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Research Paper

Participatory design of digital innovation in agricultural research-for-development: insights from practice

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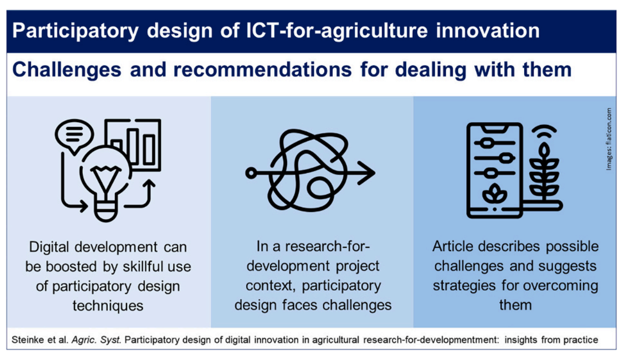
HIGHLIGHTS

- Digital development is becoming mainstream in research-for-development, requiring new skills and methods from researchers.
- Applying participatory design methodologies in digital development projects can help develop more user-centered innovation.
- Research-for-development project context creates challenges for participatory design processes.
- We present lessons learned from practical experiences within participatory design projects for digital solutions.
- Insights and recommendations may support development researchers in engaging more successfully in digital design processes.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Innovation based on information and communication technology (ICT) plays an increasingly important role in agricultural research-for-development efforts. It has been recognized, however, that the weak adoption and low impact of many ICT-for-agriculture (ICT4Ag) efforts are partly due to poor design. Often, design was driven more by technological feasibility than by a thorough analysis of the target group's needs and capacities. For more user-centered ICT4Ag development, there is now growing interest in the use of systematic, participatory design methodologies.
OBJECTIVE: Numerous methodologies for participatory design exist, but applying any of them in smallholder farming context can create specific challenges that digital development researchers need to deal with. This article aims to support future digital development efforts by contributing practical insights to recent discussions on the use of participatory design methodologies for ICT4Ag development.
METHODS: We present lessons learned from practical experiences within participatory design projects that developed ICT4Ag solutions in sub-Saharan Africa and Latin America. Based on these experiences and supported by literature, we describe common challenges and limitations that digital designers may face in practice, and discuss possible opportunities for dealing with them.
RESULTS AND CONCLUSIONS: The outcomes of digital design projects within research-for-development efforts can be affected by tensions between design ideals and project realities. These tensions may relate to, among

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others, mismatching expectations among project stakeholders, top-down hierarchies at design partners, insufficient attention to the wider digital ecosystem, and disincentives to re-use ideas and software. Depending on project context, these challenges may need to be addressed by researchers during planning and implementation of digital design projects.

SIGNIFICANCE: The insights in this article may support agricultural development researchers in facilitating more effective participatory design processes. Even though good design is not the only precondition for a successful ICT4Ag service, this can help create more meaningful digital innovation for agricultural development.

1. Introduction

Digital tools and services are expected to play an increasingly important role in the smallholder farming sector. Even in more resource-restricted parts of the world, a vast proliferation of hand-held devices, alongside continuously growing mobile network and internet coverage, have created opportunities for disruptive innovations under concepts such as 'smart farming', 'farming 4.0', or 'data-driven agriculture' (Wolfert et al., 2017, Jiménez et al., 2019, Klerkx et al., 2019, Mehrabi et al., 2020; Klerkx, 2021). Often harnessing large bodies of scientific or user-generated data, new information and communication technology for agriculture (ICT4Ag) applications offer many opportunities to inform decision-making by farmers, but also other stakeholders. Examples include sending weather forecasts and agronomic recommendations to farmers' mobile phones via voice message push-calls (Cole and Fernando, 2021) or providing time- and site-specific fertilizer recommendations in a smartphone app for extension agents (Zossou et al., 2021).

As a result of these growing opportunities, digital innovation has gained increasing attention within the international development agenda (e.g., World Bank, 2016, 2021). Growing numbers of donors and governments invest in digital tools and services to address challenges affecting agricultural development (e.g., USAID, 2020). In recent years, the global research-for-development community (including universities, public research organizations, CGIAR institutes) has increasingly integrated digital development in its research portfolios. For digital development to reach its full potential, however, development researchers may need to acquire new skillsets and adopt new research methods. A key challenge for many ICT4Ag initiatives, for example, has consisted in matching information supply with users' demand and capacities: i.e., the difficulty of offering what stakeholders need and want to know, in a way that allows them to access relevant, actionable information without extensive prior training on use of the digital service (McCampbell et al., 2021). In the early days of the ICT4Ag revolution, many new digital tools and services were created based on technological enthusiasm, rather than the actual needs and realities of farmers and other potential users. In consequence, many novel services were only weakly adopted and discontinued eventually. One important reason for these failures has consisted in mismatches between farmers' technological preferences and abilities, their information needs, and the proposed ICT4Ag solutions (Heeks, 2002; Tongia and Subrahmanian, 2006; Qiang et al., 2012; Dodson et al., 2013; Masiero, 2016).

In response to these rather disappointing experiences, the ICT4Ag community increasingly recognizes the importance of good digital design (Janssen et al., 2017; Steinke et al., 2020; Rijswijk et al., 2021; Findlater et al., 2021). This is in line with calls for more designerly approaches to agricultural R&D in general, as a means to better address the heterogeneity of farming context (Meynard and Dedieu, 2012; Berthet et al., 2016; Prost et al., 2017; Toffolini et al., 2020; Prost, 2021). Proper design implies avoiding the development of a product or service – such as an ICT4Ag tool – before thoroughly understanding target users' needs, aspirations, preferences, and abilities. Numerous methodologies and guidelines for participatory design have been presented in recent years, under names such as user-centered design (UCD), human-centered design (HCD), Design Thinking, and more (Gulliksen et al., 2003; IDEO, 2011; Brenner et al., 2016; Still and Crane, 2017). Experiences from the healthcare sector, for example, show that careful, systematic, and extensive participation of target users can help create successful digital services (Bazzano et al., 2017). Participatory design of digital tools and services for agriculture has a tradition in Western context (Parker and Sinclair, 2001; Cerf et al., 2012; Kenny et al., 2021). Recently, the use of rigorous design methodologies has started to be documented in the research-for-development community, too (Ortiz-Crespo et al., 2020; Adewopo et al., 2021; McCampbell et al., 2021). In addition, numerous researchers, development practitioners, and donors have endorsed the Principles for Digital Development (digitalprinciples.org), which highlight important checkpoints for successful digital development, such as "Design with the User" or "Reuse and Improve".

