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Understanding Interaction Design Challenges in Mobile Extreme Citizen Science

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ABSTRACT
Extreme citizen science is a bottom up practice used to empower people by supporting them, via processes and technological tools, to find solutions for local problems, but also to tackle major sustainability challenges of the 21st century. Methods and tools based on mobile computing have been utilized by communities in various parts of the world, from the Congo Basin through the Amazonian rain forest. However, extreme citizen science initiatives often face severe challenges as pre-designed technological solutions prove to be non-transferable to peculiar environments of rural developing regions. In this paper we collect and investigate evidence from the implementation of various extreme citizen science initiatives in the developing world. Our aim is to identify key obstacles towards their successful realization, mainly focusing on the problem of user interaction with mobile computing solutions. We conduct interviews with nine experienced researchers who all performed extensive field-work within these initiatives, and who reflect on the technology interaction, knowledge organization, inter-cultural, social and usability issues. Based on our analysis we report among others, symptomatic difficulties with abstractions, representational hierarchies, and navigation commands, as well as potential improvements that mobile technology developers can implement in order to create a more inclusive environment for extreme citizen science.

1. Introduction

Citizen science (CS) encompasses a collaboration and partnership between professional scientists and amateur volunteers in scientific issues. The practice has flourished to cover a wide gamut of research topics, from pollution monitoring, over ornithology, to astronomy (Theobald et al., 2015). At the same time the growth of citizen science remains highly uneven. To a large extent, citizen science initiatives target well-developed urban regions. This is partly due to to the generally higher levels of basic education and the sense of civic engagement within these communities, but also due to a wider availability of the infrastructure, such as data collection equipment and communication links, needed for running citizen science projects. More than three billion people reside in rural developing regions where collective actions based on local and indigenous knowledge could be crucial for tackling environmental, social and economic problems. This, together with the realization that the Western beliefs in techno-scientific innovation, complex legislation, and top-down approaches cannot provide the solution to global sustainability, has resulted in an increased interest in data collection practices to support *traditional ecological knowledge (TEK)* gathering.

TEK is a type of knowledge which has existed within indigenous communities for millennia, yet only recently started to receive attention from conventional knowledge structures and paradigms due to its potential to contribute to the local and global sustainability agenda. In line with the "leaving no one behind" principles of the UN's 2030 sustainability agenda (United Nations, 2015), citizen science activities can further help zoom into local indigenous environments in remote locations (of mainly developing countries) and provide insight into how people interact with the environment.

Volunteer actors may be engaged in a CS project at different stages of the scientific process and via various means of participation. The highest level of engagement, according to Haklay's taxonomy of participation, are *extreme citizen science* projects – citizen science projects where citizen scientists and volunteers collaborate at all stages of the scientific process, from problem definition, to data collection and analysis (Haklay, 2013). The Extreme Citizen Science group at University College London, UK (UCL) defines extreme citizen science as a philosophy of "situated, bottom up practices which take into account local needs, practices and cultures and which work with broad networks of people in order to design and build new devices as well as knowledge creation processes which can truly transform the world". Central to this philosophy are data collection tools to support individuals and communities in the collection of any kind of data or knowledge they deem relevant for collection, with most cases (if not all) focusing on TEK. This means that data

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collection tools should support relatively affluent, educated individuals who want to harness the potential citizen science, but also those less privileged in developing countries who want to collect and preserve their traditional knowledge or gather evidence for further actions related to local issues.

Mobile phones and ICT in general are seen as major drivers of citizen science growth, as they allow coordinated distributed efforts in data collection, analysis, and interpretation. While a rapid growth of ubiquitous computing technology and increased mobile communication penetration rates in developing countries (GSMA, 2018) promise proliferation of extreme citizen science initiatives, unique challenges prevent seamless deployment of mobile-based data collection tools in rural developing regions. Constraints stem from limited technological resources and poor infrastructure, for instance, the lack of reliable electricity grid or unavailability of wireless coverage (Brewer et al., 2005). Further, personal computing and communication devices used in modern citizen science projects tend to be prohibitively expensive for populations residing in rural developing regions. Finally, reasons why citizen science data collection initiatives cannot be easily transplanted to many remote regions are often more nuanced, and relate to cultural and educational factors, pre-exposure to technologies used for data collection, as well as the appropriateness of the existing mobile solutions for the given operating context. Within the context of information and communication technologies for development (ICT4D) research cell phones, in particular simple feature phones, represent a well-studied common platform for which adoption constraints have been studied extensively (Dell & Kumar, 2016). However, ICT4D studies with mobile phone users often "assume a reasonable amount of literacy" (Dodson, Sterling, & Bennett, 2012) and only a few studies examine how these users interact with smartphones. An even lower number of studies looks into the design of interfaces that may assist low-literate in developing countries in data collection tasks and only a few provide evidence of interaction barriers within this context (see Section 2).

