Behaviour & Information Technology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tbit20

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BEHAVIOUR & INFORMATION TECHNOLOGY
https://doi.org/10.1080/0144929X.2023.2185747

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ABSTRACT
Farm Management Information Systems (FMIS) are an important core component of modern farming companies as they allow, e.g. to document activities, create fertilisation plans, and feed digital equipment with required data. Since the entire agricultural sector is an essential component of food production, high standards of resilience should be established in the involved companies. Accordingly, the used software should also be designed with high standards on reliability and crisis capability. Based on a literature review, we found that software for farmers with certain resilience needs is lacking. Thus, we designed and evaluated a new FMIS concept with the user-centred design method. By conducting focus groups (two rounds, total $N = 57$) in 2017 and 2019, we raised specific front-end and back-end requirements of farmers. Based on the requirements, we developed our concept for both front- and back-end in terms of a decentralised and offline-working FMIS. Through the evaluation with practitioners ($N = 16$) of the implemented concept, we derived findings and implications, highlighting the need for privacy, stability, and offline-capability, as well as the UI-requirement to be supportive, e.g. with easy to understand icons and terms.

ARTICLE HISTORY
Received 7 December 2021
Accepted 6 February 2023

KEYWORDS
Digitalisation and resilience in agriculture; farm management information systems; dezentralised data management; human–computer interaction; system usability evaluation

1. Introduction

In many countries, agriculture is considered part of the critical infrastructure to safeguard food production and security. Recently, the term *agriculture 4.0* was coined to discuss and research the use of Information and Communications Technology (ICT) to improve agricultural processes (Liu et al. 2020). For instance, precision farming is expected to offer monetary advantages, allow the precise application of resources, and improve the traceability of production. A frequently used term is that of Farm Management Information System (FMIS), which can be defined as 'a planned system for the collecting, processing, storing and disseminating of data in the form of information needed to carry out the operations functions of the farm' (Sørensen et al. 2010). The most prominent functionalities of FMIS comprise field operation management, reporting, and finance (Fountas et al. 2015). However, several barriers interfere with the successful adoption and use of FMIS. For instance, the farmers' reliance on cloud-based, third-party FMIS raises questions about data ownership and, consequently, adequate regulatory frameworks (Atik 2022). Other issues relate to privacy, security, and data availability in particular, should centralised infrastructures fail (Wolfert et al. 2017).

Failing infrastructures is a serious challenge for the *resilience* of a farm and, if large-scale disasters occur, for the critical sector of agriculture as a whole. Developing resilience, which means to 'successfully deal with uncertainty and dynamic environments' (Slijper et al. 2022) is therefore crucial for the agricultural sector. Furthermore, research indicates a low adoption rate of FMIS in small and medium-sized farms and enterprisess (SMEs) due to lacking awareness (of potentials) (Bucci, Bentivoglio, and Finco 2018) and unclear economic advantages (Schulze Schwering and Lemken 2020). Yet, there is a lack of user-centred evaluation studies examining the perceived usefulness of functionality, usability, and user experience of FMIS in general. There is an even greater lack when it comes to resilience-enhancing concepts, such as decentralised systems. While such concepts have already found significant consideration in the development of conceptual frameworks for digital farming systems (Bökle et al. 2022; Kuntke et al. 2020), so far, prospective users have not been involved in design and evaluation studies of concrete FMIS adhering to these principles. Other empirical design and evaluation studies focus on different agricultural technologies, such as decision support systems (Parker and Sinclair 2001) and smartphone apps

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(Bonke et al. 2018; Kenny and Regan 2021; Michels, Bonke, and Musshoff 2019). The dependence of farmers' business operations on software is increasing and more crises are expected to cause ICT infrastructures to collapse in some regions (e.g. following the 2021 floods in Europe). We therefore see a need for further research into appropriate information systems that implement crisis-ready features for end users. Thus, this paper seeks to answer the following research question (RQ):

> **How should an architecture and user interface for decentralised data management be designed to improve farm resilience and fit the farmers' requirements in agriculture?**

By answering this RQ, the paper makes several contributions to the discipline of human–computer interaction (Wobbrock and Kientz 2016). First, Section 2 provides a literature review on digitalisation and its impact on resilience in agriculture. Then, Sections 3 and 4 provide *empirical contributions* by the user-centred requirements elicitation for the architecture (R1–R5) and interface (R6–R11). Our findings highlight that crisis capability is considered an essential feature, a strong desire for customisation, the importance of supporting multiple end-user devices, as well as User Interface (UI) requirements for specific groups of farmers. The concept and implementation of the FarmBox tool for resilient data management are the *artifact contribution* described in Section 5. Details of the scenario-based evaluation are outlined in Section 6, and the resulting additional *empirical contributions* are presented in Section 7. The subsequent *theoretical implications* on decentralised and resilient data management are discussed in Section 8. Finally, a concise conclusion is given in Section 9, which also discusses limitations and avenues for future research.

2. Literature review: digitalisation and resilience in agriculture

Our literature review introduces the foundations of digitalisation and resilience in agriculture, discussing both potential and current issues. Furthermore, a short overview of technologies for agriculture is given before outlining a research gap.

2.1. Digitalisation in agriculture: higher precision and other advantages

Digitalisation through the incorporation of new technologies in agriculture has become a major issue. Liu et al. (2020) recap the history of the *agricultural revolutions* up to the current trend of *agriculture 4.0*: Agriculture 1.0 is described as manual work from ancient times up to the end of the nineteenth century. The usage of agricultural machinery for mechanised agriculture between 1784 and 1870 leads to higher food production and less manual labours, and is referred to as Agriculture 2.0. Starting with the third agricultural revolution, information technology (IT) systems entered the food-production processes. In light of the current fourth agricultural revolution, data processing is even more crucial to allow for more precise processes all around the agri-food production and agri-food supply chain management. In this context, smart farming technologies in particular, i.e. networked and semi-autonomously interacting devices that can perceive and communicate their individual status as well as their environmental context in real time thanks to sensors (Fleisch and Thiesse 2007; Porter and Heppelmann 2014), are becoming increasingly important. In the survey of Schukat and Heise "Towards an Understanding of the Behavioral Intentions" (2021), 65.8% of the participating German farmers ($n = 523$) reported to utilise smart products in 2020.

The precise processing made possible through digitalisation offers several benefits: First of all, digitalised farm machines and equipment could offer *monetary advantages*. Smart farming approaches promise an increase in efficiency and effectiveness (Wolfert et al. 2017; Gu and Jing 2011) by evaluating the recorded data and calculating a more precise and area-specific application of seeds, fertilisers, and other resources. By utilising these advantages, time and money can be saved. The same applies to smartphone apps that offer decision support to farmers. In 2019, Michels, Bonke, and Musshoff (2020) asked German farmers in an online survey about smartphone apps in crop protection. Among the most useful considered features of crop protection apps by the 198 respondents are weather information (77%), pest scouting (75%), and infestation forecast (64%), even though actual app usage is often less widespread (Michels, Bonke, and Musshoff 2020). Hence, there is still potential for improvement, especially considering that another 2019 survey found that 95% of farmers use a smartphone (Michels and Musshoff 2021). The number of agricultural apps used is affected by individual factors such as age and education (Michels and Musshoff 2020). Elijah et al. (2018) see benefits of the Internet of Things (IoT) also in a resource reduction for feeding a growing population. Secondly, the precise application of resources (e.g. fertiliser) and specific calculations (e.g. nutrient requirements) could *reduce environmental pollution and enhance animal welfare*. Mondal and

Tewari (2007) show that there is a huge potential for an environmentally friendly, sustainable agriculture by utilising precision farming technologies. In general, the use of ICT might reduce CO_2 emissions in agriculture if potential rebound effects are addressed properly (Buhleier et al. 2022). A metastudy on energy use in agriculture is provided by Pelletier et al. (2011). The authors compare different approaches and sub-domains, such as livestock or crop production, and predict an increasing energy demand for agriculture due to population growth and changing consumption patterns. Similar results are found by Finger et al. (2019). With regard to livestock farming, Schukat and Heise "Smart Products in Livestock Farming" (2021) argue that smart farming technologies have the potential to enhance animal welfare. Thirdly, *traceability is improved*. Retailers could offer their customers information about the origin of their crops, and food scandals could be fought more efficiently. Kamath (2018) points out that better traceability may simplify countermeasures during food contamination scandals. The author refers to two food scandals in the USA (E. coli outbreak in 2006) and in China (pork mislabeling debacle in 2011).

All the named advantages require the incorporated tools and equipment to have access to data about the real-world conditions, like soil moisture, weather, plant condition, and more. Thus, FMIS seek to collect, process, store, and disseminate all kinds of farming-related data to carry out operational functions of farms (Sørensen et al. 2010). These agricultural data include farm activities, such as fuel consumption or routes driven, the documentations and reports, but also planning for future operational considerations. In an analysis of 141 commercial FMIS, Fountas et al. (2015) identified 11 distinct functions and grouped FMIS into four clusters, i.e. basic, sales-oriented, site-specific, and complete systems. Their analysis reveals that field operation management (89%), reporting (81%), and finance (64%) are the most common functions. Most FMIS are PC-based solutions (75%); only some supported mobile (16%) or web-based (15%) applications.

The review of Birner, Daum, and Pray (2021) investigates the role of different actors in digital farming, such as suppliers, software companies and differently sized farms. One of the authors' conclusion is that there is concern about a potential increase in the market power of large companies through digital farming tools. As a result, smaller companies would be less competitive. Unfortunately, we have not found reliable statements about the concrete benefit of using digital technologies for farming. Most works, like the ones of Ammann, Walter, and El Benni (2022), Annosi et al. (2019), Chandra and Collis (2021), Gautam, Bhimavarapu, and Rastogi (2021), Liu et al. (2020), OECD (2019), Schukat and Heise (2021), and Zscheischler et al. (2022) describe the potential benefits of using FMIS or other digital tools, without the proof of society-wide positive impacts (Lioutas, Charatsari, and Rosa 2021) or considerations regarding needed investments of farmers in terms of finances and time to build up knowledge and expertise for using the tools. First and foremost, most tech-positive works calls for greater dissemination so that the promised environmental and economic advances are more evident in practice. Interviews with 38 stakeholders of agriculture in the south-west of Germany conducted by Pfaff et al. (2022) support the assumption that the financial hurdles in small-structured regions are an issue for higher adoption rates. As a result, it would be difficult for these very companies to benefit from tools from the field of smart farming.

2.2. Open challenges: increasing adoption rate and making systems resilient

The process of digitalisation in agriculture has been investigated by researchers for several years now. Liu et al. (2020) detected some open challenges of multiple research areas to complete the fourth agricultural revolution. When it comes to Big Data, important aspects are the standardisation of file formats for an exchange between software products and social issues, i.e. privacy and the agricultural stakeholders' understanding of technology. Additionally, complexities in the creation, collection, maintenance, and dissemination of big data with many precision agricultural systems impair the effective provision of actionable and valuable decision support for farmers, thus impeding their further adoption (Mitchell, Weersink, and Erickson 2018). artificial intelligence (AI) has the potential to improve the management of big data and to simplify these processes even in safety-critical situations (Kaufhold 2021). However, farmers' self-confidence in their abilities to use AI systems and personal attitudes towards AI influence the acceptance of such systems (Mohr and Kühl 2021).

A study with Iranian agricultural specialists found that, among others, both perceived *triability*, i.e. the possibility of testing technologies in a small area, and *observability*, i.e. the extent to which the results of technologies can be observed, have a positive impact on the intention to use precision agriculture technologies (Kurosh and Saeid 2010). While various other quantitative studies have employed a variety of theoretical models to explore factors that influence the intention to adopt agricultural technology, the research community has attributed particular attention to individual factors, whereas only few models have recognised the significance of environmental and social factors, as well as their interrelation with individual factors (Carli, Xhakollari, and Tagliaventi 2017). The study by Li et al. (2020) is an example of a more comprehensive approach. It found that the perceived relevance of technology features to Chinese farmers' requirements, the perceived risks and benefits of technology adoption, and the perceived presence of facilitating conditions, such as knowledge, resources, and access to consultant services, have a positive impact on the intent to adopt precision agriculture technologies. Similarly, a recent meta-analysis of 23 publications in this field points to an interplay of individual and social factors, as it found that on the one hand the perceived profitability of precision agriculture and individual computer use, and on the other hand the commitment of consultants have a positive effect on technology adoption (Tey and Brindal 2022). unmanned aerial vehicles (UAVs) and autonomous field robots (AFRs), representing some of the latest technological innovations in agriculture (Michels et al. 2021; Rübcke von Veltheim and Heise 2021), are also of interest for understanding technology adoption. Studies found that Chinese farmers' intention to adopt UAVs is positively related to both individual factors (Zheng, Wang, and Wachenheim 2019), and environmental and social factors, such as cultivated land area, presence of village cadres within the family and the number of borrowing channels for money (Wachenheim, Fan, and Zheng 2021). The same applies to the factors influencing the actual adoption of UAVs by German farmers (Michels, von Hobe, and Musshoff 2020). Michels et al. (2021) argue that the communication of UAVs' benefits and a tailored demonstration of drones to farmers may change farmers' perceptions and beliefs, thus enhancing the intention to adopt such systems. Rübcke von Veltheim and Heise (2021) formulate similar advice regarding AFRs and encourage farmers' involvement in the design process.