In reality, however, it can be challenging to put these principles into practice. Tensions may arise between the ambitions of design ideals and the realities of many digital design projects. This can be due to budget and time constraints, specific technology expectations by third parties (such as donors), or social norms in the design context that challenge design practice. Although participatory design approaches are being promoted within the research-for-development community, little has been documented about actual experiences in applying design principles for ICT4Ag. In this article, a group of digital development researchers shares group members' experiences with implementing participatory design of ICT4Ag solutions within sub-Saharan African and Latin American smallholder farming contexts. Our goal is to provide a reality check for the well-founded and established principles of good practice in digital design within the context of public-good research-for-development. We intend to demonstrate some of the challenges and limitations that designers may face in practice, and suggest possible ways to deal with them. With this article, we hope to start processes of reflection and discussion around design in ICT4Ag, and support researchers without a design science background when applying digital design to develop solutions that better align with smallholder farmers' realities.

2. A brief overview of participatory design approaches

Participatory design approaches involve future users in determining characteristics of products or services. These approaches have been used for decades in sectors as diverse as mechanical engineering, ergonomics, or architecture (Norman, 2013). A number of schools of thought on participatory design co-exist, each with their own terminologies and guidelines. Given their similarity, related terms such as 'human-centered design' or 'design thinking' are sometimes used interchangeably. For agricultural development researchers potentially unfamiliar with the different participatory design philosophies and their jargon, Table 1 provides a brief and non-exhaustive overview of some key design terminology. For many of the terms, there is no universally agreed definition. How they are understood and used may depend on the sector and context. Here, we give definitions that we found useful for an ICT4Ag project context.

3. Institutional context and methodology

Design processes are not only shaped by local conditions and stakeholder characteristics, but also by the wider context surrounding the innovation process. The experiences shared in this article are embedded in global research-for-development efforts within CGIAR, a global consortium of agricultural research organizations. Our

Table 1
Key design science terms.

Term	Explanation
Design	Defined by the Merriam-Webster dictionary as "deliberate purposive planning" (Merriam-Webster, 2021). Design is a planned and open-ended process for solving any type of problem. Design projects are often motivated by an identified problem, but do not hypothesize a solution from the outset.
User-centered design (UCD) and Human-centered design (HCD)	UCD emerged as a concept in the early age of human-computer interaction, recognizing the importance of focusing on the users, their needs and behaviors for successful hard- and software development (Norman and Draper, 1986, Abras et al., 2004, ISO, 2019). UCD is often seen as a goal, rather than a specific methodology. Future users are involved passively or actively in the design process. Some authors use the terms UCD and HCD interchangeably. For others, HCD follows the same philosophy as UCD, but widens the focus, from technology users to the wider pool of stakeholders possibly affected by a design product. In either case, the designers aim at "ensuring that people's needs are met, that the resulting product is understandable and usable, that it accomplishes the desired tasks, and that the experience of use is positive and enjoyable" (Norman, 2013). A three-stage HCD process (inspiration, ideation, implementation), pioneered by design firm IDEO, is now widely established. Detailed guidance on design methods and tools is provided by IDEO.org (2015).
Design thinking (DT)	Conceptually very similar to UCD/HCD, DT is often referred to as a 'mindset' for solving complex or ill-defined problems with innovative solutions, where the affected people, their thoughts, feelings, and behaviors are at the center of the design process. DT can be applied to any industrial or business process. As a practical design methodology proposed by the 'Stanford d.school', DT typically includes five successive stages: empathize, define (the problem), ideate, prototype, and test (Hasso Plattner Institute of Design at Stanford, 2010).
Inclusive design (ID)	ID can be considered a specific type of DT, where the design process "considers the full range of human diversity with respect to ability, language, culture, gender, age and other forms of human difference" (Holmes, 2018). ID practitioners intend to proactively address the needs, perceptions and behaviors of marginalized or excluded groups, aiming for their increased inclusion through innovative solutions. In practice, ID often implies designing solutions for a very specific group and a very specific use context (e.g., illiterate women, hearing-impaired youth), and later extending the solution to more user groups. The objective is to learn from diversity, embrace it during design, and enable different ways of user engagement with a tool or service.
Design idea and design concept	Ideas are generated in the early stages of the design process. Many design methods emphasize the stimulation of unconventional ideas, intentionally disregarding feasibility at first. Ideas can range from broad directions for further thinking (e.g. 'let's focus on voice-based communication with illiterate population') to suggestions for (partial) solutions (e.g. 'let's connect a voice-recognizing hotline to a chatbot that answers users' questions'). Multiple, compatible design ideas form a 'design concept': an integrated solution concept that could be turned into a viable prototype. A number of definitions for 'design idea' co-exist in the research literature (see Inie and Dalsgaard, 2017).
Prototype, prototyping	During prototyping, the design team turns design concepts into tangible products (prototypes) that get tested and evaluated by users in an experimental setting. The goal is to observe user interactions, detect potential failures, and refine the design towards an easy and appealing user experience. Across multiple iterations, prototypes become more specified: at first, low-fidelity prototypes may consist of paper or post-its (to represent a graphical interface), or a face-to-face conversation that mimics a chatbot conversation. Later, and after various rounds of specification and user testing, high-fidelity prototypes look and feel almost like the eventual product. A 'live prototype' is a closely supervised real-life test of a first fully functional version with a small number of test users (often called a 'pilot' in the ICT4Ag community).

