situations, applying more classic methods after passing the roller, such as laying plastic mulch before sowing the vegetable crop to limit competition, or making better use of complementarity between species in the cover crop mix.

This section on results highlights three features of the design processes that helped to make the implements appropriate and adaptable: (i) over the course of the process, the implement was designed simultaneously with, and in keeping with, the cropping system (design of a 'implement-cropping system' combination), and the process took place over time, by testing prototypes in a range of agricultural situations; (ii) new resources for change were also generated (e.g. technical drawings of the implement); and (iii) during the process, the farmers and the R&D actors involved, including Atelier Paysan staff, acted together as designers with complementary skills.

4.3. Roles taken on by the R&D structure in the design process

We identified three roles that Atelier Paysan took on to support farm equipment design processes.

4.3.1. Role 1 – Organising the sharing of on-farm equipment design experiences

Atelier Paysan has organised itself to centralise and enrich a common pool of knowledge and know-how about farmer-built equipment for agroecology (Table 1). This was done under a Creative Commons license (CC-By-NC-SA 3.0), on the Web platform particularly. To feed into this common pool, Atelier Paysan combined three ways of sharing on-farm equipment design experiences:

1. Atelier Paysan offered the possibility for farmers to contribute and enrich the common knowledge pool by sharing the fruit of their own implement design processes. Farmers who had designed an implement shared what they have learnt either on the Web platform's free-access forum (Fig. 6) or by contacting Atelier Paysan.

Fig. 6. Picture of an implement designed on farm and shared on the forum with a farmer's testimony: "*This is my plastic mulch layer on a mini-cultivator base ... it lays 1m wide plastic film with drip irrigation under the mulch [...] I spent about two days on it, but thinking it out took much longer than that! I decided to build this plastic mulch layer because I couldn't find a second-hand one. As to price, it's all salvaged scrap [...] gas bottles, a piece of an electricity pole, weight lifting bars found on a waste tip, [...] all I had to pay for was welding rods, two wheelbarrow wheels and the paint.*"

2. Another method used by Atelier Paysan was to track and inventory implements designed by farmers. This sometimes involved systematic tracking, that is, searches organised in a particular area to map farmers who had designed equipment falling within the scope of investigation: "*Farmer-built equipment intended for use in agriculture, useful for small-scale (...) agroecology (…) built with an easily-accessible level of technical know-how, and not patented*" (Atelier Paysan, 2017). Sometimes the searches focused on one theme, looking for a particular equipment concept. For example, a hunt for a tube seeder for market gardens was launched, to explore the types of seeder being used on market gardens (e.g. PVC structure, adjustable handle), their uses (e.g. sowing, applying fertiliser) and the situations in which farmer-designed tube seeders were being used. These searches produced a roundup of the state of the art regarding particular equipment concepts, revealing a variety of designs from which farmers could choose according to their characteristics.
3. In supporting equipment design processes, Atelier Paysan also investigated new equipment suitable for local situations and built on the knowledge fed into the common pool.

4.3.2. Role 2 – Making available a pool of resources to stimulate on-farm equipment design

Since its creation, Atelier Paysan has gradually built up a large body of equipment design resources to support the technological autonomy of farmers with different skills and projects, "*The gaps and flaws in the system are identified as we go along, the holes that need to be plugged...*" (From an interview 29/05/2017).

4.3.2.1. Stimulating design by making available written material and videos. One kind of resource is written materials and videos. The most emblematic of these are:

Testimonies. For each implement inventoried, a written testimony was posted, open-access, on Atelier Paysan's website. These testimonies might be written by the farmer or by an R&D actor: the idea was to share the knowledge of a new implement in the context in which it was designed, to serve as a source of inspiration and to prompt discussion on the Atelier Paysan forum (Table 1). Every designer of an implement inventoried by Atelier Paysan featured on a map of France's "farmer-designers", enabling anyone who wanted to know more about an implement to contact its designer.