In the context of this study, previous research focusing on the challenges and prerequisites of the adoption of FMIS is of particular relevance. A survey with 184 participants from Denmark, Finland, Germany, and Greece in 2011 focused on potential benefits for introducing labour-saving FMIS in terms of budgeting procedures, field planning, and paperwork dealing with subsidy applications and public authorities (Lawson et al. 2011). But a majority of the participants were unsure about the benefits of new technology. Particularly for the results of the German participants, the authors see the large amount of time needed to get used to the technology as the major problem. Additionally, smaller farms did not have enough labour capacity, nor the necessary time to concentrate on precision agriculture compared to bigger farms. A positive relationship between farm size and the adoption of precision agricultural enabling technologies was also found for Switzerland (Groher et al. 2020) and with regard to Germany (Gandorfer et al. 2017). Linsner et al. (2021) confirmed these findings in 2021, stating that privacy is an upcoming issue in the adoption of FMIS. The study by Paulus et al. (2022) shows that the adoption rate of smart farming tools is higher among full-time farmers. The authors call for further research into the specific digital technology needs of part-time farmers to provide this target group with easier access to smart farming tools.

Similarly, Schukat and Heise "Smart Products in Livestock Farming" (2021); Schukat and Heise "Towards an Understanding of the Behavioral Intentions" (2021) note that ambiguities regarding data sovereignty and security may be an inhibiting factor for the adoption of smart farming systems, as they affect farmers' trust. Atik (2022) thus recommends a holistic approach to issues of agricultural data ownership, involving both the design of legal regulations and of infrastructures.

Another important issue is the demand for internet connectivity. The work of Aceto et al. (2018) shows how fragile the internet itself is. They propose a taxonomy for internet outages and provide a selection of scientifically proven examples of concrete internet outages with impacts ranging from regional to global; each of the 15 examples is referenced by at least one scientific analysis. Obviously, any internet outage could suppress the use of applications that rely on an internet connection, e.g. cloud-only services, and there are typically no precautions for such ICT breakdowns (Kuntke et al. 2022). Apart from disruptions, insufficient broadband internet availability in rural areas is a major barrier to the use of agricultural information technologies (Kenny and Regan 2021). In order to meet the farmers' demands, digital links between the increasing number of IoT devices inside the farms and farmlands provide a reliable way of digital communication. Besides mobile ad-hoc networks (MANETs) for local communication (Reuter et al. 2017), modern and far-reaching network technologies such as LoRaWAN (Davcev et al. 2018) can connect sensors within the agricultural areas even over long distances with little technical effort (Ojha, Misra, and Singh 2015; Chen et al. 2016). Furthermore, Kalle et al. (2019) show how different network technologies can be combined to enhance resilience during crises with (partial) infrastructure disruptions. The analysis of wireless sensor networks for precision agriculture by Jawad et al.

(2017) shows that current approaches typically propagate an internet connection to cloud services to analyse the sensor data and to enable later access via client computing devices, such as tablets. But at the same time, fundamental technologies like cloud services have proven to be vulnerable in case of a specific cloud-service breakdown or a failing internet connection. Unfortunately, digital infrastructure in Germany is characterised by the digital divide, which means that rural areas have less access to 4G networks (73.5%) than urban areas (82.2%) (Rizzato 2019).

By inspecting the data from the agricultural structure survey 2020 regarding agricultural holdings and utilised agricultural area by size (Statistisches Bundesamt Destatis), we see that most (about 85.49%) holdings in Germany do not exceed 100 ha, and there are about 3.6 worker per farm (Statistisches Bundesamt Destatis). In accordance with the EU Commission's limit for medium enterprises (European Commission 2015), those holdings can be seen as SMEs (small-size: less than 50 employees). SMEs, in general, are considered to be highly vulnerable to impacts from disruptions, such as the effects of increasingly extreme weather (Wedawatta, Ingirige, and Jones 2010). Despite their high vulnerability, especially SMEs seem to lack adequate strategies to prevent interruptions and to quickly return to normal continuity of their operations. Reasons identified for this are high standards for business continuity, risk and security management that SMEs cannot easily adopt (Kaufhold et al. 2018). Hence, experts call for simplified concepts (Reuter 2015; Thiel and Thiel 2010). Pipek and Wulf (2009) coin the notion of 'infrastructuring' and highlight the importance of understanding users' activities for improving IT infrastructures. Since triggers of IT infrastructure perturbations can remain simple even in complex or complicated use situations, the authors suggest a frequent reflection on available strategies to handle such perturbations. Furthermore, research indicates that agricultural software solutions must be tailorable to (changing) local regulatory policies and legal frameworks (Elijah et al. 2018); and user interfaces as well as information visualisation should be simple in order to be usable for all farmers (Michels and Musshoff 2020).

2.3. Research gap: decentralised farm management based on user centred design

Based on our literature review, we identified two central research gaps. First, the *need for research on decentralised FMIS* became apparent. With the emergence of big data analytics, cloud computing, and IoT, Wolfert et al. (2017) envision two extreme scenarios, i.e. 'closed, proprietary systems in which the farmer is part of a highly integrated food supply chain' or 'open, collaborative systems in which the farmer and every other stakeholder in the chain network is flexible in choosing business partners'. Looking at the first scenario, the reliance on cloud-based, third-party FMIS raises not only issues concerning data ownership, privacy, and security, but also regarding data availability if centralised infrastructures fail. For this reason, the integration of decentralised communication infrastructure – the second scenario – seems promising to increase resilience in crises (Elijah et al. 2018), as well to increase farmers' acceptance (Linsner et al. 2021). There is a large body of literature comprising conceptual models (Sørensen et al. 2010), software architectures (Nikkilä, Seilonen, and Koskinen 2010), infrastructures (Nikander et al. 2015), and comparisons of existing FMIS (Fountas et al. 2015). But none of those related works investigate decentralised software systems for agriculture, nor make suggestions for the development of resilience enhancing software systems.

Second, the review revealed a *need for the analysis of farmers' demands and involvement in the design process.* Involving users in design has been shown to lead to developing more usable satisfying designs as well as to establishing new technologies and innovation (Cajander et al. 2021; Shin et al. 2017). Yet, only a small number of studies focuses on such designs in the agricultural environment, like the ones by Bonke et al. (2018), Kenny and Regan (2021), Michels, Bonke, and Musshoff (2019), and Parker and Sinclair (2001). The main objective in a user-centred design processes is to involve end-users in the computerised design process (Wallach and Scholz 2012). The ways in which users participate vary: They may be consulted about their needs and participate in usability testing (more passive role of users) or participate actively throughout the design process as partners in the design. User-centred design has been shown to lead to developing more usable satisfying designs as well as to establishing new technologies and innovation (Cajander et al. 2021; Shin et al. 2017). Therefore, it was the preferred method for the design process of the FarmBox software, which is explained in the following Section 3 starting with the requirements engineering.

3. Empirical study: focus groups to derive requirements for architecture and interface design

We conducted two rounds of focus groups in 2017 and 2019 to derive requirements for the design of a novel tool for decentralised data management and resilient regional networking. This section presents the study design, participants, analysis, and a summary of results, outlining design requirements. Some results from the second round of focus groups have already been published in scientific journals (Kuntke et al. 2022; Linsner et al. 2021); however, the data were analysed with a different scope, i.e. not for the requirements elicitation.

3.1. Study design

We decided to interview agricultural practitioners in focus groups (Lazar, Feng, and Hochheiser 2017; Morgan 1997) because this gave the interviewees the opportunity to discuss with each other. In our case, these discussions brought up new aspects that might have gone undetected in individual interviews. All focus groups were conducted by two researchers in order to provide inter-subjective comprehensibility (Jenner et al. 2004). The entire process containing the creation of an interview guideline, recruitment, conduction of the focus groups, and data analysis and storage followed the guidelines of the ethical commission of the Technical University of Darmstadt university. With regard to the limited time available for interviews, we decided to outsource some background information into a survey in order to give more space for discussion in the focus groups. The survey was filled out before the focus groups took place and contained some general information about the branches they work in, their roles, and their experience with digital tools. We conducted two rounds of focus groups.

In the first round, we invited practitioners in 2017 to discuss the potentials for technology support. The participants were divided into four focus groups; each group consisted of three to six participants, and each session took about one hour. Based on this, we derived *requirements for the design of the envisioned interface* of the novel tool. In the second round, we asked practitioners about their understanding of digitalisation in 2019, including positive and negative aspects, fears, and questions regarding privacy- and data ownership. The participants were invited to 12 one-hour focus groups, whereof each session consisted of three to six participants. The output of the focus groups of the second round was analysed to identify *requirements for the envisioned architecture*. The used session guidelines of both rounds started with a short welcome and introduction, conveying the goals of the focus groups, and asking for approval to record the session. During the focus groups, participants were asked to share their experience with agricultural technologies and to discuss possibilities for future improvement.

3.2. Participants

Our participants were recruited in the context of public-funded research projects called HyServ (Bernardi et al. 2019) and Geobox-II (Kuntke et al. 2020), which comprises partners from the private sector, federal institutions, and associations for farmers. We recruited most of the participants at a federal advanced training institution for agriculture, which offers different degrees for farmers with practical experience. The clients and members of the project were invited to our focus groups for requirements elicitation. Everyone participated voluntarily, and no compensation was paid. Each participant was informed about the aims and topics of the study via informed consent, which was signed by each person. In total, 67 agricultural practitioners participated in two rounds of our focus groups.

The first round involved 15 practitioners (2 female, 13 male), which were organised into four focus group sessions: The first focus group was composed primarily of water conservation advisors that had little to no experience with FMIS. Group two had a mixed composition: one person was a teacher and consultant for viticulture, one participant was a participant for electronic area applications, and one participant worked first as a farmer in viticulture and then in a machinery ring (association of local farmers) in the field of fertilisation technology. The third group consisted of three farmers, two of whom already had experience with FMIS. Finally, the fourth group consisted of a technical instructor for viticulture and plant protection, a vintner and member of the board of directors of the machinery ring, as well as a vintner's wage worker. The strong role of vintners was not forced, but resulted from the recruitment of the focus groups in an area in Germany that has a comparatively large number of viticultural areas. Nevertheless, most participants had experience in other areas of agriculture in addition to their current occupation.

The second round involved 52 participants (7 female, 45 male) who were interviewed in 12 focus group sessions: For the first focus group, we consulted a machinery ring. This way, an expert round was established, including the head of the machinery ring, a soil lab owner, and federal counselors. The aim was to conduct an exemplary focus group interview with them and to validate our interview guidelines with these very domain experts. The second and third focus groups were conducted with the help of our project partner John Deere, who invited customers (farmers) to be interviewed. The remaining nine focus groups were conducted with farm managers and farm worker who took part in a federal graduation to earn the title of state-recognised technician in the field of agriculture.

Especially in this second-round focus group, the participants had quite a broad background regarding their affinity to digital technologies in their business, as some of the participants had no software for farming in use.

3.3. Analysis

The focus group sessions were audio-recorded, transcribed, and anonymised for coding. In our subsequent analysis, we employed open coding according to Strauss and Corbin (1998), i.e. gathered data into approximate categories to reflect the issues and requirements raised by the respondents based on repeated readings of the data and organised them into similar statements. The resulting categories are reflected by the requirements outlined in Tables 1 and 2. The categorisation of the first-round focus group was conducted by the second author, while the first author coded the second-round focus groups. We decided to do so in order to grant a homogeneous analysis of the data in the first stage of coding. To prevent subjective biases and to achieve an intercoder consensus, the first and second authors reviewed, discussed, and revised, if required, their codings mutually (Cascio et al. 2019). Thereafter, the coding was presented to the other authors for a second round of review. As most of the analysis was conducted in German, selected quotes were translated into English by the authors.

4. Empirical study: summary of findings

All four first-round groups were made up of different members: water conservation advisors, agronomists, vintners, machinery ring employees, and agricultural students. Only a few participants already had experience with FMIS. It turned out that the participants used the FMIS either to communicate between farmers and (water conservation) advisors or to communicate between farmers and contractors (with forms and route planners for drivers). Used FMIS were compared several times with GIS systems, with which some participants have already gained experience. Three groups independently expressed the wish to be able to include a route planner for drivers. Other frequently requested features were clarification of access permissions for the app, a possibility to rename column names, conflict resolution in case of conflicting changes to files, and a possibility to indicate the current status of jobs. In addition, one participant expressed the wish to being able to tick off areas he had already visited and also note how far he had come with e.g. fertilising a field. A similar practice already seems to be done with paper and pencil.