experiences with digital design generally took place in a project context, funded by bilateral donor funds or CGIAR Research Programs (Table 2). The insights shared in this article are colored by our experiences and limited to these projects. As is typical for the research-for-development sector, these projects last between two and four years, are pre-designed in a linear fashion with time-bound deliverables, and have pre-approved budget lines with limited flexibility to re-allocate funds. This project structure by no means precludes effective digital design, but it has specific implications for the design process. Other organizational environments – such as start-ups or big corporations – may bring along different challenges and different success strategies. Another important feature of the experiences presented here is the absence of commercial pressure. Increasingly, donors emphasize the creation of viable business models in ICT4Ag projects, and, more generally, value-for-money in research projects. Overall, however, our work has been driven by a commitment to delivering innovative solutions, rather than financial returns to the project lead organization or the design client. Lastly, the experiences shared here were predominantly made within pilot projects. Although some of the digital tools and services have been implemented at scale, the experiences reported here do not cover the stages of scaling and adoption, as this would be outside the scope of this article.

To synthesize the positions in Section 4, we compiled our practical experiences through qualitative deliberations among the authors. Through inductive analysis, comparing the different cases, we identified specific challenges that either emerged in multiple projects, or that seemed particularly divergent from common, idealized views on participatory design, or both. We then clustered the challenges, and our suggestions on how to deal with them, into nine lessons learned. For context, the following paragraphs provide brief descriptions of the digital tools and services we have designed.

ClimMob, ClimMob was designed as an online platform to support on-farm testing of technology options, following a citizen science approach (van Etten et al., 2019). It facilitates the entire cycle of experimentation, from experimental design to data collection and analysis. The design involved the development of data collection (combining simple paper formats and Open Data Kit) and analysis processes (see Steinke et al., 2017), and subsequently the creation of online software to support this process. Development took place across multiple donor-funded projects. Involving the digital development team directly in the delivery of training courses especially helped to provide a constant stream of user feedback to iteratively improve the software.

Food security decision support tool, Seasonal food insecurity is a recurrent problem in the Guatemalan dry corridor. Government responses are often late and not well-targeted, in part due to the lack of

Table 2
Digital tools and services referred to across the article.

Name of digital tool or service	Design period	Description	Design partners	Reference
ClimMob	2014–2019	Online platform for managing agricultural citizen science experiments, where large numbers of farmers test different agricultural technologies (e.g. seed varieties, fertilizer dosage)	Individual users in breeding programs across the Global South	https://climmob.net/
Food Security Decision Support Tool	2016–2019	Online platform for community-based food security monitoring	SESAN: Government body coordinating food and nutrition security interventions at national level (Guatemala)	Müller et al. (2019)
Ushauri	2017–2019	IVR hotline linked to online platform with push-call function to enhance farmer-advisor communication	Public extension service (Tanzania), Private extension service managed by NGO Lutheran World Relief (Kenya)	Ortiz-Crespo et al. (2020)
Seed Information Exchange Platform	2018–2020	Online platform that collects seed stock data per variety, seed class and geographical location from research institutions and seed companies in Ethiopia	ISSD Ethiopia, Public sector seed companies (Ethiopia), Ministry of Agriculture (Ethiopia)	CGIAR Platform for Big Data in Agriculture (2021)
Seasonal seed scenario planning tool	2020–2021	Decision support tool for seed supply planning using climate forecasts, implemented as an MS Excel workbook with embedded web links	Private sector seed company SeedCo Ltd. (Zimbabwe), Public sector seed companies ESE & OSE (Ethiopia)	Steinke and Ortiz-Crespo (2021)

relevant and timely information. Supported by the CGIAR Research Program on Climate Change, Agriculture and Food Security, and together with NGO Action Against Hunger and the Guatemalan government, we supported the design and scaling of a community-based monitoring and early warning system. Local information on food security is regularly enumerated from community committees and uploaded to an online platform via ODK. The platform estimates the alert level and shares it with decision-makers at local and national level.

Ushauri, In a three-year project funded by the British government's Department for International Development (DFID), our goal was to develop a scalable solution that helps resource-restricted extension services better serve their clientele. Partnering with public extension in Tanzania (TARI-Naliendele) and a private extension provider in Kenya (Lutheran World Relief, an NGO), we designed and created Ushauri: a customizable software template that allows setting up an interactive voice response (IVR) hotline with pre-recorded agro-advisory messages for farmers. In this telephone hotline, farmers can ask questions in local language, which then appear at their extension agent's online dashboard. Agents can then respond to farmer requests by sending voice messages via pre-recorded push-calls.

Seed information exchange platform, In Ethiopia, public seed companies produce seed of different varieties according to farmers' pre-orders. However, when the season starts and environmental or market conditions are different from expected, many farmers demand varieties other than those they had ordered. To mitigate this frequent mismatch between local seed supply and demand, we designed an online platform together with Integrated Seed Sector Development (ISSD) Ethiopia and public seed companies. At the platform, seed producers enter their up-to-date stocks by variety, seed class, amount, and physical location. Potential buyers or distributors (e.g., regional bureaus of agriculture) can use a search engine to locate the seed they are looking for.

Seasonal seed scenario planning tool, Farmer demand for commercial seed varies with climate. For example, in drought years, farmers typically demand higher shares of early-maturing varieties. This variation can lead to suboptimal outcomes: high-demand varieties may sell out, and carry-over of surplus, undistributed seed has a cost. Together with private and public seed companies from Zimbabwe and Ethiopia, and funded by the Swiss Agency for Development and Cooperation, we designed an MS Excel workbook that helps decision-makers better anticipate farmers' seed demand. Users enter historical seed demand, rainfall records, and a next-season climate forecast. The tool then predicts tendencies on upcoming seed demand at variety level.