Implement technical drawings were another type of resource that Atelier Paysan created and shared, based on what they had learnt from farmers' equipment-building activities. Atelier Paysan produced technical drawings: (i) if a group of farmers expressed interest in an implement that existed on a farm; or (ii) if Atelier Paysan was supporting an equipment design process (e.g. for the Buzuk crimper roller). Making the decontextualised equipment technical drawings from what was known about an implement on a farm required additional information, such as technical analysis of the implement's engineering design or a state of the art on implements with similar properties. Several criteria had to be met: (i) the technical drawings had to be usable by individual farmers and in training sessions for building DIY farm equipment; (ii) the implements had to be reproducible using materials available on the market; (iii) from an agronomic point of view, the implement as shown in the technical drawings had to be at least as effective as the original implement; (iv) the cost of building it had to be affordable; and (v) it had to be reproducible with basic and easily obtainable metalworking tools (e.g. drill, grinder, arc welding unit). The drawings gave 3D views of the implements, produced using CAD software. Many of the drawings were accompanied by videos presenting the implement and showing it in operation.

Testimonies and technical drawings were intended to enrich the pool of knowledge available on designing a new implement. To help users find their way around the pool of information on the Web platform, Atelier Paysan structured the knowledge in several ways, classifying each implement as follows: (i) by the cropping technique it could be used for, as for instance, a listing for cover crops, for biodynamic agriculture; (ii) by the degree of general applicability of the knowledge offered: testimonies on the forum versus de-contextualised drawings on a tab on the website; or, sometimes, (iii) by the implement prototype's degree of testing, for example technical drawings of several versions of the implement - some marked "R&D in progress" - and a progression in the testimonies.

4.3.2.2. Stimulating design by doing. Atelier Paysan offers help to farmers for experimenting with equipment design, enabling them to learn by doing it themselves. We found (Table 3) that this help took the form of: (i) a wide range of training sessions: training in designing and building equipment, or in reading technical drawings, etc.; and (ii) monitoring farmers' experiments on their own farms during the design of an implement or its adaptation to their particular situation.

4.3.3. Role 3 – Linking up equipment farmer-designers scattered across the country

Atelier Paysan structures its work around the vision of a new form of agriculture, replacing dominant design representations with "*small-scale organic farming*", "*farmer-built equipment*" and "*open-access equipment and knowledge*" (statutes of the Atelier Paysan cooperative). By expressing and sharing this ambition, they aim to bring together the scattered community of farmer-designers across the country. Their ambition for change is open: it does not focus a priori on types of equipment, cropping systems or farm situations. We noted that the definition of this goal is dynamic, progressively refined over time, mainly in connection with: (i) exploration of new equipment (e.g. the exploration, historically centred around market gardening implements, now covers implements for arable crops, vineyards and orchards); (ii)

Table 3
Roles taken on by the Atelier Paysan workers to support farm equipment design processes. The quotations are drawn from interviews (*), Atelier Paysan working documents (**) and internet website (***).