An employee from a machinery ring told us some usability weaknesses of older technologies, such as a difficult installation, missing explanations for features, or the selection of a file export directory. Also, a vintner contractor briefly described their approach to planning with Google Earth, as they were unable to find

Table 1. List of identified requirements for interface design.

Requirement	Description
Tailorability for diverse agricultural subdomains (R1)	Support of different domains, customisation according to their needs, i.e. granularity of information, and interfaces for interoperability with third-party systems.
Low complexity of field data filtering operations (R2)	Establish usability for personnel with less technical expertise, integrate usable data filtering views for field data, and automate the setup of background maps.
Location-independent technology support for field works (R3)	Support different devices, such as personal computers and smartphones (e.g. by responsive design) to allow operation both in field or office settings.
Prioritisation and monitoring of field processing tasks (R4)	Allow for the prioritisation of fields, display the progress of a task execution, facilitate the documentation of wage workers' days, and support time recording.
Navigation and recommendation system for wage workers (R5)	Provide a routing component for wage workers considering the width of paths and vehicles, giving tips for navigation, and suggesting the order of field processing.

Table 2. List of identified requirements of the system architecture.

Requirement	Description
Offline capability for infrastructure disruptions (R6)	Allowing the basic functionality without a proper internet access, e.g. by introducing caching mechanisms to offload data on the end-device proactively. Synchronisation between multiple devices must be ensured.
Extendable and modular feature design (R7)	The basic feature set could be small but must be extendable by future modules (e.g. task monitoring and navigation features) that could be individual for different workflows.
Data sovereignty for confidentiality and privacy (R8)	Privacy and confidentiality are very important factors in this domain and must be respected. Therefore, outwards data transmission must be reduced to just permitted traffic.
Data safety and recovery mechanisms (R9)	Safety of data must be ensured, that is to say proper backup and recovery mechanisms. The whole backup process must be an integral property of the system, with a minimum on required user interaction.
Affordability for small and medium enterprises (R10)	The complete solution must be cheap in both acquisition and time for initial setup to align with the limited budget of small and medium-sized enterprises.
Integration of multiple and open data formats (R11)	To allow the integration into existing work processes, an easy exchange between established software must be possible by simple file exchange based on compatible file formats.

affordable planning tools suitable for viticulture. They make tables and maps for drivers so that they can find their customers and use the contractor's tables to complete the necessary documentation. As a contractor, they create their own maps for customers, which they described as a time-consuming process. When analysing the different points of discussion in the four focus groups, we identified five major requirements, which are summarised in Table 1.

Also the 12 second-round focus groups were made up of different members: agronomists, farming advisors, machinery ring employees, farm managers and agricultural students. Only a few participants already had experience with FMIS. The intention of the second-round focus groups was to develop and understand more basic requirements, important for the design of a system's architecture (backend). We received many statements that are on a more abstract level than directly connected to possible user interface requirements. For example, harvesting could be scheduled in narrow time frames due to possible weather changes, that makes any system's faults involved in this operations not tolerated. Especially combined with bad internet connectivity in rural areas, a desire for internet-independent solutions arises, meaning pure cloud solutions are opposed. Besides the technical requirements, we were often confronted with statements that management operations, which typically take place via computers in offices, are tasks conducted rather reluctantly. As a result of the analysis of the 12 focus groups, we identified six requirements for architecture design, which are summarised in Table 2.

5. Concept and implementation: a toolbox for decentralised data management and resilient regional networking in agriculture

As the next step, we conducted a synopsis of requirements to derive and explain design decisions that led to both the back-end and front-end concepts and implementations of FarmBox.

5.1. Synopsis of requirements

The identified requirements for the interface design (Table 1) and the system architecture (Table 2) were considered as a whole for developing the concept of the complete FarmBox system. The concept and implementation phase started in 2017 with first prototypes, and lead to a continuous development in multiple stages until the user evaluation in late 2020 and early 2021. Some parts of conceptual ideas at a higher level were already part of other publications during this time (Eberz-Eder et al. 2021; Kuntke et al. 2020). By inspecting the requirements, we came up with high demands for a flexible system, which must be: extendable (R1) and fast to use (R2), as well as supportive by reducing the interface complexity (also R2) and being able to run on multiple (common) devices (R3). For this reason we decided to build the front-end with the Progressive Web App (PWA) pattern. Using this pattern allows for developing the app with web technologies and being able to run the application on several operating systems and device classes with just one code base. As computational end device categories tend to flow into each other – e.g. convertible laptops with touchscreens, or smartphones than can fold up to tablet-size – web apps with responsive designs seem to be an easy way to handle this situation with the increasing range of *typical* screen-sizes and input-modalities. Demands for specific functions, like task monitoring (R4) or navigation feature (R5), could therefore be outsourced to own function modules and be part of later revisions. In this way, we first focused on developing a back-end concept, that is able to fit the system architecture requirements.

Figure 1 presents a simplified schema of our target architecture. We have grouped the architecture in three clusters of device classes: global (external) server, local server and client devices. The focus in this present paper lies mainly on the client devices' application. However, the overview of the complete system's architecture is helpful to understand some design considerations. Especially the used concept of the local (mini) server, which allows for some system architecture requirements by design and is a concept that is rather rarely used in practice, today. The conceptual introduction of a mini-server is a result of the demands for offline capability (R6), data sovereignty (R8) and data safety (R9). Our conceptual requirement for additional hardware – local server – negatively affects the demand for affordability (R10). As we think of small and rather cheap hardware, we therefore refer to *mini-servers*.

5.2. Back-end: multi-purpose mini-server

The local mini-server is designed as a central hardware unit, that is used in first instance to synchronise data between different end-devices. Often, modern software is designed with a *cloud* pattern, meaning that the entire data storage is outsourced to external servers, and synchronising between devices is done via a complete data alignment of each device with the external server. But based on our identified requirements, our goal should be to reduce the data flows to third-parties to ensure privacy (R8). Just the requirement of reducing

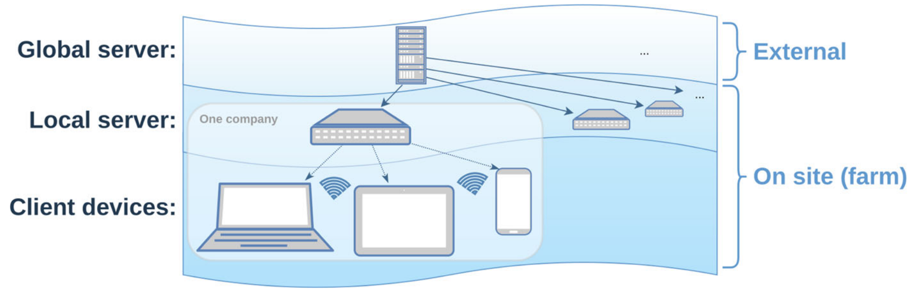

Figure 1. Scheme of the complete system, with the three different classes of devices: global server, local server and client devices. The concept of local (mini) servers is used to have a resilient data storage on the company level.

data synchronisation to external servers could also be fulfilled by peer-to-peer transmissions between the end-devices. Yet, we see a higher practicability when all devices of a company could synchronise with one server instance at all the time. Additionally, such a mini-server can also host local server apps (R7) similar to the *cloudless* approach (Grosmann and Ioannidis 2020) and cache data from the internet for the front-ends. In cases of limited internet bandwidth, those transfer speed limits could be exceeded, assuming the local network, e.g. WiFi, is faster than the internet link. A local network for field applications can be established via LPWAN technologies for small data (Kuntke, Sinn, and Reuter 2021), in addition to WiFi for high bandwidth applications in specific areas, like machine building, workshop and farm office. In cases of internet outages, the databases of those local mini-servers could be reached from inside the company (R6), in contrast to pure cloud solutions. A simple data safety consideration is the mirroring of the used database between end-devices and the central mini-server (R9), so a single broken device should be able to recover. By keeping the hardware-requirements low, we are able to run the complete server distribution on cheap hardware (R10).

5.3. Front-end: interacting with temporal and spatial data

The end-users mainly interact with the whole system by using the front-end. To reach multiple devices (R3) within the same code base, we decided to develop a PWA, that could be translated into software for smartphones, tablets, and desktop computers and their different operating systems (Microsoft Windows, Apple macOS, GNU/Linux, Google Android, Apple iOS/iPadOS). Our first development stage should establish a basic functionality set with a low complexity (R2), but a cross-domain usage (R1). We decided to implement the following application features to have a usable application:

- visualisation of spatial data on a *map* (e.g. all cultivated fields of a company),
- documentation of processes in a *journal* (e.g. applied fertilisation),
- sending/receiving orders/jobs in a *form management* (e.g. soil sample examination),
- creating *calculations* (e.g. calculation of optimal amount of fertiliser), and
- getting an overview of business data in a *tabular* view (e.g. how many fields have been fertilised).

Those functions are represented by own modules on the main dashboard (see Figure 2). For the evaluation, we focused on the features *map*, *form management*, and *journal*: The *map* function allows for both getting a visual overview about the own area and adding, modifying or removing geographic references of the database, primarily used for own fields, but also paths, buildings or arbitrary polygons. The *form management* function is used to import forms of a specific file format and fill those. Most forms require a geometric reference, that automatically show a map view side-by-side next to the form view. A convenience function allows to directly send the form to the recipient through the integrated messenger or via e-mail, based on the integrated metadata of a form file. Each filled form could also be exported as a file to being able to manually hand it over to the recipient. The *journal* function allows to document tasks or operating material. The UI to document something has a similar interface to the form management.

One implementation detail of the developed application is a specific database scheme, i.e. every entry is a triple of {location, time frame and change set}. A change set itself consists of one or more object-values tuples, whereas objects are defined by multiple ontologies. By having these rules for aligning data that are stored into the system's database, we allow for some automatic evaluation processes inside the functions and reduce necessary user input in cases, the semantic

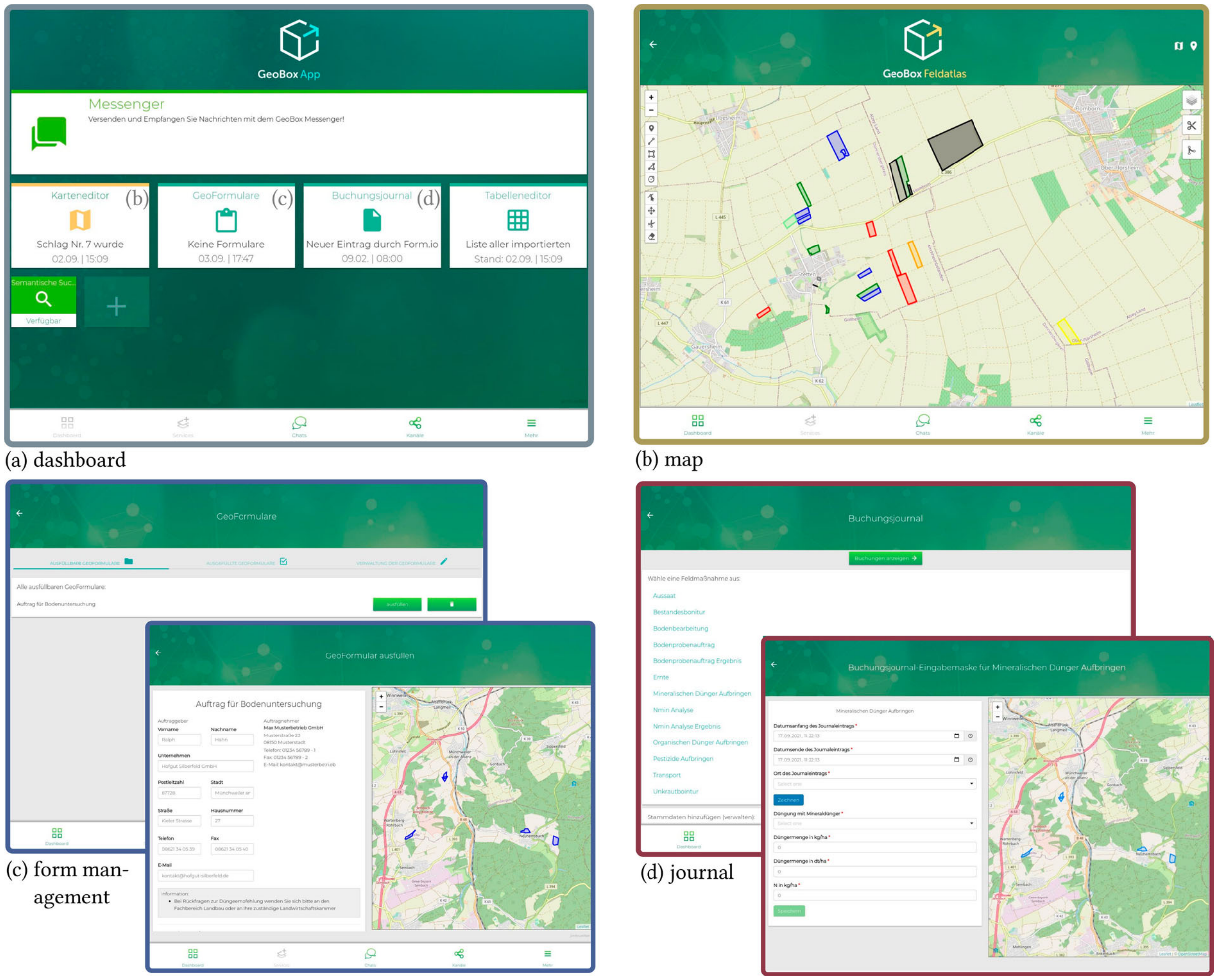

Figure 2. Navigation inside the application starts on (a) dashboard, that allows to open the distinct functions; (b) map; (c) form management; and (d) journal.

of input field is retrievable via the stored data. Reducing required user interactions also reduces the complexity of the user input forms (R2). The home screen of the application (see Figure 3) is a grid view (dashboard) with shortcuts to sub-functions, that are called partial apps.