4. Lessons learned

4.1. Managing stakeholders' expectations

Many digital design processes involve diverse stakeholders, such as researchers, farmers, governmental organizations, or donor agencies. While each stakeholder may be motivated by different expectations to become part of the design process, these expectations often define how they perceive their own roles, interactions with other stakeholders, and the ultimate objective of the design process. Currently, many stakeholders have experiences with software and ready-made digital services as consumers only. These experiences can generate assumptions and expectations that mismatch a co-design process. We have encountered at least three sets of mismatching expectations that are common and that need to be managed.

Firstly, clients[1] often expect that the researchers will devise a solution, and that the client will provide little input into the process. In some cases, for example with the *Food Security Decision Support Tool* in Guatemala, this expectation of 'solution delivery' was held even though the problem was not well defined at the outset of the project. This has led to frustration with the level of commitment required from stakeholders, the perceived low quality of intermediate prototypes, and the time it takes to arrive at an eventual solution. To avoid frustration and ensure productive collaboration by all stakeholders, researchers need to be frank, from the beginning, about the iterative and collaborative nature of the design process. Over the course of the project, it is important to repeat the message and regularly indicate the current stage of the process. It may help to have standard visual materials (e.g., posters, infographics, slideshows) to explain the process in a short time to different types of design stakeholders. But learning about design processes is also highly experiential. Design participants may need time to become comfortable with their role: that their subjective feedback rather than mere approval is wanted, that the design process is a safe space to express opinions and formulate ideas, and that the design process is progressively closing in on a solution. This experiential learning can be stimulated by quick development cycles. If the first design iterations are done quickly, stakeholders may gain more insight and confidence in the process and may contribute more actively in subsequent iterations.

Secondly, many clients do not foresee that a design process may go beyond the digitalization of existing data and information processing. Digital design is not restricted to 'business as usual, but digital' (although more centralized digital bookkeeping, for example, can be a reasonable solution in some cases). Rather, effectively introducing novel

[1] Client here refers to the main design partner, i.e., the organization in charge of implementing, maintaining, and possibly scaling the solution.

digital tools and services into sectors such as agricultural extension, input supply, or breeding may require organizational changes, such as business simplification (Massie and Davis, 2012). Not all parts of the solution emerging during a digital design process must be tightly linked to the digital product itself. The need for organizational change as a condition for successful adoption of digital tools and services has been highlighted before (e.g. Walsham, 2017). In Ethiopia, for example, aggregating data on seed stocks from the lowest to the highest level required approval of each intermediate layer in the Ministry of Agriculture. The first prototypes of the *Seed Information Exchange Platform* deliberately did not challenge this existing rule and replicated the hierarchical system of approvals. This was then flagged as inefficient by design participants, starting a reflection that led to a simplification of the approval process. In all stages of the digital design project, including the original proposal, researchers can highlight that digitalization is not a holy grail and technical innovations may need to be accompanied by social or organizational innovation.

Thirdly, the open-ended and iterative nature of digital design processes can contrast with the expectations of donor agencies. Donors may seek disruptive, highly scalable and/or replicable solutions. Expectations around the possibility of scaling the user base of ICT4Ag innovations and the efficiency increases they will generate, however, have often turned out overly optimistic (CTA, 2019). A successful digital design process requires collective reasoning and ideating by the design team that is, as much as possible, unbiased by technology preferences or overall solution expectations expressed by the donor or client. In reality, however, donors and senior management at the design clients will often have concrete expectations, preferences, or commitments towards others, which set boundaries to the creative space and predetermine parts of the solution (see Kenny et al., 2021). In the case of the *Seasonal seed scenario planning tool*, for example, the design assignment specified a decision-support tool that uses seasonal climate forecasts to improve planning of seed distribution. This tool was designed, but eventually, the design partners (public and private seed companies in Ethiopia and Zimbabwe) saw limited applicability of the tool. The time range of seasonal forecasts (up to six months ahead of the season) was too short to influence the really big decisions, i.e., about seed production (one year ahead of the season). With a more open-ended approach towards ‘improving seed distribution planning with digital media’, the eventual product might have had a stronger use case. Highlighting the importance of an open-ended, unprejudiced approach to designing a solution already in the project proposal is important. This, however, may require raising awareness about digital design among donor agencies, as research-for-development donors prefer to fund proposals that are able to outline their expected outputs in advance. In design projects, however, even the understanding of the problem that motivated the whole exercise frequently evolves over time (Dorst and Cross, 2001). Thus, describing expected, hypothesized solutions in the project proposal is not advisable.

4.2. Considering future scaling from early on

“Design for scale” is one of the nine Principles for Digital Development (digitalprinciples.org), and donors commonly expect research-for-development organizations to work on solutions that can be scaled to maximize impact. The expectation is that ICT4Ag innovations, though developed with a small group of test users, have the potential to subsequently contribute to improved livelihoods of many or all farmers facing the identified challenge, be it universal or context-specific. Scalability, however, is complex and requires dedicated efforts from the very beginning of the design process (Woltering et al., 2019; Schut et al., 2020). If scaling is viewed as a downstream activity (“first the pilot, then we'll work on scaling”), ICT4Ag projects risk creating solutions that fit local context well, but cannot be scaled later on.

Expected future scale and design decisions mutually affect each other. A highly modular and adaptable service design can facilitate scaling to heterogeneous contexts. *ClimMob*, for example, has been designed to support experiments involving a wide range of crops, crop traits, languages, etc. But modularity also increases overall efforts in coding, maintenance, and training users, which may not be justified if only limited scaling is intended. In return, a strong emphasis on scaling can limit the extent to which the tool or service addresses the local context in the design pilot. A strong vision of future scale may discourage the implementation of features conceived by design participants to be locally useful, but which would not be feasible at scale. For example, the *Seed Information Exchange Platform* addresses the complexity of matching supply and demand under the specific, bureaucratic seed distribution system of Ethiopia. Trying to make this tool scalable to other contexts would, in turn, likely make it less fit-for-purpose in the original Ethiopian context. Where donors assess the success of an ICT4Ag pilot project via metrics of use or usability of the piloted tool or service, researchers may be incentivized to prioritize local fit over wider scalability. One way to explicitly consider scaling during design could be to involve a more diverse group of design participants. A pilot might run in one region and with a certain type of users, only. But forecasting what types of modifications could be needed in other contexts – by engaging with a wider group of potential future users early on – allows the software developers to consider potential adaptations in the original digital architecture. This way, likely pathways for future scaling can be built into the pilot tool or service from the beginning.