In this paper we critically investigate a selection of extreme citizen science initiatives in the developing world by gathering and analyzing anecdotal evidence from various cases with different contextual characteristics, in order to design guidelines that support practitioners in realizing the true potential of extreme citizen science in developing regions. We take a holistic view and examine different challenges pertaining to planning and organizing data collection studies using mobile phones, we investigate motivational factors in extreme citizen science, and we explore how mobile data collection technologies (fail to) support these projects. In our work we pay close attention to technology interaction issues. Unlike most of the other challenges, technology interaction issues are inherently connected to cultural and educational characteristics of target end-users. Thus, overcoming interaction challenges requires, first, the understanding of the social, anthropological, and cultural characteristics of the intended user (and the broader community), and subsequently, the identification of technological affordances that can address specific user needs and enable successful implementation in a the specific operating context.

Our scientific approach relies on an in-depth critical investigation of selected extreme citizen science initiatives in developing regions. The methodology we employ consists of extensive interviews with primary researchers on these projects and the examination of the related publications, blogs, and video recordings. In the interviews, we examine issues related to project organization, implementation, and evaluation. Further, we ask the researchers to reflect on the technology interaction, knowledge organization, inter-cultural and usability issues in their projects.

Our analysis reveals that, like most other ICT4D projects, extreme citizen science projects face barriers at all levels of implementation. At the top level, for example, project uptake requires the identification and engagement of all the relevant stakeholders, which in egalitarian societies might include each individual of the target community. At the implementation stage, requirements posed by modern commodity technologies often remain unmet. For instance, reliable power, connectivity, auxiliary equipment, repair parts, and similar, are seldom readily available in rural developing regions. When it comes to technology interaction, we observe problems stemming from the dissonance between the context in which the technology was designed and the context in which it is actually used, as well as problems caused by the unfamiliarity of the target users with the concepts employed within the technological solutions. We then distill experiences of our interviewees and provide specific guidelines for designing and implementing extreme citizen science projects in developing regions. The derived guidelines are systematized along project organization, participant mobilization and motivation, technology support, and technology interaction design aspects. Within the last aspect, we provide particularly detailed guidelines pertaining to human-computer interface organization, interaction modalities, and graphical design. While most of the HCI issues and guidelines we examine have been considered before, we for the first time provide systematic analysis across diverse mobile data collection projects from Congo to Amazon. Finally, we conclude with a few hypotheses that emerged during our analysis, requiring further attention and charting the way for the future efforts in this field.

2. Related work

Recent proliferation of mobile computing has lowered the entry barrier for citizen science, as data collection and interpretation can be conducted and coordinated remotely via mobile phones. This was followed by a surge of research examining citizen science initiatives (Follett & Strezov, 2015). However, initiatives in rural developing regions, being few and far between, have not been critically examined, yet; especially for the opportunities and barriers they create to their unique user audience. Our work sheds light on extreme citizen science in developing regions, and compared to the existing surveys of CS, which had concentrated on different levels of participation, outcomes and outputs of citizen science projects, we put additional focus on previously overlooked technology interaction issues. Consequently, more relevant to our research is the existing work in the area of human-computer interaction for development (HCI4D)

(Winters & Toyama, 2009) and in this section we gradually introduce the reader to various disciplines and previous research that our work unavoidably brings together.

2.1. Mobile-based data collection in developing regions

Access to high-quality data is a key enabler of development in the post-industrial age, and with the advent of mobile computing data collection efforts spread worldwide. However, unique limitations, particularly the lack of supporting infrastructure and know-how with respect to mobile application development, resulted in data collection tools specifically designed for developing region use. Open Data Kit (Brunette et al., 2013) and EpiCollect (Aanensen, Huntley, Feil, & Spratt et al., 2009) are examples of frameworks that greatly simplify data collection implementation and management. However, these solutions are based on digital forms often requiring textual input, and thus, assume a certain level of literacy from the users.