In summary, this concept utilises a novel approach, taking advantage of a small hardware server (*mini-*

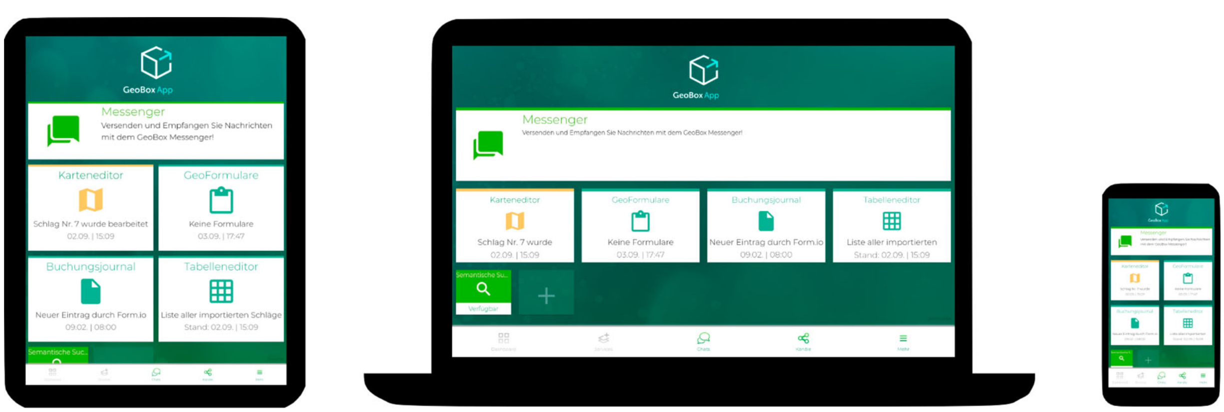

Figure 3. Responsive home screen (dashboard) on three most used client devices of the targeted end-users: tablet, laptop (desktop computer) and smartphone. The tiles represent distinct functions of the app, like visualisation of cultivated fields on map, documentation of done actions, etc.

server), which acts primarily as a local database for the purpose of synchronisation between multiple clients. By keeping data local, in contrast to existing solutions, this approach achieves privacy-by-default, as well as a high offline capability. In addition, various import and export functions expand the possibilities of using the managed data to work even in unfamiliar situations.

6. Empirical evaluation: usability tests with agricultural practitioners

We conducted an evaluation of FarmBox with three major objectives in mind. First, we performed a usability test to reveal positive and negative aspects of the interface, stated by the participants. Second, we worked in an offline scenario to test the understanding of the offline-first character of the developed architecture. Finally, we analysed ideas and inspirations for future improvements of both the front-end and back-end. The philosophy behind the evaluation process was derived from the notion of *situated evaluation* (Twidale, Randall, and Bentley 1994), in which qualitative methods are used to draw conclusions about real-world use of technology using domain experts. The aim here is not only to measure the relationship between evaluation goals and outcomes but to derive subjective views from experts about how useful and relevant the technology might be in use. The entire process comprising the creation of an interview guideline, recruitment, evaluation, and data analysis and storage followed the guidelines of our ethical commission. As a limitation, it should be noted that the individuals who developed the prototype are affiliated with the individuals conducting the research, in the form of being colleagues in the same research group or collaborating on the same research projects.

6.1. Study design

Due to the ongoing COVID-19 pandemic, we decided to conduct the evaluation in a remote setting with the help of a video conference software between 12/2020 and 03/2021. The participants were once again recruited in the context of a public-funded research projected called GeoBox-2 as described in Section 3. However, the participants were not the same as in the focus groups. Everyone participated voluntarily, and no compensation was paid. At first, the participants were informed about the ideas of this evaluation and the involved data processing. To proceed, the participants had to agree with the audio recording and later data processing of all the results. To get some socio-demographic and farm structural data for a rough categorisation of the participants, we asked about age and location and high-level information about the job profile, as well as a standardised questionnaire about their technical affinity (Karrer et al. 2009).

The main part of the evaluation constitutes supervised scenario-based walkthroughs (Twidale, Randall, and Bentley 1994) and think-aloud combined with integrated semi-structured interviews at the end of each task. A scenario description was presented to help all participants to get their minds into the same hypothetical setting. The scenario itself starts with being without any internet connection in the local area due to a major technical problem on part of the responsible internet service provider. That means there is no online help available and the user has to use just the given system (decentralised data management). The tasks were (i) to migrate backup data from another (cloud-based) data management and update the data, (ii) to fill out a form for a soil analysis order, and (iii) to document a farming task. The tasks are considered as easy, but it is the first time the participants interact with this interface, so there is potential for some delays during the exploration of the overall application interface.

After the tasks, we asked the participants to fill out the standardised questionnaire called System Usability Scale (SUS) (Brooke 1996), so we are able to compare the state with other applications as well as previous states of our system and in the future with the next stages of development. At the end, we also gave participants room to settle down and recap the tasks. In this way, we hoped to receive additional helpful information about the evaluation itself and possibly more important statements about our developed software, as some people tend to be more open to sharing their thoughts when a formal setting is in its final stage. The paper contains an evaluation schedule summary (Appendix A.1) and a detailed evaluation guideline (Appendix A.2).

6.2. Participants

Every participant has to agree to the recording and proper data analysis. We did not keep track of sensitive personal data, and after transcription of the audio recording, we deleted the recorded audio files. A test run of the complete test setup was performed with a Human–Computer Interaction (HCI) expert, while the main evaluation was performed with 16 participants in total (I1-I16). Most of these 16 participants work on agricultural farms ($N = 10$); the others are official advisors ($N = 3$), researchers ($N = 2$), or educators ($N = 1$) – all in the domain of agriculture. The age distribution is shown in Table 3. We acknowledge that our set of participants cannot be seen as representative

Table 3. Age distribution of the 16 participants (I2-I17) of the usability tests.

Age range [years]:	21–30	31–40	41–50	51–60
Count of participants:	7	5	2	2

regarding their age, as our participants are rather young with a median of 31–40 years. In the domain of working people of agriculture in Germany just about 24% are below 35 years old, and 49% are 45 years or older (Bundesministerium für Ernährung und Landwirtschaft 2020). This reduces the likelihood that our results will be transferable to the entire domain. However, since our results should be of interest for future software in agriculture, the focus on a currently below-average aged target group is to some extent justifiable in our view.

7. Empirical evaluation: presentation of findings

Due to our test strategy, we got impressions of how new users interact with the user interface, out-spoken opinions about the software prototype, aspects that should be considered for future development, and statements about the software landscape for agriculture. Based on the comparable SUS (Brooke 1996), we also have a value that can be compared to and be aligned with existing systems. The SUS-values ranged between 62.5 and 82.5 (mean 73.75, SD 5.84), which could be interpreted as a good (but not great) value according to Bangor et al. (2009). The distribution among all questions of the SUS is shown in Figure 4. Most participants stated that they found the system easy or very easy to use. 88% said they would like to use the system frequently. Notably, 81 % stated that they would not need the help of a technophile person to use the system. But 19% saw too many inconsistencies in our prototype, with 13% unsure.

In the following, we highlight positive as well as negative reactions to the tested parts of our system, as well as further considerations for future developments that seem to be of particular interest to the targeted domain of agricultural professionals. In this way, we gain better insights to understand this specific target group and their needs.

7.1. Reactions to the overall system

The general design of the app was mostly seen as *'comprehensibly structured'* (I02), and mentioned positively by 14 of the 16 participants. Also, we could not see any problems regarding the understanding of the internal navigation, i.e. to open a specific function (partial app), one has to go to the app's home screen (*dashboard*) and in every partial app (e.g. *map*) one can go back one step by clicking on a back-arrow in the upper-left, or directly to the dashboard, by clicking the appropriate symbol on the lower left (see Figure 2). We also got some positive mentions regarding the used colours (I10, I15) and icons (I10, I16).

One suggestion for improvement relates to the fact that the light font used may be difficult to read for some people, primarily older people (I16). Accordingly, one participant also had problems reading labels in a partial app:

> I10: *' This [headings in the form application] I can now read on my PC almost not at all.'*

Two participants considered the import functionality as too cumbersome (I12, I13). However, the possibilities of data exchange with open formats that are also compatible with other programs (e.g. spreadsheet files like `.csv`) were highlighted positively and considered important by 13 respondents. Particular attention was paid by participants to the choice of symbols and labels, which at the time of the tests were still partly based on the examples of the frameworks used (e.g. Leaflet[1]). Six persons pointed out that simpler descriptions should be chosen and that foreign words (English descriptions) should be avoided since this would be an obstacle, especially for the older generation. This is particularly interesting since there is a trend towards modern-sounding descriptions in other software.

7.2. Specific reactions to the tested functionalities

7.2.0.1 The map is appreciated, but icons are not understood. There were no problems with the general navigation of the map application, which was described as 'relatively easy to use' (I02), and comparable to other domain specific map applications. As farmers regularly have large areas to manage, map applications are used frequently and on a daily basis. Therefore, a good map experience is crucial for the overall acceptance of the app. When drawing in new areas, however, about half of the test persons had initial difficulties and could not find the correct tool right away. Geometric primitives typical for drawing on maps, such as polylines or polygons, were often unfamiliar: *'That strange thing there with the three points …uh I don't know'* (I06). Potential improvements noted here are the direct display of size information when drawing lines and areas (I07, I09)

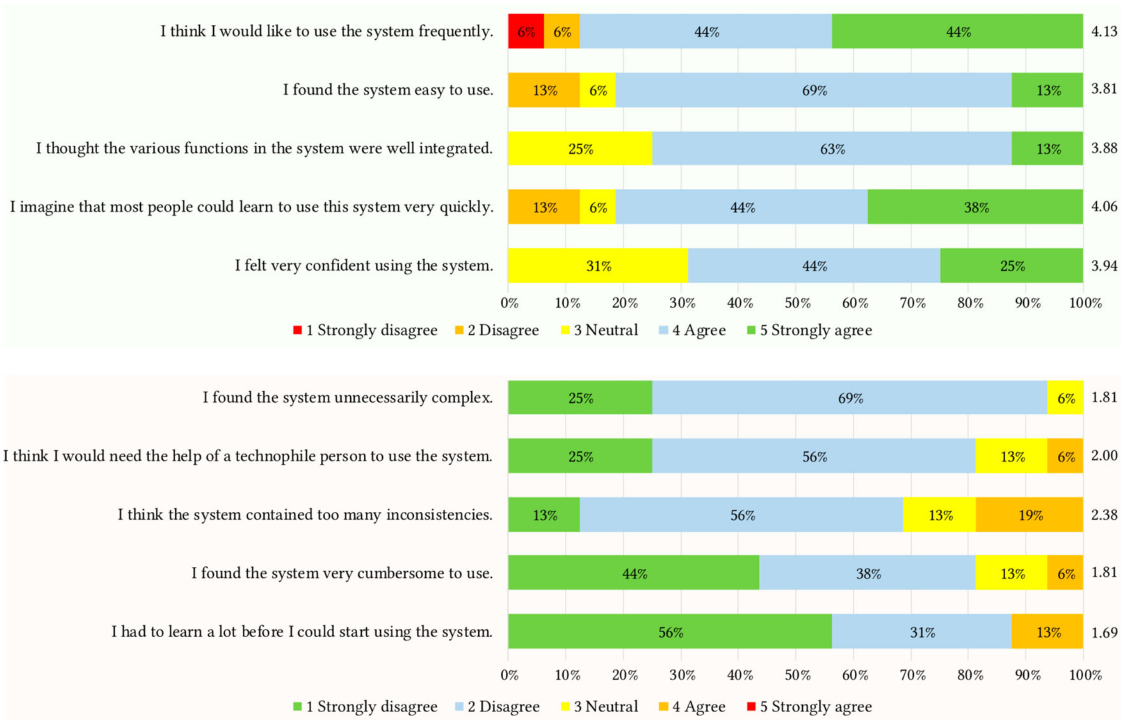

Figure 4. Results of the SUS questionnaire. The number on the right of each bar indicates the mean score for the question (ranging from 1 to 5).

and the display of cadastral data to directly mark existing properties (I05, I16).