For development researchers, scalability often means serving as many users as possible. Thus, digital tools are often designed with an ‘average’ user in mind. *Ushauri*, for example, is most useful to users with access to a mobile phone, some familiarity with the extension system, and reasonable decision-making power in the farming context. This type of approach, however, can reinforce existing forms of marginalization and exclude ‘non-average’ groups from benefiting from the ICT4Ag tool or service (McCampbell et al., 2022). It is unlikely, for example, that remote farmers, who have not had the chance to build trust into extension agents through in-person interactions, will follow the advice given by these extension agents through voice messages. Choice of topics also matters: a digital information service that is designed with male users in mind, and that emphasizes the topics most relevant to male farmers, can perpetuate gender inequities in access to relevant information (Spielman et al., 2021). In consequence, actual scaling is limited to the ‘average’ user group. A practical recommendation would be to apply inclusive design methodologies, i.e. to first explicitly design for the marginalized groups. For example, ideation and prototype creation could be undertaken with women farmers, or illiterate farmers, only. In a second step, the design would be reviewed to make sure it also fits ‘standard’ users, for example, by evaluating prototypes with the marginalized users as well as with literate male farmers.

4.3. Creating a clear and coherent team experience

Successful ICT4Ag design processes require commitment and collaboration from diverse stakeholders, including target users. Engaging all design participants in a single design team throughout the process, rather than involving different types of participants sequentially, is important to avoid mismatches between different stakeholders' perspectives (Ng et al., 2021). Smooth teamwork can be challenged, however, by the lack of a shared ‘design language’. What is a ‘design concept’? And what does it mean ‘to prototype’? Even within ICT4Ag research teams, different definitions are common. To avoid frustration due to misunderstandings, all design participants, including researchers, software developers, and target users, need to ensure a consistent use of such terms. One term deserves special emphasis: the ‘designer’. In our experiences, even among engaged and motivated participants, the general expectation was strong that ideas and decisions would originate from researchers. This may often reflect the researchers' enthusiasm and their accountability towards the donor. But to achieve a creative, productive, and truly participatory design process, it is important to deliberately step back and curb exaggerated expectations towards the researchers. Clarifying roles is important: development researchers facilitate the process, stimulate discussions by making suggestions, and provide design tools, such as prototypes. They may guide participants in the formulation and specification of design ideas. The evaluation and eventual selection of ideas, however, must be primarily the role of target users (and the design team's software developers or data scientists, who need to assess feasibility).

Direct and equitable collaboration between diverse stakeholders of a design process – say, farmers, researchers, government officials, and software developers – can be hard to organize and facilitate. Understanding others' perspectives, however, can be crucial for shaping one's own opinions and ideas across the entire design process. In developing *Ushauri*, we prototyped 'the farmer side' and 'the extension agent side' of the service separately, with homogenous groups. While both processes generated promising design ideas, not all ideas were compatible within a single prototype. Prototyping with functionally diverse groups, despite possible hierarchies, is more likely to generate realistic, integrated design concepts. In particular, the importance of involving software developers already in early stages of design can be easily underestimated. To achieve a smooth user experience, we suggest that software developers need to be personally involved in context exploration (e.g., learning about target users' attitudes towards technology), and later should observe user interactions firsthand. During the development of the *Food Security Decision Support Tool*, the software developer participated in prototyping sessions and immediately learned about the challenges experienced by users. In our work for the *Seed Information Exchange platform*, however, software developers joined only for training sessions for the pilot version. Only at this point, the importance of seemingly trivial problems became clear, such as the difficulty of some users to locate the 'Next' button.

4.4. Understanding local context with limited time budgets

Extensive, empathetic immersion into the targeted local context has many benefits, but also has costs, and striking a balance is necessary. Context exploration helps to identify challenges and user needs. By spending time in targeted communities, researchers progressively become familiar with expected future users' daily routines, problem perceptions, attitudes towards technology, and other features of local culture that may crucially influence design decisions (Nova, 2014; Medhi, 2007). Insufficient context immersion can affect the design process: in the case of *Ushauri*, for example, participants in prototyping activities (farmers and extension agents) largely overstated the degree of mobile network availability in rural areas. Our initially strong reliance on mobile internet usage was a design flaw that could have easily been avoided by stronger context immersion prior to prototype development.

As mentioned, this process also has costs. Especially when digital development projects target remote regions, such as indigenous villages, thorough context immersion can be time-consuming and costly for reasons of travel requirements or language barriers. As a result, for many researchers or software developers in research-for-development organizations, spending a couple of days with a remote, rural family will conflict with other duties. In practice, context exploration is then often minimized, or commissioned to consultants or interns. Digital design teams need to identify strategies for dealing with the trade-off between the need for substantial context immersion and the limited scope for personal investment by members of the design team.

One possible solution consists in training local collaborators in design methods, rather than bringing trained designers into context. When a member of the targeted community is sensitized with a design mindset and joins the core design team for the entire project period, local context expertise becomes internalized to some extent. This individual perspective should not replace ideation activities with a more diverse group of future users, as other persons are likely to have different ideas and see different challenges. But actively engaging at least one expert on local context consistently across all design stages may help to avoid seriously flawed decisions. In selecting and training such a local design collaborator, it is worth considering potential biases. Design advice can be biased, for example, towards the person's own specific experiences as a farmer, or towards confirming earlier projects ("that other project gave rainfall forecasts and people liked it, so let's give rainfall forecasts again"). Despite this call for caution, training a local community member in design methods may be more easily compatible with the typical job routines of development researchers than the intense, personal immersion that is usually recommended by design experts. But this strategy may also inflate the initial phases of the design project, further extending the time span from project inception to first report of tangible results. While design teams may feel under pressure to deliver outputs to donors, the latter should recognize the value of an extensive context immersion phase, laying the foundation for overall success of the digital design project.