Roles	Actions performed to fulfil these roles	Quotations
Organising the sharing of on-farm equipment design experiences	To offer the possibility for farmers to contribute and enrich the common knowledge pool by sharing the fruit of their own implement design processes	"We identify and document inventions and adaptations of equipment created by farmers who have not waited for ready-made solutions from experts or industry, but have invented or tweaked their own machinery. We seek to promote these farmer-driven innovations."*** "The forum is the collective draft of the structure, there to inspire and be inspired without being definitive. We put everything we find in it, we describe as much as possible to put things in context and describe the design process if we want to take things back."*
	To track and inventory equipment designed by farmers	"Farmer-led initiatives are gathered by our team and compiled into technical factsheets with photos, videos and testimonies documenting the equipment developed by farmers. More than 500 technical factsheets have already been compiled."*** "It is a census of everything that can exist on farms, in terms of DIY equipment, it is thematic or geographical. When I arrived there was a tour in Alsace, in Brittany and Pays de la Loire, we called everybody, all the organisations we work with and we told them we were there, looking for farmers."*
	To support equipment design processes on farm	"We are also equipped to support and assist working groups that wish to develop equipment adapted to their agricultural practices. Together, we compile a specification sheet for the equipment we want to create. Our staff produce a draft design which is then corrected by the working group. After a number of rounds of feedback and responses, we begin prototyping. Depending on the equipment, prototyping can involve a training course where the group can learn or build on their metal working skills. The prototype is then tested on farms and continues to evolve. Once the group has reached a consensus on a design, Atelier Paysan can produce open source technical drawing and begin to disseminate the equipment through workshops and training courses."***
Making available a pool of resources to stimulate on-farm equipment design	To stimulate design by making available written material and videos	"Information tailored to the needs of small-scale farmers: forum posts, articles, designs, tutorials and our DIY guide. The technologies and practices we have developed through farmer-led research and development are freely accessible through articles, designs and tutorials, on our website. We would like to create an open source encyclopaedia, where people can freely contribute and make use of available resources. We believe that farming skills are common goods, which should be freely disseminated and adapted."*** "There are the plans and tutorials which are the heart of this knowledge dissemination, with for each one a small article, and then links to the various articles of the forum and the necessary bibliography. And then, there is the index of the resources, the thematic index which makes it possible to search on the site and on the forum"*
	To stimulate design by doing	"We provide training courses for farmers to learn to make their own implements. In the course of 3 to 5 days, agricultural implements are created in the workshop which are either non-existent on the marketplace, too costly or not adapted to small-scale organic farming. As well as building an implement, farmers gain in autonomy as they learn metal work. A farmer who has built rather than bought his/her implements is better placed to repair or adapt it in future." *** "During experiments, the farmers use the implement and make them evolve, supported by the technical team."*
Linking up equipment designers scattered around the country	To structure its work around a shared vision/project for a new form of agriculture	"The collective knowledge developed within the Atelier Paysan cooperative is a common good for agriculture, freely circulating and modifiable. No patents! We publish it under a free Creative Commons license. (…) Open source is also supposed to accelerate contributions. As everything is open, there is no barrier to get involved in the evolution of equipment."**
	To animate and make known a network of geographically scattered designers	"The idea is to make the dynamics apparent by explaining what we do. There are still people who have a partial vision of what we do, there is a whole job of explaining our activities (…) generally I criss-cross the territory, I make calls, I send emails, I go there, we exchange with the facilitators, administrators (…) there are quite a few new territories that have been added, the east, the south-west, a bit of PACA, people with whom we didn't work much and who are now entering the dynamic."*

more partnerships, for instance, the partnership with the non-profit organisation Demeter enabled Atelier Paysan to explore such concepts as "equipment for biodynamic agriculture"; and (iii) the increasing number of skills among the collectives involved (e.g. from low-tech equipment to the use of software in equipment design).

The evolution of this shared project is based on Atelier Paysan's nationwide facilitation work. Its innovation tracking, national events, map of farmer-designers and participation in seminars have made the cooperative well known, stimulated communication within the community, drawn attention to the cooperative's projects and initiated discussion about them in various collectives.

5. Discussion

We have organised this discussion around two themes. In Section 5.1. we discuss features of processes for designing appropriate and adaptable equipment for agroecology; then in Section 5.2. we discuss the implications of considering farmers as designers in design processes involving R&D.

5.1. Designing appropriate and adaptable equipment for agroecology: coupled innovation processes

Our findings suggest some avenues for research to stimulate the design of agricultural equipment that contrasts with the dominant design. Appropriateness and adaptability are often mentioned in connection with the challenges of shifting to new agricultural systems (Voß et al., 2007; Dedieu et al., 2008; Darnhofer et al., 2010; Brédart and Stassart, 2017) but rarely, as far as we know, regarding equipment design. The only references we found are works dealing with 'appropriate technologies' (e.g. Jolly et al., 2016). The notion of autonomy at the Atelier Paysan contrasts with the "autonomy" sought in the dominant design, where the main idea is to reduce the brainwork required of farmers, as some mental tasks are performed by the machinery instead (e.g. Relf-Eckstein et al., 2019). Whereas in the dominant design, farmers choose from a range of equipment and settings offered to them, in the case of Atelier Paysan, they participate directly in the design of the equipment and not only in its adjustment. They thus contribute to defining the equipment's properties, according to their own situations and expectations. The properties of the equipment are not known at the beginning of the design but are gradually discovered as the design of the equipment and the cropping system progresses.