7.2.0.2 The form is well understood. Overall, the forms management was described as well-structured (I04, I06, I10, I11, I15, I16). The functionality of the auto-fill support of form input fields by already known business data of the app's internal database was also positively mentioned (I03, I04, I16). However, comfort functions were missed: the forwarding to the form input view after file import, more button icons for faster recognition of actions, and the identification of the processing status of forms in the overview. Furthermore, the buttons for import and export were often difficult to find and are therefore not yet optimally placed or insufficiently recognisable as such. But the idea of migrating the paper forms-based process – e.g. awarding contracts or ordering placements – into the digital farm management ecosystem was mostly seen as overdue.

7.2.0.3 The journal is seen as important, but capable of improvement. Overall, the journal was considered important. Its functionality and structure received positive remarks. Certain aspects were, however criticised, such as labels and unnecessary input fields. The function itself was also seen as important due to increasing regulations:

> I04: *'And when it comes to something like area applications, where you might have to fear penalties if you don't provide certain data, then it [having access to a journal of activities] could become important. I would say that such an independent system would fill a gap, so that you could at least provide proof or something similar: "Here, I have done this then and there" …'*

However, there is room for improvement with regard to the description of some elements. Thus, some terms were badly chosen and came across negatively to many test persons, e.g. the word 'pesticides', which has a negative connotation in German and should be replaced with the term 'plant protection products' (German: 'Pflanzenschutzmittel').

7.3. Farmers appreciate the offline-capable design

As part of the evaluation, we also asked participants about the importance of aspects of offline capability in software, which is one of the unique features of the farm management concept compared to commercially available tools. The capabilities to have routines that are designed to work also offline (nearly) fully functional is seen as an important feature by some participants (I02, I03, I05, I09, I10, I13, I16), resulting in statements like:

> I09: *'It can be that a network line is somehow disrupted and that this can also happen over a longer period of*

time, there can be a power failure, there can be computer problems or something. So it's good that you can still continue to work there and that perhaps at a later time then reconciles again. Or that it is automatically synchronised, however that may be. So whether that happens actively or passively. So such a scenario should be taken into account.'

The increasing dependence of modern software on the internet is also creating problems for farms in some rural areas with poor internet connections, pushing the entire sector into an increasing dependence on infrastructure. Even in our rather small set of participants, we received statements about missing internet connectivity, which is not handled by current software:

I04: *'Because here in the country, mobile internet is still very poorly developed. So I don't have 4G and so on. And you can't do anything with it in normal applications. Therefore, an offline application would not be bad.'*

Also, outage scenarios are well-known and feared. In the event of power outages lasting from a few hours to a few days, some companies are still able to generate electrical energy themselves using emergency generators. The necessary fuel stock is also usually present as the agricultural machinery require it. But as the increasing dependence on data and network connectivity is new in this sector and therefore rarely considered – it is becoming increasingly important and difficult to overcome. Self-sufficiency in electrical power is well known, but it is not as easy to ensure communication in the event of outage scenarios, as happened after the 2021 flood in some rural areas of western Germany. And the possibility of being in an offline scenario at one point due to an outage was also considered likely. Even at the time of the evaluation – when no catastrophe had occurred in the area for a long time – network outages were very present:

I16: *'actually, with regard to last week [a city-wide internet outage for about two hours], I will say that it [being offline for some hours to days] is very valid'*

One problem for the UI design was the trade-off between an easy-to-use design and elements to support the offline capability. A specific concern was to embed functionality for offline capability without limiting comfort, as it may be limited through more buttons or more cumbersome procedures. But eight participants explicitly did not see any danger or problem with this regard. With respect to managing a business in crisis scenarios, one respondent (I06) explicitly pointed out that the system has to react quickly in very hectic situations and must be fully functional precisely then. To our understanding, especially the property of offline capability allows continuing business operations in such scenarios, in contrast to cloud-based tools.

7.4. Privacy aspects are scrutinised by some participants

When asked about the perceived loss of control over data when using the software, opinions differed. This result is in line with the analysis of the privacy perception of the sector (Linsner et al. 2021). The investigated farmers tend to be privacy-aware stakeholders, who want to be very cautious with their own data, but are constrained by external circumstances. On the one hand, there were statements that the software was already *'confidence-inspiring'* (I02) and that there were no fears that the software would send any data on unknowingly (I07); on the other hand, there were also farmers who wanted to be convinced and approached the software with skepticism due to bad experiences (I03). Likewise, the desire to be informed about all data leaving the system was expressed (I04, I05, I11), e.g. they would prefer one additional confirmation button before sending a form to the contractor. In this context, the complexity of terms and conditions and privacy statements was also mentioned negatively, and the desire was expressed to present these in a language that is easy to understand (I04).

8. Discussion

In order to address our research question (Section 1) and the issues identified in our literature review (Section 2) and the elucidated requirements from practitioners (Section 3), we designed the FarmBox tool for resilient, decentralised data management in agriculture (Section 5). Then, we conducted a user-centred evaluation of FarmBox using scenario-based walk-throughs, semi-structured interviews and a usability questionnaire (Section 6). In the following subsections, we present our main findings and contextualise these into the existing body of knowledge. Also, we sum up our empirical and artifact contributions and discuss theoretical implications for the design of agricultural software and future research.

8.1. Findings

Our findings indicate that **crisis capability is considered an essential feature** for business continuity but is not available to currently used technologies. We found that the practitioners we interviewed in the empirical studies already had a sense for business contingency in crisis scenarios (*R6 Offline capability for infrastructure disruptions*). This whole topic of crisis-capability is not covered by recent related work that also analysed requirements for farming software by empirical methods, like (Michels and Mußhoff 2020). Especially in such difficult situations like extreme weather events that harm the environment, a farmer would not like to face the additional challenge of non-functional systems. Although this claim applies to several sectors, it has a particular flavor in agriculture because of the small farms and the large amount of time required for the necessary field activities. The time-consuming aspect prevents a high degree of self-organising prevention mechanisms. Therefore, the used equipment must be designed with the crisis capability in mind. Other business domains usually have dedicated staff responsible for managing corporate IT and can take the necessary actions for the situation at hand. Also, in most domains, the job can often be delayed for some hours or days, and there are *only* additional employee costs or production losses with its corresponding consequences. The result of the work is delayed – but could be finished. In agriculture, field operations usually have to be carried out in narrow time slots; otherwise, sudden changes in weather can result in poor harvests or even the destruction of the crop. A technical problem in such a time slot can have dramatic effects on the company if the machinery is striking or not performing well due to missing data for precision agriculture. The identified requirements are also reflected by some statements of our software prototype evaluation (Section 6). For the reason of *crisis-capability*, the goal was to design an architecture that is able to withstand crises without the need for expensive specialised hardware (*R10 Affordability for small and medium enterprises*). As electrical power can be produced locally with *emergency power generators* in crisis situations, the concept of mini-servers could be analogously seen as *emergency data generators*, i.e. as local data storage for the businesses' end-devices (e.g. smartphone, tablet, laptop, IoT equipment). By developing the software with an *offline-first* mindset, we ensure that our system also works in scenarios without a proper internet connection.

Second, the **contrast between strong desire for customisation and time-efficient operation** became apparent. One aspect mentioned in both the requirements engineering and our evaluation is the high need for customisation of the farm management software to fit the demand for different workflows. From the outside, this is an interesting fact, as it seems that despite the different sizes of companies, the daily routines should be similar across the domain. On the other side, we also received statements saying the less time a software takes away from relevant tasks, the better. Farmers typically did not choose their profession because they like to do office work; they probably also do not want to spend more time than necessary with a software. However, since application customisation is very time-consuming and requires a more detailed investigation of a software's capabilities, this seems to be a conflict of interest. Other commercial apps typically presuppose a specific way of doing things that might not fit every company's workflow, according to the statements of some participants. In this way, further research on this area of conflict may be required. Third, our participants highlighted the **importance of support for multiple end-devices**. As already mentioned, it is important to support multiple end-devices with modern software. This allows the software to fit to different user behaviours, and therefore might increase the target group. But most professional (business) software is dedicated for stationary devices or mobile devices and must not adapt to different screen sizes and user conditions. But farmers would like to do some simple management or documentation tasks on the go on a smartphone. Other tasks might profit from more screen space and are easier to do on a regular desktop computer / notebook. So the farmer user-base is a good example of the need for responsive enterprise software design. Finally, we identified different **UI requirements for the specific groups of farmers**. It is a rather trivial fact that a specific target group has its own specific needs and requirements regarding software design, which also holds for the group of farmers. Within our evaluation we got two surprising insights: (1) Although we thought that all farmers are experienced in digital map software, not all symbols and labels common to us are recognised. Therefore, we see the need for simplified icons and rather farming-related graphics to improve the visual understanding of map actions, like drawing a new area. (2) Foreign words should be introduced very carefully, even in cases where it seems to be common knowledge. To further improve the understanding of foreign words, they should be combined with illustrations like pictograms. Similarly, the demand for terms and conditions, as well as privacy statements, that are phrased easy to understand was underscored. In fact, we did not find any analysis on service agreements in lay language; this could be an interesting open topic for future research.

8.2. Contributions

First, this work provides the empirical contribution of **design requirements for the architecture and**

interface of a resilient farm management information system. Empirical contributions provide 'new knowledge through findings based on observation and data-gathering' using sources, including interviews, surveys, focus groups, and many others (Wobbrock and Kientz 2016). In Section 3, we summarised the findings of two rounds of focus groups to distill design requirements for the FarmBox tool-set. In terms of the interface, participants required a cross-domain usage and tailorability (R1), a low complexity of operation (R2), and location-independent technology support (R3). Furthermore, they asked for specific features, such as the monitoring of fields task progress (R4) and a navigation system for wage workers (R5). With regard to the system architecture, offline capability (R6) and data safety (R9) were mentioned requirements for a resilient system, while an extendable and modular design (R7) as well as multiple open data formats (R11) were required to ensure connectivity. Moreover, from a business perspective, participants desired an affordable solution (R10) that respects the confidentiality and privacy of data (R8).

There is little literature covering requirements analysis for management software for agriculture, like the one of Sørensen et al. (2010). Other works that adopt a user-centred perspective mainly cover domain-specific topics like the analysis of farmers' perspectives on smartphone usage for developing a geotag smartphone app (Kenny and Regan 2021). Some of our detected requirements are consistent with existing analyses, i.e. a low complexity of operation ('information overload'), location-independent technology support ('on-line data acquisition in the field'), and monitoring of fields task progress ('monitor field operations'). But as previous works did not extensively elaborate on implementable requirements, our detected requirements are more extensive, and most of our detected requirements (e.g. offline-capability) are not covered by the existing body of literature. Other works do not analyse the needs from a user-centred perspective, but rather focus on existing solutions by inspecting the current usage of FMIS (Munz, Gindele, and Doluschitz 2020), detecting factors that influence the usage and adoption of smartphone apps for dairy heard management or crop production (Michels, Bonke, and Musshoff 2019, 2020) or analysing functions of existing FMIS (Fountas et al. 2015).

Second, an artifact contribution is achieved by the design and evaluation of **toolbox for resilient data management**. Artifact contributions arise from generative design-driven and invention-driven activities, resulting in 'new systems, architectures, tools [and] toolkits' which then are 'evaluated in a holistic fashion according to what they make possible and how they do so' (Wobbrock and Kientz 2016). In Section 5, we created the ready-to-use system FarmBox for potential users, mainly targeting farmers of crop or fruit production, but also usable for the livestock sector. First, we have shown our basic concept of the complete system that allows for cloud-like synchronisation without the need for an internet connection to solve everyday tasks. And in accordance with this concept, we implemented a prototype with the most important features.

In Section 6, we present the results of the evaluation of FarmBox. The concept of the system with the decentralised approach as one core aspect was appreciated and could therefore be an aspect to increase the adoption rate of agricultural software. The general usability of the client application's user interface was not seen influenced at all by the decentralised system's design. In line with some of the related literature (Linsner et al. 2021; Klerkx, Jakku, and Labarthe 2019), we received statements about the importance of privacy, especially for software that manage all relevant business data. However, users rely on trusting software developers to not spy on the generated data, with some statements conveying a general mistrust in software. But the feature to work without an internet-link could be a confidence building measure.

Finally, we provide theoretical implications by a **novel concept for decentralised and resilient data management**. Theoretical research contributions consist of 'new or improved concepts, definitions, models, principles, or frameworks' (Wobbrock and Kientz 2016). Our paper contributes to the area of digitalisation and resilience, applied to the domains of agriculture and, in particular, to farm management software, with implications also for other SME domains, especially where important operations are managed with the help of software. In both the requirements engineering as well as the evaluation, we received statements that highlight the importance of systems' stability, even – or particularly – in crisis scenarios. It can be crucial in such situations to have the important applications running to do everyday tasks without a working internet connection, even when interacting with other people or hardware systems. An effective way to ensure the offline-capability is to design the whole software architecture so that the offline capability is not a specific function but an intrinsic architecture design, as is the case with decentralised systems. A rather uncommon element of our concept is the local mini-server to overcome the need for internet connectivity for easy-to-use data synchronisation of multiple end-devices.