4.5. Achieving representation of target users and stakeholders during prototyping

Prototyping aims at generating feedback from a relevant group of target users and other stakeholders who could be affected by the use of the digital solution. Socio-demographic diversity among participants, for example, with regard to gender, age, education, wealth, and other aspects influencing their individual perception of both the problem and the potential digital solution is important at this stage (Ng et al., 2021). Inclusivity during prototyping helps to avoid overlooking constraints that affect only certain groups of users and to ensure that design decisions do not lead to their exclusion. Especially in early stages, when prototypes are 'low fidelity', the focus is on gaining insights rather than quantitative evidence. To evaluate design concepts and prototypes in a user-centered way, observing interactions by diverse users is needed, but researchers may not always be able to ensure full representation of the expected user base. In the design process for the *Food Security Decision Support Tool*, for example, participants were assigned by the management of the design client, with little input from the researchers. When recruitment happens more freely, design processes can suffer from similar biases as other forms of participatory research, where individuals with higher social status tend to dominate deliberations (de Vente et al., 2016). In other cases, achieving broad representation during prototyping may be challenging due to high costs of mobility, language barriers, or uncertainties about the future user base.

There are ways to address such limitations, at least partially. At project inception, discussing all stages of the design cycle with the design partner and highlighting the importance of diverse participants is a first step. Another strategy consists in the use of 'personas' (Pruitt and Grudin, 2003). Design concepts and prototypes can be evaluated by stepping into the shoes of different types of users and imagining their interactions. These perspectives may be identified through the development of personas: a collection of imaginary users, each having contrasting (but internally coherent) characteristics. By thinking through how one persona would interact with the product, the knowledge in the stakeholder group can be mobilized and focused on the diversity of the target user group, even in limited situations. While prototyping the *Seed Information Exchange Platform*, we designed a set of eleven personas in a workshop to generate different user perspectives. Each appeared with a picture and a list of characteristics (see Fig. 1 for an example). As a group, the participants identified the tasks each persona has, the problems they face, and the resulting expectations towards the digital tool. This helped to diversify the potential feedback on design concepts, but also to broaden the perspective on the type of system that would address the challenges at hand. This type of exercise can also help to gain legitimacy for including a larger group of stakeholders in subsequent iterations of the design process.

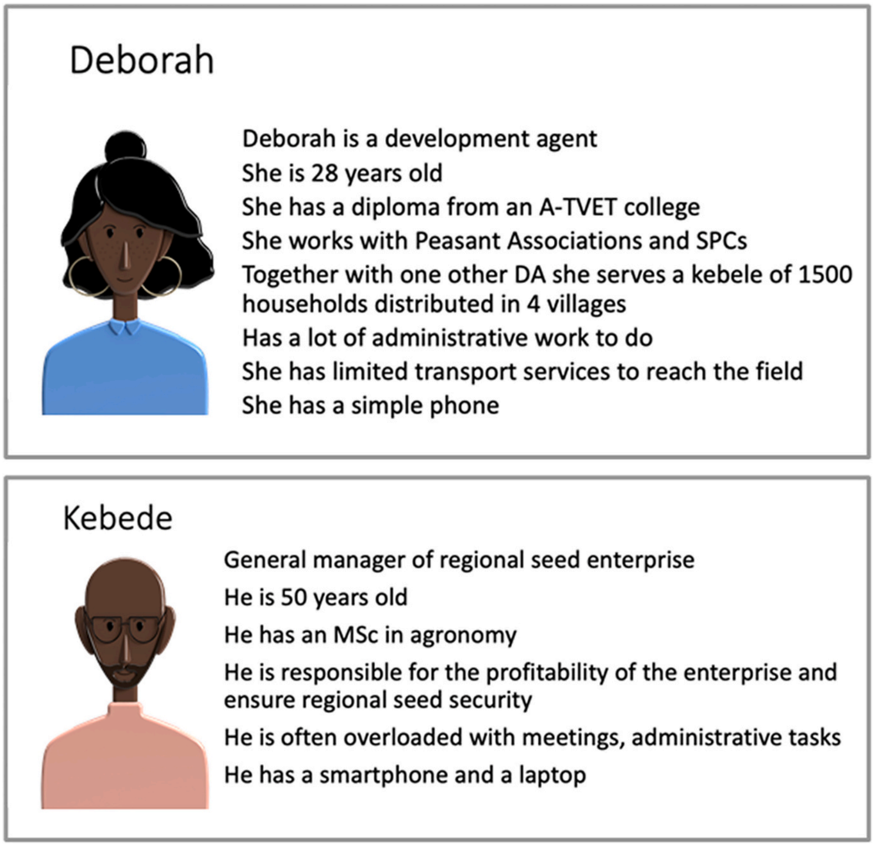

Fig. 1. Two out of eleven 'personas' that were used to evaluate prototypes of the *Seed Information Exchange Platform.*

4.6. *Choosing the right design tools for target context*

In participatory design, future users may take an active role in all stages of the design process. Their perceptions, skills, and abilities ultimately determine the characteristics of the solution. Additionally, these features of the target group must also determine the choice of design methods, as each context can require a different set of tools (Ramírez Galleguillos and Coşkun, 2020). To choose the most appropriate methods that enable diverse and productive collaboration, it is important that researchers thoroughly understand cultural context and social rules and norms in the targeted community. Gendered roles, for example, can influence who actively participates in facilitated groups (Cornwall, 2003). In our work on *Ushauri* in Kenya, we encountered low participation of women in prototyping activities, partly because extensive workshop formats clashed with household duties. The women who did participate hesitated to express their opinions within a majority male group. While open-group discussions are indispensable, non-verbal and off-site options for eliciting ideas and opinions are also valuable for making design processes more inclusive. Examples include the use of drawing or modeling clay to depict the current situation or intended future (at design sessions), or documenting and commenting the current problem situation through autonomous capture of videos or photos (Rose and Cardinal, 2018).