On the other hand, data collection tools that focus on Traditional Ecological Knowledge (TEK) gathering have to adapt to low-literate users. CyberTracker, first developed for PDAs in early 90s and initially used to assist low-literate San animal trackers to collect animal behaviour data in Namibia, represents one of the earliest documented mobile ICT4D efforts (Liebenberg, Blake, Steventon, Benadie, & Minye, 1998). Lewis describes a partnership between an indigenous African community and Congolaise Industrielle des Bois, a logging company in the Congo basin, for the development of a PDA-based application to support the local community in data collection and resource management (Lewis, 2012). The project led into the development of Sapelli, a pictorial smartphone-based interface that allows non-literate communities in Congo, Brazil, Cameroon, and Namibia to collect data that supports knowledge co-production practices (Stevens et al., 2014). In Section 6 we further discuss data collection tools used in the initiatives analyzed in this paper.

There are several examples that demonstrate that participatory mapping is a well-established methodology for obtaining knowledge from local communities concerning their living conditions and environment. However, most examples do not involve ICTs and they are outside the scope of this paper. For those that do involve ICTs, there are very few related publications and experiences remain mostly anecdotal. A first attempt to discuss these experiences and produce a set of lessons learned to inform future research took place in April 2018 at UCL, London, UK in the Workshop on "Lessons learned from volunteers' interactions with Geographic Citizen Science"; a workshop inspired by the research described in this paper.

2.2. User interface design for low-literate users

UNESCO defines literacy as the ability of a person to read and write a simple sentence in his or her everyday life (Sector, 2004). Medhi et al. use the term *low-literate* to refer to non-literate – i.e. those with an inability to read or write – and semi-literate – i.e. those that are able to read only with difficulty (Medhi, Cutrell, & Toyama, 2010). The term low-literate in this paper has the same meaning.

Early research in the use of mobile phone user interfaces (UIs) in developing countries mainly consisted of observation and evaluation studies exploring contextual characteristics and user needs, in order to understand how technologies should be designed in this particular environment (Belay, McCrickard, & Besufekad, 2016; Chipchase, 2006; Dodson, Sterling, & Bennett, 2013). Recent studies discuss prototype development and usability evaluations to test mainly communication features (on basic phones, feature phones and some on smartphones) such us using the phone's diary to make a call and text-message functionalities (Dodson et al., 2013; Friscira, Knoche, & Huang, 2012; Lalji & Good, 2008). As the number of Internet-connected mobile phones grew, research has also started to explore design implications of more complex applications, for example those providing water quality information and alerts (Brown, Marsden, & Rivett, 2012), supporting users in the search for a job or navigating the city (Medhi, Sagar, & Toyama, 2006), and mHealth applications (Chaudry, Connelly, Siek, & Welch, 2012; Kumar & Anderson, 2015).

Research studies have demonstrated that pictorial interfaces, fully embedded into cultural contexts, local meanings (Lalji & Good, 2008; Medhi et al., 2006) and user preferences (Frommberger & Waidyanatha, 2017; Lalji & Good, 2008), with little or no text are more useful for low-literate users than text-heavy apps (Medhi, Prasad, & Toyama, 2007; Medhi et al., 2006; Parikh, Ghosh, & Chavan, 2003). However, a few studies suggested augmenting, rather than eliminating, text-based features, as text could be perceived a status symbol – lack of it would encourage stigmatization of low-literate. Furthermore, mixed text/picture interfaces could be used as a proxy-literacy aid (Knoche & Huang, 2012). Lack of education and literacy skills influence not only one's ability to read text, but also that person's cognitive abilities and linguistic sequential memory (Medhi et al., 2010). This has a direct influence on a person's ability to understand abstractions that are now commonly used in interface design, such as hierarchical menus. Thus, a number of studies conclude that linear structures are more appropriate for low-literate users (Chaudry et al., 2012; Lalji & Good, 2008; Medhi et al., 2010; Winschiers-Theophilus, Bidwell, Blake, Kapuire, & Rehm, 2010). Nevertheless, extended exposure to technology may lead to improved digital literacy skills and familiarity with mobiles phone use and can support low-literate users overcome interface usage problems (Medhi, Gautama, & Toyama, 2009). With respect to icon design, Medhi has demonstrated that low-literate users are better with hand-drawn, semi-abstracted graphics that incorporate some action cues, while photo-realistic images are usually more effective in deeper interaction modes (Medhi et al., 2006).