Furthermore, we have shown some details of the design of the front-end application for end-devices like smartphones, tablets, and desktop computers. The graphical design concept and colour scheme were adjusted in an iterative manner. Especially the cloudless (Grosmann and Ioannidis 2020) approach is new to the domain of agricultural applications, and in general, rarely considered as an alternative design for modern inter-connected systems concept. The similar (from a technical perspective) *fog* pattern itself is not a novel concept of this present paper, but mostly seen as an addition to cloud services for reducing network traffic, to ease pressure on the core server, and to improve network latency and speed. However, we have not seen works that use this approach for a resilient service distribution for business operations. Related approaches are community projects like yunohost[2] that share the privacy aspects, but are motivated more from an autonomy perspective, rather than the need for resilient services. But especially the hardening of new solutions against outage scenarios is important. Long-lasting network unavailability could also be the result of weather catastrophes, e.g. the 2021 European floods. Even if the power grid is rebuilt quickly, a couple of weeks could pass until basic internet connectivity is restored.

9. Conclusion

The digitalisation process for agriculture is still ongoing, promising more precise and less labour-intensive farming production. One aspect that comes with this digitalisation process is the need for farm management software to control, plan, and document farming activities. One of our contributions to this process is a recent requirements analysis (Section 3) in which 57 experts in the agricultural domain were interviewed using the focus group method. In contrast to related works, we grouped the requirements into front-end and back-end requirements. Based on the identified requirements, we created a concept for a complete farm management software system, which forms the second contribution. To our knowledge, this concept is the first technical description of a *crisis-capable* software design for farmers, which ensures that it works as well as possible in outage scenarios, e.g. without relying on a working internet connection. The third contribution is the evaluation (Section 6) of the implemented front-end application with 16 domain experts.

On the limitation side, we have only tested a subset of the functionalities of the front-end software in an artificial test environment. Overall, most participants emphasised the meaningfulness to reduce the dependency of software/hardware on a working internet connection. In this way, we provide an example of a business software with the ability to exchange data that is not developed based on the cloud pattern and thus does not require a reliable internet connection to interact with data. Our approach introduces a mini-server at the company level for caching and synchronisation purposes, as well as many ex- and import functions within the client-application to manually manage data in unforeseen situations.

Use-cases for decentralised systems seem to be underrepresented in the current scientific landscape. As decentralising could increase the resilience in outage scenarios, there should be more engagement into developing and evaluating such concepts with regard to the users perspective, especially for critical businesses like food production. Furthermore, research on how to increase the adoption rate of precise farming tools is necessary, e.g. how to support the trust relating to the privacy behaviour of a software.

Notes

1. https://leafletjs.com
2. https://yunohost.org - self-hosting of (web-)services
3. https://experience.sap.com/skillup/system-usability-scale-jetzt-auch-auf-deutsch/

Acknowledgments

We would also like to thank our project partners as well as Elmar von Radziewski and Roxanne Keller for their valuable support during the first pre-study. Furthermore, parts of the second pre-study have already been published in two different papers, but were analysed with a different scope focusing privacy (Linsner et al. 2021) and resilience (Kuntke et al. 2022).

Disclosure statement

The authors report no conflict of interest.

Funding

This work was supported by funds of the German Government's Special Purpose Fund held at Landwirtschaftliche Rentenbank in the projects Geobox-II and AgriRegio, and by the German Federal Ministry for Education and Research (BMBF) in the project HyServ [01IS17030B].

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References

Aceto, Giuseppe, Alessio Botta, Pietro Marchetta, Valerio Persico, and Antonio Pescapé. 2018. "A Comprehensive Survey on Internet Outages." *Journal of Network and Computer Applications* 113 (March 2019): 36–63. doi:10.1016/j.jnca.2018.03.026.

Ammann, Jeanine, Achim Walter, and Nadja El Benni. 2022. "Adoption and Perception of Farm Management Information Systems by Future Swiss Farm Managers – An Online Study." *Journal of Rural Studies* 89: 298–305. doi:10.1016/j.jrurstud.2021.12.008.

Annosi, Maria Carmela, Federica Brunetta, Alberto Monti, and Francesco Nati. 2019. "Is the Trend Your Friend? An Analysis of Technology 4.0 Investment Decisions in Agricultural SMEs." *Computers in Industry* 109: 59–71. doi:10.1016/j.compind.2019.04.003.

Atik, Can. 2022. "Towards Comprehensive European Agricultural Data Governance: Moving Beyond the "Data Ownership" Debate." *IIC-International Review of Intellectual Property and Competition Law* 53: 701–742. doi:10.1007/s40319-022-01191-w.

Bangor, Aaron, Technical Staff, Philip Kortum, James Miller, and Technical Staff. 2009. "Determining What Individual SUS Scores Mean: Adding An Adjective Rating Scale." *Journal of Usability Studies* 4 (3): 114–123.

Bernardi, Ansgar, Christian Reuter, Wolfgang Schneider, Sebastian Linsner, and Marc-André Kaufhold. 2019. "Hybride Dienstleistungen in digitalisierten Kooperationen in der Landwirtschaft." In *39. GIL-Jahrestagung: Informatik in der Land-, Forst- und Ernährungswirtschaft Fokus; Digitalisierung für landwirtschaftliche Betriebe in kleinstrukturierten Regionen – ein Widerspruch in sich?, Lecture Notes in Informatics (LNI)*, edited by A. Meyer-Aurich, 25–30. Vienna, Austria: Gesellschaft für Informatik. http://gil-net.de/Publikationen/139_25-30.pdf.

Birner, Regina, Thomas Daum, and Carl Pray. 2021. "Who Drives the Digital Revolution in Agriculture? A Review of Supply-Side Trends, Players and Challenges." *Applied Economic Perspectives and Policy* 43 (4): 1260–1285. doi:10.1002/aepp.v43.4.

Bökle, Sebastian, Dimitrios S. Paraforos, David Reiser, and Hans W. Griepentrog. 2022. "Conceptual Framework of a Decentral Digital Farming System for Resilient and Safe Data Management." *Smart Agricultural Technology* 2: Article ID 100039. doi:10.1016/j.atech.2022.100039.

Bonke, Vanessa, Wilm Fecke, Marius Michels, and Oliver Musshoff. 2018. "Willingness to Pay for Smartphone Apps Facilitating Sustainable Crop Protection." *Agronomy for Sustainable Development* 38 (5): 1–10. doi:10.1007/s13593-018-0532-4.

Brooke, John. 1996. "SUS – A Quick and Dirty Usability Scale." *Usability Evaluation in Industry* 189: 4.7.

Bucci, Giorgia, Deborah Bentivoglio, and Adele Finco. 2018. "Precision Agriculture As a Driver for Sustainable Farming Systems: State of Art in Litterature and Research." *Quality – Access to Success* 19 (S1): 114–121.

Buhleier, Laura, Patrick Gantner, Tobias Frey, Michael Boers, Marc-André Kaufhold, and Christian Reuter. 2022. "Effizienz und Nachhaltigkeit durch Green-IT: ein systematischer Literaturüberblick im Kontext der Klimakrise." In *INFORMATIK 2022: 52. Jahrestagung der Gesellschaft für Informatik*, GI-Edition-Lecture Notes in Informatics (LNI), Hamburg, Germany.

Bundesministerium für Ernährung und Landwirtschaft. 2020. Arbeitsmarkt Landwirtschaft in Deutschland. 136. Accessed July 31 2022.

Cajander, Åsa, Marta K. Lárusdóttir, Thomas Lind, and Gerolf Nauwerck. 2021. "Walking in the Jungle with a Machete: ICT Leaders' Perspectives on User-Centred Systems Design." *Behaviour and Information Technology* 41: 1230–1244. doi:10.1080/0144929X.2020.1864776.

Carli, Giacomo, Vilma Xhakollari, and Maria Rita Tagliaventi. 2017. "How to Model the Adoption and Perception of Precision Agriculture Technologies." In *Precision Agriculture: Technology and Economic Perspectives*, edited by Søren Marcus Pederson and Kim Martin Lind, 223–249. Frederiksberg C, Denmark: Springer. doi:10.1007/978-3-319-68715-5.

Cascio, M. Ariel, Eunlye Lee, Nicole Vaudrin, and Darcy A. Freedman. 2019. "A Team-based Approach to Open Coding: Considerations for Creating Intercoder Consensus." *Field Methods* 31 (2): 116–130. doi:10.1177/1525822X19838237.

Chandra, Ranveer, and Stewart Collis. 2021. "Digital Agriculture for Small-Scale Producers: Challenges and Opportunities." *Communications of the ACM* 64 (12): 75–84. doi:10.1145/3454008.

Chen, Xu, Lei Jiao, Wenzhong Li, and Xiaoming Fu. 2016. "Efficient Multi-User Computation Offloading for Mobile-Edge Cloud Computing." *IEEE/ACM Transactions on Networking* 24 (5): 2795–2808. doi:10.1109/TNET.2015.2487344.

Davcev, Danco, Kosta Mitreski, Stefan Trajkovic, Viktor Nikolovski, and Nikola Koteli. 2018. "IoT Agriculture System Based on LoRaWAN." *IEEE International Workshop on Factory Communication Systems – Proceedings, WFCS* 2018-June: 1–4. doi:10.1109/WFCS.2018.8402368.

Eberz-Eder, Daniel, Franz Kuntke, Wolfgang Schneider, and Christian Reuter. 2021. "Technologische Umsetzung des Resilient Smart Farming (RSF) durch den Einsatz von Edge-Computing." In *41. GIL-Jahrestagung: Informatik in der Land-, Forst- und Ernährungswirtschaft*, edited by Andreas Meyer-Aurich, Markus Gandorfer, Christa Hoffmann, Cornelia Weltzien, Sonoko Bellingrath-Kimura, and Helga Floto, 79–84. Bonn, Germany: Gesellschaft für Informatik. https://dl.gi.de/handle/20.500.12116/35651.

Elijah, Olakunle, Tharek Abdul Rahman, Igbafe Orikumhi, Chee Yen Leow, and Mhd Nour Hindia. 2018. "An Overview of Internet of Things (IoT) and Data Analytics in Agriculture: Benefits and Challenges." *IEEE Internet of Things Journal* 5 (5): 3758–3773. doi:10.1109/JIoT.6488907.

European Commission. 2015. *User Guide to the SME Definition*. Luxembourg: Publications Office of the European Union.

Finger, Robert, Scott M. Swinton, Nadja El Benni, and Achim Walter. 2019. "Precision Farming At the Nexus of Agricultural Production and the Environment." *Annual Review of Resource Economics* 11: 313–335. doi:10.1146/resource.2019.11.issue-1.

Fleisch, Elgar, and Frédéric Thiesse. 2007. "On the Management Implications of Ubiquitous Computing: An IS Perspective." In *ECIS 2007 Proceedings*, 71. AIS.

Fountas, Spyros, Giacomo Carli, Claus Grøn Sørensen, Zisis Tsiropoulos, Chris Cavalaris, Anna Vatsanidou, Vasileios

Liakos, et al. 2015. “Farm Management Information Systems: Current Situation and Future Perspectives.” *Computers and Electronics in Agriculture* 115: 40–50. doi:10.1016/j.compag.2015.05.011.

Gandorfer, Markus, Sebastian Schleicher, Sebastian Heuser, Johanna Pfeiffer, and Markus Demmel. 2017. “Landwirtschaft 4.0 – Digitalisierung und ihre Herausforderungen.” In *Ackerbau-technische Lösungen für die Zukunft*, edited by Georg Wendl, 9–19.

Gautam, Rahul Singh, Venkata Mrudula Bhimavarapu, and Shailesh Rastogi. 2021. “Impact of Digitalization on the Farmers in India: Evidence Using Panel Data Analysis.” *International Journal of Management and Humanities* 6 (1): 5–12. doi:10.35940/ijmh.

Groher, Tanja, Katja Heitkämper, Achim Walter, Frank Liebisch, and Christina Umstätter. 2020. “Status Quo of Adoption of Precision Agriculture Enabling Technologies in Swiss Plant Production.” *Precision Agriculture* 21 (6): 1327–1350. doi:10.1007/s11119-020-09723-5.

Grosmann, Marcel, and Christos Ioannidis. 2020. “Cloudless Computing – A Vision to Become Reality.” In *2020 International Conference on Information Networking (ICOIN)*, 372–377. IEEE: Barcelona, Spain.

Gu, Yu, and Tiaobin Jing. 2011. “The IOT Research in Supply Chain Management of Fresh Agricultural Products.” In *2011 2nd International Conference on Artificial Intelligence, Management Science and Electronic Commerce (AIMSEC)*, 7382–7385. IEEE.

Jawad, Haider, Rosdiadee Nordin, Sadik Gharghan, Aqeel Jawad, and Mahamod Ismail. 2017. “Energy-Efficient Wireless Sensor Networks for Precision Agriculture: A Review.” *Sensors* 17 (8): article number: 1781. doi:10.3390/s17081781.