Prototyping typically involves exposing design participants to simple embodiments of design ideas, for example, paper sketches of a digital interface, or simulated recordings of a telephone hotline. Design science recommends keeping prototypes as basic as possible, as unfinished sketches are more likely to elicit rich feedback than seemingly finished, shiny products (Snyder, 2003). Nonetheless, in our experience, users can find it difficult to imagine hypothetical products based on abstract sketches. Creating simple, but actually digital mock-ups of design ideas ("Low-fidelity software prototypes") can be a helpful middle path (de Sá and Carriço, 2006). Graphical interfaces, for example, can just be set up in MS PowerPoint, which allows viewing them on a screen. For designing mobile apps or websites, online tools allow mimicking interactive functionalities with little effort (e.g., marvelapp.com). Similar quick mock-up services exist for automated IVR hotlines, messenger chatbots or SMS services (e.g., botsociety.io).

Low-fidelity prototypes must suit local context also in content, as providing examples that divert from participants' realities can cause confusion. During prototyping activities in Kenya for designing the visual results output of *ClimMob*, we presented different visual designs, all representing the same hypothetical results (a ranking of crop varieties). The objective was to discuss the ideal visual representation, but participating farmers spent most of the time discussing the made-up ranking because it did not match their experiences. During prototyping, design facilitators need to ensure that examples and methods suit the local environment and participants' experiences. In-depth initial context exploration can help in choosing locally suitable design tools.

4.7. *Dealing with top-down hierarchical settings*

Participatory design embraces democratic principles and requires eye-level collaboration among the design team, including target users. To be effective, participation requires a work culture that allows for agility, equality of voices and transparency. This can create tensions when design takes place in a bureaucratic environment with mostly top-down decision-making (Blomberg and Karasti, 2013). Public sector organizations, such as ministries of agriculture, can be characterized by a work culture that emphasizes following orders and pursuing performance indicators, rather than embracing diverse opinions and focusing on impact. In our experience, designing in this type of environment can face specific challenges.

Firstly, design participants who are used to little or no participation in decision-making processes outside their routine tasks may be reluctant to express ideas and voice their opinions because they are not 'experts' on the matter. Negative effects of steep organizational hierarchy on employee creativity have been shown elsewhere (Hu et al., 2018; Wang et al., 2019). In both Guatemala (*Food Security Decision Support Tool*) and Ethiopia (*Seed Information Exchange Platform*), it has been challenging to foster a design attitude among the public servants assigned to participate. There was a general expectation that the researchers – the supposed 'digital experts' – would come up with a solution ready for implementation. The idea of jointly evaluating design concepts and prototyping before running a pilot – common practices that acknowledge the iterative nature of design – was met with skepticism. This may be because in steep hierarchical settings, acknowledging failure can sometimes have strong negative consequences for the individuals involved (Thompson and Wildavsky, 1986; Cannon and Edmondson, 2001). Design processes, however, are inherently transparent about failures, trying to improve with each iteration. In Guatemala, it seemed that the emphasis on fulfilling verifiable performance indicators ('establish a digital system for data collection') overruled the goal of creating a meaningful and useful tool ('make better-informed decisions and reduce food insecurity'). The Guatemalan client never agreed to pilot or test the developed tool before scaling, which did not result in a favorable outcome.

Secondly, design processes within top-down hierarchical organizations can be characterized by a tension between practical knowledge and agency. Staff at the lower end of the hierarchy are often more aware about the real-life issues that should influence design decisions. In design sessions involving various levels of internal hierarchy, however, the higher-ranking staff are more likely to take decisions. During our design sessions, senior staff often dominated discussions, despite being less involved and less knowledgeable about the reality on the ground. When design decisions were made in a more participatory manner, they had to be approved by the higher level and were, in some cases, overruled without further consultation. In Guatemala, for example, the leadership of the partner institution defined data collection indicators that were not realistic. None of the subordinates in the room challenged this decision.

Despite these disillusioning experiences, we believe it is possible to implement effective participatory design in top-down hierarchical settings. The risks can be mitigated, to some extent. Especially when working with the public sector, recognizing hierarchies and acknowledging possible tensions between organizational culture and participation is an important first step. If possible, the topic should be addressed with higher-level decision-makers, explaining why diverse inputs specifically from lower-ranking staff are needed. Adjusting mutual expectations is key: researchers need to know the extent to which the client is willing and able to cultivate participation. And the client needs to understand why the researchers expect multiple prototyping iterations with staff, producing mediocre intermediate products, rather than just delivering the solution. Recognizing the constraints to effective participatory design in otherwise non-participatory environments remains important, however. Non-verbal and non-group formats for eliciting ideas and testing prototypes (see previous section) may help overcome such constraints. But in some cases, design processes may rather help to uncover the root causes of a problem. Developing and implementing a functional solution that gets used may not be possible under all circumstances.

4.8. Beyond users, considering the local digital ecosystem

Beyond user needs and preferences, the characteristics of the local digital ecosystem also condition the user experience and the potential for sustained adoption and benefit. These factors need to be considered during design. For internet-based services, for example, the availability and cost of mobile data can affect user interaction. For example, during tests of *Ushauri* in Tanzania, extension agents were able to record, upload, and send advisory messages using their smartphones. At later stages, however, mobile internet coverage was found to be unreliable, as upload speed varied with agents' location. *Ushauri* was then adjusted to let agents also record messages through telephone calls, which do not require mobile internet connection.