Other UI modalities, such as audio feedback and voice annotation, have been also proposed (Chipchase, 2006; Deo, Nichols, Cunningham, Witten, & Trujillo, 2004; Lalji & Good, 2008; Medhi et al., 2007, 2006); although, as we argue later in the paper, the use of such modalities should depend on whether they are relevant and feasible in a specific context of use. Research around input methods explores the use of keypad, as most studies involve feature or standard phones (Bailly, Oulasvirta, Brumby, & Howes, 2014; Lalji & Good, 2008; Medhi et al., 2006). Still, evidence shows that low-literate users may be hesitant to touch the screen of a touchscreen device and may struggle with different types and outcomes of tapping. For example, Katre explains how low-literate users lack fine motor skills due to non-practice in writing (Katre, 2010). Considering these findings, a notable recommendation in the literature is that low-literate participants should be trained in the basics of touchscreen interaction before any other UI features or applications are further tested with these users.

2.3. Participatory design in HCI4D and in extreme citizen science

Since the early 1990s research in cross-cultural HCI has been demonstrating the importance of considering cultural aspects in the design of interfaces and in understanding culture-driven usability issues. As Irani puts it "There is ample evidence that design conventions and heuristics do not move easily across cultural contexts. HCI visual conventions have proven not to be universal – systems effective in the US may fail utterly in Japan or South Africa. For example, design aesthetics vary wildly from place to place and taken-for-granted symbolic literacies, such as recognizing an image representing a GUI button, are strange in less computer-saturated cultures" (Irani, 2010)(p2940). Not only is considering local cultural aspects important for efficient HCI design, but also for the solution acceptance and sustainability. Winters and Toyama explain that in HCI4D research "It is not enough to understand the issues from a technical point of view; researchers and practitioners must work together to come to a common understanding of the context in which they are working, a context that usually involves technical, social, political, and economic elements, in addition to the domain-specific ones necessary to work in, say, veterinary medicine" (Winters & Toyama, 2009)(p4).

To a large extent today's technological solutions are designed by and for affluent users in the developed world. Implementing the same or similar solutions to other contexts has been proven ineffective. At the same time, without their voices being heard during the design process, users from rural developing regions often end up with technologies that are inappropriate for the particular context of, for example, Brazilian rainforests, Namibian grasslands, or Indian slums. In his pioneering work Gary Marsden advocates a shift towards the *empowered design* where technology is created so that can be modified and adapted by the end user (Marsden, 2008). Participatory design has the potential to empower local people and support the development of more user-friendly technologies (Ho, Smyth, Kam, & Dearden, 2009), but it can also be an important method for tackling the challenges of defamiliarization in ethnographic HCI-based research (Chetty & Grinter, 2007) that does not always allow for "local interpretations" (Winschiers-Theophilus & Bidwell, 2013)

Participatory design methods are additionally emphasized through examples coming from anthropological research (Hakken & Maté, 2014; Palmer, 2010). Palmer describes a living labs methodology in rural areas on the Wild Coast of the Eastern Cape in South Africa for the development and adaptation of ICT and for an in-depth study of cultural and socio-economic contexts, demographics and users' prior ICT experiences and needs (Palmer, 2010). The author emphasizes the importance of participatory and co-developed ethnographic research. On the more critical side, Winschiers-Theophilus et al. are skeptical about the application of participatory methods in HCI4D (Winschiers-Theophilus, Bidwell, & Blake, 2012). In particular, whether their implementation is applicable to local contexts and how well it corresponds to "the socio-economic, cultural and political context that shapes users' behaviours and actions"(p90). Research has also demonstrated that participatory design in developing regions can be deemed problematic until adequate training is provided to increase ICT literacy levels (E. Blake, 2010).

Extreme citizen science initiatives for data collection purposes (especially those which we discuss herein) rely heavily on community engagement and participatory design processes. CyberTracker, was developed using participatory action research and user-centered design in order to involve end-users at various stages of product design and testing (E. Blake, 2010; Gruijters & Blake, 2008). However, the existing publications on CyberTracker provide limited evidence on the extent and the means of end-user participation in the consideration of ethical aspects, as well as for the elicitation of end-user requirements prior to conceptualization and development of the application. For the development of Sapelli – a data collection platform that supports communities and individuals in data collection and citizen science practices regardless of their literacy levels and prior experience in interacting with technologies – partnerships with local actors played an important role in project initiation and were fundamental for the project's sustainability (Stevens et al., 2013).