Jenner, Bryan, Uwe Flick, Ernst von Kardoff, and Ines Steinke. 2004. *A Companion to Qualitative Research*. London, UK: Sage Publications.

Kalle, Timo, Marc-André Kaufhold, Franz Kuntke, Christian Reuter, Amr Rizk, and Ralf Steinmetz. 2019. “Resilience in Security and Crises through Adaptions and Transitions.” In *INFORMATIK 2019: 50 Jahre Gesellschaft für Informatik – Informatik für Gesellschaft (Workshop-Beiträge), Lecture Notes in Informatics (LNI)*, edited by C. Draude, M. Lange, and B. Sick, 571–584. Kassel, Germany: Gesellschaft für Informatik e. V. https://dl.gi.de/bitstream/handle/20.500.12116/25097/paper12_02.pdf.

Kamath, Reshma. 2018. “Food Traceability on Blockchain: Walmart’s Pork and Mango Pilots with IBM.” *The Journal of the British Blockchain Association* 1 (1): 1–12. doi:10.31585/jbba-1-1.

Karrer, Katja, Charlotte Glaser, Caroline Clemens, and Carmen Bruder. 2009. “Technikaffinität Erfassen – Der Fragebogen TA-EG.” *Der Mensch im Mittelpunkt technischer Systeme* 8: 196–201.

Kaufhold, Marc-André. 2021. *Information Refinement Technologies for Crisis Informatics: User Expectations and Design Principles for Social Media and Mobile Apps*. Wiesbaden, Germany: Springer Vieweg.

Kaufhold, Marc-André, Thea Riebe, Christian Reuter, Julian Hester, Danny Jeske, Lisa Knüver, and Viktoria Richert. 2018. “Business Continuity Management in Micro Enterprises: Perception, Strategies and Use of ICT.” *International Journal of Information Systems for Crisis Response and Management (IJISCRAM)* 10 (1): 1–19. doi:10.4018/IJISCRAM.

Kenny, Ursula, and Aine Regan. 2021. “Co-Designing a Smartphone App for and with Farmers: Empathising with End-Users’ Values and Needs.” *Journal of Rural Studies* 82: 148–160. doi:10.1016/j.jrurstud.2020.12.009.

Klerkx, Laurens, Emma Jakku, and Pierre Labarthe. 2019. “A Review of Social Science on Digital Agriculture, Smart Farming and Agriculture 4.0: New Contributions and a Future Research Agenda.” *NJAS – Wageningen Journal of Life Sciences* 90-91: Article ID 100315. doi:10.1016/j.njas.2019.100315.

Kuntke, Franz, Sebastian Linsner, Enno Steinbrink, Jonas Franken, and Christian Reuter. 2022. “Resilience in Agriculture: Communication and Energy Infrastructure Dependencies of German Farmers.” *International Journal of Disaster Risk Science* 13 (2): 214–229. doi:10.1007/s13753-022-00404-7.

Kuntke, Franz, Christian Reuter, Wolfgang Schneider, Daniel Eberz, and Ansgar Bernardi. 2020. “Die GeoBox-Vision: Resiliente Interaktion und Kooperation in der Landwirtschaft durch dezentrale Systeme.” In *Mensch und Computer 2020 – Workshopband*, edited by C. Hansen, A. Nürnberger, and B. Preim, 1–6. Magdeburg: Gesellschaft für Informatik e.V..

Kuntke, Franz, Marcel Sinn, and Christian Reuter. 2021. “Reliable Data Transmission Using Low Power Wide Area Networks (LPWAN) for Agricultural Applications.” In *The 16th International Conference on Availability, Reliability and Security*, 1–9. Vienna Austria: ACM.

Kurosh, Rezaei-Moghaddam, and Salehi Saeid. 2010. “Agricultural Specialists’ Intention Toward Precision Agriculture Technologies: Integrating Innovation Characteristics to Technology Acceptance Model.” *African Journal of Agricultural Research* 5 (11): 1191–1199.

Lawson, Lartey G., Søren Marcus Pedersen, Claus Grøn Sørensen, Liisa Pesonen, Spyros Fountas, Armin Werner, and Frank W. Oudshoorn, et al. 2011. “A Four Nation Survey of Farm Information Management and Advanced Farming Systems: A Descriptive Analysis of Survey Responses.” *Computers and Electronics in Agriculture* 77 (1): 7–20. doi:10.1016/j.compag.2011.03.002.

Lazar, Jonathan, Jinjuan Heidi Feng, and Harry Hochheiser. 2017. *Research Methods in Human–Computer Interaction*. Cambridge, USA: Morgan Kaufmann.

Li, Wenjing, Beth Clark, James A. Taylor, Helen Kendall, Glyn Jones, Zhenhong Li, and Shan Jin. et al. 2020. “A Hybrid Modelling Approach to Understanding Adoption of Precision Agriculture Technologies in Chinese Cropping Systems.” *Computers and Electronics in Agriculture* 172: Article ID 105305. doi:10.1016/j.compag.2020.105305.

Linsner, Sebastian, Franz Kuntke, Enno Steinbrink, Jonas Franken, and Christian Reuter. 2021. “The Role of Privacy in Digitalization – Analyzing Perspectives of German Farmers.” *Proceedings on Privacy Enhancing Technologies* 2021 (3): 334–350. doi:10.2478/popets-2021-0050.

Lioutas, Evagelos D., Chrysanthi Charatsari, and Marcello De Rosa. 2021. “Digitalization of Agriculture: A Way to Solve the Food Problem Or a Trolley Dilemma?.” *Technology in Society* 67: Article ID 101744. doi:10.1016/j.techsoc.2021.101744.

Liu, Ye, Xiaoyuan Ma, Lei Shu, Gerhard Petrus Hancke, and Adnan M. Abu-Mahfouz. 2020. “From Industry 4.0 to Agriculture 4.0: Current Status, Enabling Technologies, and Research Challenges.” *IEEE Transactions on Industrial Informatics* 3203 (c): 1–1. doi:10.1109/TII.9424.

Michels, Marius, Vanessa Bonke, and Oliver Musshoff. 2019. “Understanding the Adoption of Smartphone Apps in Dairy Herd Management.” *Journal of Dairy Science* 102 (10): 9422–9434. doi:10.3168/jds.2019-16489.

Michels, Marius, Vanessa Bonke, and Oliver Musshoff. 2020. “Understanding the Adoption of Smartphone Apps in Crop Protection.” *Precision Agriculture* 21 (6): 1209–1226. doi:10.1007/s11119-020-09715-5.

Michels, Marius, and Oliver Musshoff. 2020. “An Empirical Study of Smartphone Use Intensity in German Agriculture.” *German Journal of Agricultural Economics* 69 (2): 127–142. doi:10.30430/69.2020.2.127-142.

Michels, Marius, and Oliver Musshoff. 2021. “The Timing of Smartphone Adoption in German Agriculture.” In *Precision agriculture’21*, edited by John V. Stafford, 427–446. Budapest, Hungary: Wageningen Academic Publishers.

Michels, Marius, and Oliver Mußhoff. 2020. “An Empirical Study of Smartphone Use Intensity in German Agriculture.” *German Journal of Agricultural Economics* 69 (2): 127–142. doi:10.30430/69.2020.2.127-142.

Michels, Marius, Cord-Friedrich von Hobe, and Oliver Musshoff. 2020. “A Trans-Theoretical Model for the Adoption of Drones by Large-Scale German Farmers.” *Journal of Rural Studies* 75: 80–88. doi:10.1016/j.jrurstud.2020.01.005.

Michels, Marius, Cord-Friedrich von Hobe, Paul Johann Weller von Ahlefeld, and Oliver Musshoff. 2021. “The Adoption of Drones in German Agriculture: A Structural Equation Model.” *Precision Agriculture* 22 (6): 1728–1748. doi:10.1007/s11119-021-09809-8.

Mitchell, Sean, Alfons Weersink, and Bruce Erickson. 2018. “Adoption of Precision Agriculture Technologies in Ontario Crop Production.” *Canadian Journal of Plant Science* 98 (6): 1384–1388. doi:10.1139/cjps-2017-0342.

Mohr, Svenja, and Rainer Kühl. 2021. “Acceptance of Artificial Intelligence in German Agriculture: An Application of the Technology Acceptance Model and the Theory of Planned Behavior.” *Precision Agriculture* 22 (6): 1816–1844. doi:10.1007/s11119-021-09814-x.

Mondal, Pinaki, and V. K. Tewari. 2007. “Present Status of Precision Farming: A Review.” *International Journal of Agricultural Research* 2 (1): 1–10. doi:10.3923/ijar.2007.1.10.

Morgan, David. 1997. *Focus Groups as Qualitative Research*. Vol. 16. 2455 Teller Road, Thousand Oaks California 91320 United States of America: SAGE Publications, Inc.

Munz, Jana, Nicola Gindele, and Reiner Doluschitz. 2020. “Exploring the Characteristics and Utilisation of Farm Management Information Systems (FMIS) in Germany.” *Computers and Electronics in Agriculture* 170: Article ID 105246. doi:10.1016/j.compag.2020.105246.

Nikander, Jussi, Markku Koistinen, Mikko Laajalahti, Liisa Pesonen, Ari Ronkainen, and Pasi Suomi. 2015. “Farm Information Management Infrastructures in the Future.” In *2015 26th International Workshop on Database and Expert Systems Applications (DEXA)*, 104–107. IEEE.

Nikkilä, Raimo, Ilkka Seilonen, and Kari Koskinen. 2010. “Software Architecture for Farm Management Information Systems in Precision Agriculture.” *Computers and Electronics in Agriculture* 70 (2): 328–336. doi:10.1016/j.compag.2009.08.013.Special issue on Information and Communication Technologies in Bio and Earth Sciences.

OECD. 2019. “Digital Innovations and the Growing Importance of Agricultural Data.” In *Digital Opportunities for Better Agricultural Policies*, 20–36. Paris, France: OECD. doi:10.1787/367ac383-en.

Ojha, Tamoghna, Sudip Misra, and Narendra Singh. 2015. “Wireless Sensor Networks for Agriculture: The State-of-the-Art in Practice and Future Challenges.” *Computers and Electronics in Agriculture* 118: 66–84. doi:10.1016/j.compag.2015.08.011.

Parker, Caroline, and Murray Sinclair. 2001. “User-Centred Design Does Make a Difference. The Case of Decision Support Systems in Crop Production.” *Behaviour and Information Technology* 20 (6): 449–460. doi:10.1080/01449290110089570.

Paulus, Michael, Sara Anna Pfaff, Andrea Knierim, and Heinrich Schüle. 2022. “Landwirtschaftliche Digitalisierung im Vergleich von Haupt- und Nebenerwerb.” In *42. GIL-Jahrestagung, Künstliche Intelligenz in der Agrar- und Ernährungswirtschaft*, 213–218. Bonn: Gesellschaft für Informatik e.V. https://dl.gi.de/handle/20.500.12116/38399.

Pelletier, Nathan, Eric Audsley, Sonja Brodt, Tara Garnett, Patrik Henriksson, Alissa Kendall, Klaas Jan Kramer, et al. 2011. “Energy Intensity of Agriculture and Food Systems.” *Annual Review of Environment and Resources* 36 (1): 223–246. doi:10.1146/energy.2011.36.issue-1.

Pfaff, Sara Anna, Michael Paulus, Andrea Knierim, and Heinrich Schüle. 2022. “Welche spezifischen Anforderungen impliziert die klein- strukturierte Landwirtschaft für die Digitalisierung?” In *42. GIL-Jahrestagung, Künstliche Intelligenz in der Agrar- und Ernährungswirtschaft*, 219–224. Bonn: Gesellschaft für Informatik e.V. https://dspace.gi.de/handle/20.500.12116/38400.

Pipek, Volkmar, and Volker Wulf. 2009. “Infrastructuring: Toward An Integrated Perspective on the Design and Use of Information Technology.” *Journal of the Association for Information Systems* 10 (5): 447–473. doi:10.17705/1jais.

Porter, Michael E., and James E. Heppelmann. 2014. “How Smart, Connected Products are Transforming Competition.” *Harvard Business Review* 92 (11): 64–88.

Reuter, Christian. 2015. “Towards Efficient Security: Business Continuity Management in Small and Medium Enterprises.” *International Journal of Information Systems for Crisis Response and Management* 7 (3): 69–79. doi:10.4018/IJISCRAM.

Reuter, Christian, Thomas Ludwig, Marc-André Kaufhold, and Julian Hupertz. 2017. “Social Media Resilience During Infrastructure Breakdowns Using Mobile Ad-Hoc Networks.” In *Advances and New Trends in Environmental Informatics – Proceedings of the 30th EnviroInfo Conference*, edited by V. Wohlgemuth, Frank Fuchs-Kittowski, and Jochen Wittmann, 75–88. Berlin, Germany: Springer.