Another important characteristic of the digital ecosystem relates to the availability of local expertise for maintaining a service. In a project context, funding will often cover design, software development, and initial scaling. Over time, however, changing needs, new insights on users' interactions with the tool, or new user groups adopting a service will often require design and development to continue (Fleming et al., 2021). For long-term sustainability, it is thus critical to consider – during the original design process – the local availability and costs of design experts, data scientists, and software developers capable of troubleshooting and adapting a service. Knowing these costs in advance, as well as the design client's capacity to assign internal resources to maintenance, will then likely influence decisions on functionalities, software architecture, and financial sustainability mechanisms.

In developing the *Food Security Decision Support Tool*, for example, the design work focused on the frontend user experience. At the same time, the use of *Python* as a backend software environment limited the possibilities to troubleshoot, improve and develop the service after the project phased out: local programmers trained in *Python* turned out to be scarce and too expensive for SESAN, the Guatemalan government's office for food and nutrition security. In consequence, even minor troubleshooting required fundraising efforts, with negative implications to the functioning of the tool. We recommend involving, as much as possible, local IT experts in software development, and adapt the software infrastructure to locally-available skills and capacities. By all means, decisions on software infrastructure must not be taken without intense involvement of local stakeholders, including the organization meant to maintain the service in the future.

4.9. Embracing a culture of re-use

Innovation in the ICT4Ag sector does not need to re-invent the wheel. Projects can benefit from a strong and conscious culture of re-use, where the design team considers as much as possible which existing services, tools, or concepts are able to address the problem under consideration. Unfortunately, the concept of re-using, re-purposing, and adapting existing ideas and software can conflict with the motivations of both researchers/designers and donors. Project proposals and theories of change often emphasize the development of entirely new services and tools. To comply with donor expectations and the unwritten rules of the scientific community (the more innovative, the better), design teams can feel committed to developing digital innovations from scratch, including time- and cost-intensive software development. In many cases, however, a culture of re-use will be in the interest of donors, as projects may test prototypes more rapidly and at lower overall cost. Such savings in time and cost can also be in the interest of researchers, as they may allow longer live prototyping or more extensive evidence generation on impacts.

To establish a productive culture of re-use, we suggest that digital designers consider three aspects: Firstly, it is important to be well aware of past and current ICT4Ag services and tools, both within and beyond the target context. Being able to capture existing ideas and concepts (not even necessarily code) and adapting them to one's own project context is also important. The development of *Ushauri*, for example, drew concrete ideas from documented experiences of various earlier voice-based ICT4Ag services, such as 'Avaaj Otalo' in India (Patel et al., 2010; Cole and Fernando, 2021).

Secondly, using existing software or generic platforms avoids lock-in effects, where digital designers stick to what they created due to heavy investment into coding. For both *Ushauri* and the *Food Security Decision Support Tool*, we re-used code originally developed for *ClimMob*. Recycling code or adapting available digital platforms makes it easier to reassess, change, or entirely dump initial designs during the prototyping stage. The Center for Acceleration of Social Technology (CAST) suggests that for "90% of ideas for tech for good, there will already exist code or platforms that provide 80% of the required functionality" (CAST, 2017). Now, 'low code' platforms that facilitate rapid, modular software development have potential to substantially speed up prototype creation (Sahay et al., 2020). It needs to be clear, however, that an emphasis on re-using code must not funnel ideation into addressing all problems with the same software solution ("if all you have is a hammer, everything looks like a nail"). Whenever possible, preference should be given to digital media with which users are already familiar, minimizing efforts of both coding and training users. The *Seasonal seed scenario planning tool* was built in MS Excel because target users are known to be familiar with this program, and user inputs (data on seed sales) can be easily copy-pasted from existing MS Excel sheets. In Kenya, for example, WhatsApp messenger is already being used by large numbers of farmers (CTA, 2019). This opens many opportunities, for example, for agricultural advisory services.

Thirdly, a culture of re-use involves actively contributing to the community. To inspire and enable others, ICT4Ag designers and researchers need to share and demonstrate their work, and consider each project as part of a greater movement. Admittedly, offering and requesting ideas, concepts, images, or code is easier in the non-profit sector than for commercial enterprises.

In a donor-funded project context, one strategy to enhance a culture of re-use could consist in a two-stage project cycle. In the first period, the digital design team explores how far the project gets by strictly re-using existing solutions. By the end of this stage, actual needs for new code would become clear and can be justified to the donor. At this point, second-stage project resources can be re-allocated between remaining software development on the one hand, and activities related to piloting, iterating, and generating evidence on the other hand.

5. Concluding remarks

Over the last two decades, the digital revolution has already shown its great potential for supporting agricultural development, especially for farm advisory services. Now, governments, companies, and non-governmental development stakeholders are increasingly willing to invest in developing ICT4Ag services. To date, the digital revolution in agriculture is strongly driven by tech firms moving into the farming sector, in addition to the agricultural sector 'going digital' (Birner et al., 2021). This underscores the importance of sectoral expertise in software development and user research, which, so far, tends to be scarce in research-for-development teams working on ICT4Ag from an agricultural, social, or economic science perspective. With this article, we hope to support agricultural development researchers in engaging successfully in (future) multi-disciplinary teams that bring together IT capacity and development expertise. Although failure is a natural part of any iterative design process (and sometimes desirable for the new perspectives it creates), avoiding some failure may speed up digital development efforts and contribute to more effective donor investments. Of course, the insights and suggestions reported here need to be cautiously reviewed within the context of future projects: diverting from generic tutorials and obvious answers is, after all, the essence of a design mentality. It also needs to be clear that good design alone is not enough to generate the benefits of the digital revolution in agriculture. Enabling policy environments, rigorous cost-benefit analyses and solid financial sustainability strategies remain priorities if new digital services shall permanently transform the smallholder farming sector. Also, while opportunities for digital innovation grow, digital divides persist within target populations, for example, regarding digital literacy, network coverage, or access to mobile devices. Digital development researchers must emphasize inclusive design to mitigate the risk of increasing social inequities (e.g., between men and women, or farm-owners and farm laborers) through digital innovation.

Declaration of Competing Interest

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

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