Working mainly with anthropologists in the field, extreme citizen science initiatives often start with a *free, prior and informed consent (FPIC)* process refined to explore and adapt to local conditions and which leads into the establishment of effective participatory partnerships with local communities. FPIC is a tool that ensures mutual understanding and agreement between the external participants and the local community. According to the United Nations Commission on Human Rights definition:

> Free, prior and informed consent recognizes indigenous peoples' inherent and prior rights to their lands and resources and respects their legitimate authority to require that third parties enter into an equal and respectful relationship with them, based on the principle of informed consent.

FPIC involves a dialog between the stakeholders, so that project goals, methods, potential risks, and other issues are fully disclosed. When administering FPIC, it is important to ensure that the information is not only conveyed, but also understood by the local community. Consent from the community needs to be *free*, in a sense that is possible for the community to defer from participation, as well as *prior*, i.e. achieved before the project commences. FPIC is commonly used to safeguard indigenous communities, especially in situations related to commercial exploitation of natural resources these people depend on. The FPIC process that extreme citizen science initiatives use is described in detail in Lewis (Lewis, 2012). A participatory design process is the followed at all stages with sufficient evaluation, redesign and reflection cycles adapted to the cultural characteristics and the challenges in running HCI4D in developing countries (for more information see (Vitos et al., 2017)). Some of these cases, but also other examples from the context of ICT4D share of the lessons learned in conducting participatory design in developing regions (Braa, Titlestad, & Sæbø, 2004; Puri, Byrne, Nhampossa, & Quraishi, 2004), or define ethical requirements for working with indigenous communities (South African San Institute, 2017).

2.4. Methodological challenges in HCI4D research

It is widely acknowledged that conventional HCI methods are not culturally universal (Irani, 2010) and therefore an 'out-of-the-box' implementation is mostly inappropriate for cross-cultural HCI and HCI4D research (Anokwa et al., 2009; Ho et al., 2009). Sambasivan and Smyth suggest that understanding the social norms and dependencies before an invention can improve the effectiveness of community-centred design (Sambasivan & Smyth, 2010). As noted in the previous section, different notions of participation may have a completely different effect on how methods are implemented and their outcomes. For example, Anokwa et al. explain that in conservative communities, different protocols should be consider for accessing and working with female users (Anokwa et al., 2009)

One aspect that HCI4D research focuses on is the evaluation of technologies and interfaces for their usability, i.e. ease of use; an interaction element which is widely recognized for its importance in the Western world and which comes with a set of well-established methods for its evaluation. Winschiers and Fendler (2007) explain that the way usability is evaluated and achieved through design might differ significantly between different cultures (Winschiers & Fendler, 2007); e.g. Namibians prioritize integrity and trust in knowledge sources over task completion time and user satisfaction. Creating tasks for controlled usability experiments can be a major challenge as creating abstract scenarios is not a concept that all cultures are familiar with and therefore it is not always understood (Vitos et al., 2017).

A growing number of studies discusses field experiences, which among other problems, highlight various methodological issues such as "what constitutes appropriate criticism" (Chetty & Grinter, 2007)(p.2330), interrupting people considered being "offensive" (Vitos et al., 2017); people's limited technical skills complicate achieving meaningful interactions (Kimaro & Titlestad, 2008); and so on. One of the most highly cited issues is getting helpful feedback. Chetty and Grinter explain that in HCI4D studies user feedback is rarely honest with focus groups sessions eliciting more frank opinion that individual feedback sessions (Chetty & Grinter, 2007). Anokwa et al. agree that feedback might not be truthful as "users were often eager to please researchers" (Anokwa et al., 2009)(p106). Some of these issues are acknowledged by our interviewees in this study and in following sections we emphasize on their experience and elaborate on those issues.

3. Extreme citizen science initiatives

Since 2012, extreme citizen science methods and tools have been successfully used by various communities, where local people are directly involved in environmental monitoring and issues of local concern (e.g. cattle invasion, illegal logging etc); they collect data and participate in data analysis and visualization to identify locally acceptable solutions. The process enables the creation of "spaces" for reflection as well as building up and communicating knowledge and people's local wisdom which has the potential to in turn truly empower them. The extreme citizen science methods, tools, as well as the shape and form of the overall approach depend and build upon contextual frameworks heavily influenced by environmental, cultural, and socio-political structures. As the approach unfolds, it also creates and supports the need for local capacity building (see *Unique traits of extreme citizen science* below).