Rizzato, Francesco. 2019. Parts of Rural Germany See Less Than 50 Availability. https://www.opensignal.com/

2019/07/17/parts-of-rural-germany-see-less-than-50-4g-availability.
Rübcke von Veltheim, Friedrich, and Heinke Heise. 2021. "German Farmers' Attitudes on Adopting Autonomous Field Robots: An Empirical Survey." *Agriculture* 11 (3): Article ID 216. doi:10.3390/agriculture11030216.
Schukat, Sirkka, and Heinke Heise. 2021. "Smart Products in Livestock Farming–An Empirical Study on the Attitudes of German Farmers." *Animals* 11 (4): Article ID 1055. doi:10.3390/ani11041055.
Schukat, Sirkka, and Heinke Heise. 2021. "Towards An Understanding of the Behavioral Intentions and Actual Use of Smart Products Among German Farmers." *Sustainability* 13 (12): Article ID 6666. doi:10.3390/su13126666.
Schulze Schwering, Dorothee, and Dominic Lemken. 2020. "Totally Digital? Adoption of Digital Farm Management Information Systems." In *40. GIL-Jahrestagung, Digitalisierung für Mensch, Umwelt und Tier*, edited by Markus Gandorfer, Andreas Meyer-Aurich, Heinz Bernhardt, Franz Xaver Maidl, Georg Fröhlich, and Helga Floto, 295–300. Bonn: Gesellschaft für Informatik e.V..
Shin, Youngsoo, Chaerin Im, Hyosun Oh, and Jinwoo Kim. 2017. "Design for Experience Innovation: Understanding User Experience in New Product Development." *Behaviour and Information Technology* 36 (12): 1218–1234. doi:10.1080/0144929X.2017.1368709.
Slijper, Thomas, Yann de Mey, P. Marijn Poortvliet, and Miranda P. M. Meuwissen. 2022. "Quantifying the Resilience of European Farms Using FADN." *European Review of Agricultural Economics* 49 (1): 121–150. doi:10.1093/erae/jbab042.
Statistisches Bundesamt (Destatis). 2021. 2020 Census of Agriculture Shows Continuing Decline in Workforce. Accessed August 18 2022. https://www.destatis.de/EN/Press/2021/09/PE21_N053_13.html.
Statistisches Bundesamt (Destatis). 2021. Agricultural Holdings and Utilised Agricultural Area by Size of the Utilised Agricultural Area. Accessed: July 18 2021. https://www.destatis.de/EN/Themes/Economic-Sectors-Enterprises/Agriculture-Forestry-Fisheries/Agricultural-Holdings/Tables/agricultural-holdings-and-utilised-agricultural-areaby-size-of-the-utilised-agricultural-area.html.
Strauss, Anselm L., and J. Corbin. 1998. *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*. Thousand Oaks, USA: Sage Publications.
Sørensen, Claus Grøn, Spyros Fountas, Edward Nash, Liisa Pesonen, Dionysis D. Bochtis, Søren Marcus Pedersen, Bruno B. Basso, and Simon Blackmore. 2010. "Conceptual Model of a Future Farm Management Information System." *Computers and Electronics in Agriculture* 72 (1): 37–47. doi:10.1016/j.compag.2010.02.003.
Tey, Yeong Sheng, and Mark Brindal. 2022. "A Meta-Analysis of Factors Driving the Adoption of Precision Agriculture." *Precision Agriculture* 23 (2): 353–372. doi:10.1007/s11119-021-09840-9.
Thiel, Christian, and Christoph Thiel. 2010. "Business Continuity Management Für KMU." *Datenschutz und Datensicherheit - DuD* 34 (6): 404–407. doi:10.1007/s11623-010-0114-3.
Twidale, Michael, David Randall, and Richard Bentley. 1994. "Situated Evaluation for Cooperative Systems." In *Proceedings of the Conference on Computer Supported Cooperative Work (CSCW)*, Lancester, 441–452.
Wachenheim, Cheryl, Linfeng Fan, and Shi Zheng. 2021. "Adoption of Unmanned Aerial Vehicles for Pesticide Application: Role of Social Network, Resource Endowment, and Perceptions." *Technology in Society* 64: Article ID 101470. doi:10.1016/j.techsoc.2020.101470.
Wallach, Dieter, and Sebastian C. Scholz. 2012. "User-Centered Design: Why and How to Put Users First in Software Development." In *Software for People*, edited by Alexander Maedche, Achim Botzenhardt, and Ludwig Neer, 11–38. Berlin, Heidelberg: Springer Berlin Heidelberg. doi:10.1007/978-3-642-31371-4_2. Series Title: Management for Professionals.
Wedawatta, Gayan, Bingunath Ingirige, and Keith Jones. 2010. "Coping Strategies Against Extreme Weather Events: A Survey of SMEs in the UK." In *Construction and Building Research Conference (COBRA)*, RICS.
Wobbrock, Jacob O., and Julie A. Kientz. 2016. "Research Contribution in Human–Computer Interaction." *Interactions* 23 (3): 38–44. doi:10.1145/2907069.
Wolfert, Sjaak, Lan Ge, Cor Verdouw, and Marc-Jeroen Bogaardt. 2017. "Big Data in Smart Farming – A Review." *Agricultural Systems* 153: 69–80. doi:10.1016/j.agsy.2017.01.023.
Zheng, Shi, Zhigang Wang, and Cheryl Joy Wachenheim. 2019. "Technology Adoption Among Farmers in Jilin Province, China: The Case of Aerial Pesticide Application." *China Agricultural Economic Review* 11 (1): 206–216. doi:10.1108/CAER-11-2017-0216.
Zscheischler, Jana, Reiner Brunsch, Sebastian Rogga, and Roland W. Scholz. 2022. "Perceived Risks and Vulnerabilities of Employing Digitalization and Digital Data in Agriculture – Socially Robust Orientations From a Transdisciplinary Process." *Journal of Cleaner Production* 358: Article ID 132034. doi:10.1016/j.jclepro.2022.132034.

Appendix

A.1. Evaluation schedule summary

(1) Introduction
   (a) Consent about processing of recorded data
   (b) Questionnaire: demographics and job (4–9 questions) + technical affinity (Karrer et al. 2009) (19 questions)
(2) Main part: Tasks with software based on a given scenario (Remote Usability Test)
   (a) Import (available) backup files (from hypothetical other application)
   (b) Update field details on map (changes since imported backup was created)
   (c) Place an order for a soil sample examination
   (d) Record a conducted fertilisation
(3) Concluding part
   (a) Questionnaire: SUS (Brooke 1996) (10 questions)
   (b) Conclusion (interview with 2 lead questions)

A.2. Evaluation guideline

A.2.1. Introduction/explanation

Aim of the evaluation. Evaluation of the current state of development with regard to user interfaces and planned functionalities.

Aim of the project. Decentralised data storage and regional networking for agricultural businesses. This includes storing the data in open formats and possible compatibility with other products that may rely on the data. This is why the system is also called a data hub.

Important information. We will treat all data confidentially, but we ask you to provide us only with information that is not secret or internal to the company. If you are unsure about certain points, please let us know.

Procedure. You will first get an online questionnaire with 8 questions about yourself, such as your age range and experience with computers. Then the recording of the system will be started. At this point, I will again specifically point this out and then ask for your permission. From then on, the recording will record images and sound and store them on servers of the German research network. Only we will have access to the file. Afterward, you will be given a scenario and tasks to be solved with the current state of development of the system. We ask you to express your thoughts and impressions directly so that we can also assess where there is potential for improvement, what may already be good, and where improvements are absolutely necessary. After each task, we would like you to answer a few questions, which we will ask you. At the end, there is another questionnaire with 7 questions, which refers to the usability of the system. We expect this to take about 30 to 60 minutes, including the introduction, which we are already in. You are welcome to ask questions about the process now, otherwise, I'd like to get right to it.

Consent to record audio/video?.

- Secure storage of data internally at the university
- Use of data only anonymised and for research purposes

A.2.2. Statistical classification of participants (questionnaire).

(1) What age range are you in?
(2) In which federal state do you work? (if more than one, please choose the one with the largest percentage)?
(3) Do you work on a farm? (No: jump to the last question)
(4) In which employment relationship do you work on the farm?
(5) Which agricultural sectors does your farm serve?
(6) Is your farm operated on a full-time or part-time basis? (Main occupation: end)
(7) In which (non-agricultural) sector do you operate?
(8) How confident do you feel in using computer technology?k?

A.2.3. Scenario-based tests (remote-usability-test)

Role. You manage a family business with one permanent employee and cultivate cereals, primarily wheat, on a farm area of approximately 60 hectares. As the role of the farm manager, you typically also handle the planning and ordering. Likewise, only you have full access to the operational data.

Description of the scenario. It is winter, and it is time to start planning for the coming business year. An important fiber optic cable was destroyed during construction work, and as a result, the distribution nodes experienced a technical defect, leaving the large area in which you operate without a functioning internet connection. According to the companies responsible, it will take up to several days to repair the damage.

Task part 1 – familiarise. You now want to load the farm data that you exported earlier into the new application since it has promised to be able to act offline as well. To do this, start the application and first familiarise yourself a bit with the interface by drawing in a newly leased field.

Script

(1) Download operating data
(2) Initial start of the app via the browser
(3) Follow dialog to load data
(4) Open partial app map editor
(5) Draw in new field

Concluding questions for task part 1.

(1) How do you feel about the interface after the first steps?
(2) What suggestions do you have for improving the user interface?
(3) How important would it be for you to be able to import data from other programs that previously stored your operational data? And, from your point of view, which programs should be paid special attention to?
(4) Does the user interface give the impression of being expandable?

Task part 2 – submitting a soil sample order (usability-test). By now, you know that you have to place an order for a soil sample test to an appropriate laboratory. You have chosen the laboratory 'PEASEC-Lab'located in your neighborhood. Fortunately, the soil sampling laboratory offers compatible forms for download. Unfortunately, the internet access is still not working at your company. Therefore, you now use the possibility to download the form file at a friend's in the neighboring town and then import it back to your company computer via USB stick. Therefore, download the form from the website as a file and import it into the application. Fill in the form and save the completed form as a file. If the file has been saved, the task has been completed. In this case, we assume that the file can be sent via USB stick either directly to the soil sampling laboratory, or it can be sent via a neighboring place again via e-mail or web form.

Script:

(1) Find and download form via website

(2) Open geo-forms sub-app
(3) Import form in the third tab
(4) Open and fill in form in first form
(5) Save form
(6) Export completed form

Concluding questions for task part 2.

(1) Could the scenario occur like this, in your opinion?
(2) Do you have any ideas on how to improve import and export?
(3) How important is it to you to always be able to go back to the file level, i.e. to be able to export (and also import) smaller data sets (e.g. a single form) from a program as a file?
(4) Do you feel that you have control over the data in the user interface, i.e. that they are not sent on without permission? How could this feeling be strengthened/supported in case of doubt?

Task part 3 – documentation. After the soil sample has been taken, fertiliser has been applied successfully in the meantime. The applied amounts of fertiliser are now to be documented again by hand since the automatic transmission did not work. On the field with the name 'field for winter wheat', the fertiliser Alzon 46 was applied with 2.7 dt/h and a total of 125 kg N/ha. Please record the fertiliser quantities accordingly in the 'Buchungsjournal' sub-app.

Script:

(1) Sub-app Buchungsjournal
(2) Open input mask for field measure 'apply mineral fertiliser'
(3) Enter values, given: 'Field for winter wheat', 'Alzon 46', '2.7 dt/h', '125 kg N/ha'.

Concluding questions for task part 3.

(1) Would you have expected the input masks elsewhere, and if so: where?
(2) How intuitive do you find the documentation option?
(3) Which actions should be available by default (offline)?

A.2.4. Standardised usability evaluation (questionnaire)

System usability scale (SUS). Use of SUS (Brooke 1996) in German translation,[3] whereby each question is answered on a scale from 1 (do not agree at all) to 5 (completely agree)

(1) I think I would like to use the system frequently.
(2) I found the system unnecessarily complex.
(3) I found the system easy to use.
(4) I think I would need the help of a technophile person to use the system. System benutzen zu können.
(5) I thought the various functions in the system were well integrated.
(6) I think the system contained too many inconsistencies.
(7) I imagine that most people could learn to use this system very quickly.
(8) I found the system very cumbersome to use.
(9) I felt very confident using the system.
(10) I had to learn a lot before I could start using the system.

A.2.5. Closing questions (interview).

(1) According to your estimation, how long would it take you to be able to use the interface confidently?
(2) What potentials and problems or challenges do you see in using this application for basic data management?
(3) How important is the issue of offline capability to you? Or: How acute do you see the dangers of internet failures, and how dependent do you think companies are on applications that require the internet to function?
(4) Topic GeoBox: Do you see fundamental problems and dangers with the offline-first approach (if necessary, this will be explained), e.g. impairment of usability?
(5) Do you have any general comments on the test procedure or the tested functions, and if so, which ones?

Thank you for participating in our test!