One major result of our work is to show that equipment for agroecology emerges from *coupled innovation design processes,* a concept which was introduced by Meynard et al. (2017) in a discussion about coordinating innovations between cropping systems and food processing. We propose to extend the use of this concept to the design of 'cropping systems' and 'inputs', such as equipment, but also varieties, biocides, etc. In other word, this concept allows us to question the historical separation of input design (e.g. by agro-industry) and cropping system design (by farmers), and to organise their joint emergence on farms by considering farmers as designers of both objects. Thus, regarding the equipment as an object to be designed, rather than a contingent variable, offers farmers new opportunities for designing in situ. For example, finding that it was necessary to level the soil, the designers were able to think of acting simultaneously on the cropping system, by adding a tillage operation at the appropriate moment, and on the equipment, by adding a bogie system. However, designing equipment and cropping systems in tandem raises research questions that could only be addressed if agronomists and the few researchers working on equipment worked together. Until now there had been little collaboration between the two (Piovan, 2018; Guillou et al., 2013).

We show also that these *coupled innovation design processes* – and the emergence of *appropriateness* and *adaptability* of equipment – are constructed in the course of action, in situ. This finding ties up with a feature of the design processes described by Schön (1983), when he wrote of the dialogues designers set up, in the course of their work, between emerging objects and the situational dynamic. We show how designing through action in in-situ experiments can help someone "manage the exploration of an unknown space" in a situation where: (i) one has little knowledge and faces uncertainties (as with the Buzuk crimper roller); and (ii) one wants the equipment to be appropriated and adapted to farmers' expectations and particular situations. The case of the Buzuk crimper roller shows that it is in the course of practical action, and by testing in new situations, that *systemic representations* of objects gradually emerge. Our findings highlight an original feature of such a process: these *systemic representations* serve both for the gradual definition of equipment and cropping systems suited to farmers' situations and expectations, and for the emergence of new resources for change that Atelier Paysan will disseminate, such as technical drawings of the implement. The literature sometimes points to the co-emergence of cropping systems and resources for change (e.g. design briefs, scale models, visualisations, Klerkx et al., 2012), and our findings contribute to highlighting how this process unfolds. More precisely, the results show that it is in action, in a real situation, by observing and interpreting what is going on, that designers can establish systemic links: they identify interactions between the equipment, the cropping system and processes in the agroecosystem. They can then judge the choices they have made. And this will sometimes lead them to consider other actions: e.g. if they deem the result to be undesirable, they may want to change the cover crop.

Lastly, we show that the emergence of systemic representations – supporting the *coupled innovation design processes* – are contingent on the use of indicators which help to trigger technical operations, to follow their implementation, and to assess the results the farmers are seeking. These indicators are consistent with those described by other authors: e.g. "*indicators used by managers when trying to integrate ecological systems and production-oriented activities"* (Girard et al., 2014); or "*indicators used by farmers to design agricultural systems*" (Toffolini et al., 2016). In our study, we show that these indicators play a central role in the construction of systemic representations of different objects; they enable the designer to manage uncertainties, and to establish links between the cropping system, the equipment, its behaviour and the dynamics of the agro-ecosystem, and to evaluate the success of the "equipment-cropping system" combination. A challenge would be to find ways to capitalise on these indicators and on these systemic representations, and thus to support the design of equipment and cropping systems in other situations.

5.2. Supporting farmer-designers

This study sheds light on some implications of design processes involving R&D and in which farmers are regarded as "designers". Unlike the dominant design model, where equipment is designed off-farm by industrial firms that distribute them with a user's manual, Atelier Paysan sets out to help farmers design their own equipment. 'How to support farmer-designers' is an emerging research field (e.g. Chizallet et al., 2019); until recently farmers were mainly considered as appliers, deciders or optimisers (Salembier et al., 2018).

1. One contribution of this work is to revise the figure of the "user" in design processes. The literature on relations between R&D and farmers in a design situation more or less explicitly regards farmers as users of the "object" to be designed. Either: (i) they are the end-users of something generated upstream by R&D (top-down dissemination), or (ii) they are end-users but R&D involves them so as to take their needs and demands into account (e.g. Bellon Maurel and Huyghe, 2017), or (iii) they are users of objects generated by R&D, but continue to redesign them in their own situation (continuous design in use, Cerf et al., 2012). In the approach we spotlight here, the farmers and the R&D actors are both designers and users: together they generate new equipment, new technical systems and new resources for change and, to do so, they use the technical drawings, the prototypes of the future equipment, the observations made in the fields, and so on. The process thus involves *multiple designers*, with each one's work feeding and fertilising the work of the others.
2. Another contribution concerns the way R&D can support farmer-designers. First, we show that it implies the opening of new channels for the circulation of knowledge and know-how, so that what is generated by some farmer-designers can be used by others. This can be done by opening new spaces of exchange (e.g. Atelier Paysan forum), by centralising and capitalising on knowledge scattered around the country (e.g. internet platform), and by using

appropriate knowledge production methods (e.g. tracking on-farm innovations). Such pooling depends on the free circulation of knowledge and know-how, allowed by the Creative Common license at the Atelier Paysan (Chance and Meyer, 2017), and on the Atelier Paysan network facilitation work (e.g.) to link up farmer-designers working on their own here and there around the country. Considering farmers as designers also implies updating the nature of resources designed by R&D, which used to be decision support systems, rules for action, etc. We see that the Atelier Paysan resources have been designed to equip different 'moments' of design processes (Hatchuel and Weil, 2009; Schön, 1983), such as training for learning by doing, supporting generative on-farm trials, or furnishing skills that farmers are lacking (e.g. on equipment modelling). These resources have also been designed to support the *empowerment* of farmers in the design of their own equipment, so that they can enrich the common pool of knowledge on new equipment, and in turn accompany other farmers in the design of their equipment locally. The traits of this organisation refer to characteristics of social, distributed and open innovation processes (Chesbrough et al., 2014; Joly, 2017), conducive to agroecology (Prost et al., 2016; Berthet and Hickey, 2018).

6. Conclusion

This research has explored equipment that could be suitable for agroecology, and the ways in which such equipment are designed that differ from those of the dominant design model. Our study of the work of Atelier Paysan highlights two desirable properties for farm equipment: appropriateness and adaptability. These properties are very different from those of the dominant design, and in line with principles associated to agroecology, such as taking account of ecological and social uncertainties and of the diversity of situations. The study also sheds light on features of design processes in which such equipment can emerge: they are designed on-farm, by or with *farmer-designers*, at the same time as the cropping systems they are to be used for. They emerge from *coupled innovation design processes* that take place during their application on the farm. Results also show that both farmers and R&D actors are designers of the equipment, the cropping systems, and resources for the design process, to which they all contribute: by sharing past experiences, by bringing together farmers, by producing technical drawings, etc. We also shed light on three roles taken on by the R&D actors to foster the on-farm design of equipment: organising the sharing of on-farm equipment design experiences, making available a pool of resources to stimulate on-farm equipment design, and linking up equipment designers scattered around the country. Atelier Paysan's approach to farm equipment design offers an alternative to the dominant design, but such processes depend on active commitment by farmers and investment (training, time), which not all farmers can make and for which no support is available yet. These results open the avenues for further research on *designing coupled innovations* and on supporting *farmer-designers*, in and beyond the farm equipment sector.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This work was supported by the Science for Action and Development (SAD) division of INRA and the French Environment and Energy Management Agency (ADEME). It was carried out under the umbrella of the Initiative for Design in Agrifood Systems (IDEAS). The work benefited from rich exchanges with Vincent Bratzlawsky, whom we gratefully thank for his rich testimony on the Buzuk Project. We are furthermore deeply grateful to the two anonymous reviewers, their very rich and constructive feedbacks helped us to improve the article. We also thank Harriet Coleman and Liz Libbrecht for the English revision of this paper.

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