3.1. Selected extreme citizen science-related initiatives

In this paper we examine eight extreme citizen science initiatives (Table 1) at various design, development and implementation stages, all relying on mobile computing data collection tools and all but one targeting rural developing regions. It should be noted that although most citizen science initiatives follow the same procedure in terms of introducing the technology to the local communities, implementation practices differ significantly due to contextual factors (e.g. purpose of the project, privacy concerns) and the barriers to adopt the technology itself, which is what we are trying to uncover. Therefore, despite being aware that in some of the initiatives the technology was not successfully utilized, or that there were significant issues and concerns for doing so, we still include findings from those initiatives in this paper.

Here we briefly present the examined initiatives:

- **I1 – Tackling cattle invasions in Namibia**: The Nyae Nyae Conservancy in south west Africa was officially registered in 1998 in an area where the Ju'hoansi community has hunted and gathered for over 25,000 years. The area came under threat since local communities have come into contact with agricultural economies and especially due to extensive cattle farming in the traditional hunting and gathering grounds. In 2015, local communities approached a London School of Economics anthropologist, to support them with the process of gathering data to help fight illegal cattle invasion. The data to be collected required GPS-enabled photographs of cattle ear tags to document illegal land invasions. The project was initially supported by crowdfunding. Smartphone-based data

Unique traits of extreme citizen science

1. Extreme citizen science envisions user participation at all stages: understanding what data needs to be collected, collecting it, analyzing it, deciding how to act;
2. Supporting local needs as expressed by the people themselves (traditional ICT4D initiatives for data collection are often driven by external authoritative sources);
3. Extreme citizen science is often used to collect TEK and, thus, crucial for global sustainability goals;
4. Extreme citizen science tools are designed to address needs and contextual characteristics of the environment and the users; when the users are low-literate individuals the interfaces are mainly pictorial.

Table 1. Selected extreme citizen science initiatives.

ID	Location	Description and goals	*P*-pants.	Literacy	Tool	Res.	Refs.
I1	Namibia	Geotagged photographing of cattle invasions, with the goal of protecting Ju'honasi community area	7 (male rangers from the community)	Mix of literate and low-literate	Sapelli	R1	Laws (2015)
I2	Brazil (Pantanal wetlands)	Mapping natural resources (fish, wood, drinking water, etc.) for improved management.	two families (four phones)	Mix of literate and low-literate	Sapelli	R2	Chiaravalloti (2017a, 2017b); Chiaravalloti et al. (2017); Chiaravalotti (2018)
I3	Cameroon (rainforest)	Reporting illegal poaching in a biosphere reserve by Bantu farmers and Baka hunter-gatherers in order to preserve natural resources.	40 (eight monitors in each of the five communities)	Mix of non-literate (Baka) and low-literate (Bantu)	Sapelli	R3	Hoyte (2018)
I4	Brazil (border with Peru)	Reporting illegal fishing and hunting intrusions in order to preserve natural resources.	13 (one female)	Mix of non-literate and low-literate	Sapelli	R4	Comandulli (2018); Comandulli et al. (2016)
I5	Southern Africa (Namibia, Botswana, South Africa)	Wildlife tracking, natural resource mapping, and poaching reporting, with the goal of preserving TEK and managing natural resources.	unknown	Mix of non-literate and low-literate	Cyber Tracker	R5	E. H. Blake (2002); Liebenberg et al. (1998), Liebenberg et al. (2017))
I6	Brazil (Amazon)	Mapping forest resources for visualization of carbon reserves	unknown	Mix of non-literate and low-literate	ODK	R6	Boyle (2005); Surui (n.d.); van Roosmalen (2019)
I7	Brazil (Curitiba)	Geographical data collection usability study among low-literate urban poor.	30 (most with previous smartphone experience)	Low-literate	Sapelli	R7	Pican¸co Junior (2017)
I8	Congo Basin	Study of the usability of Sapelli resource mapping interface with illiterate intended users.	80	Mix of non-literate and low-literate	Sapelli	R8 and R9	Altenbuchner (2018); Vitos (2018a); Vitos et al. (2017)

collection tool Sapelli (see Section 6) was used to support community in evidence gathering, as well as for other tasks, which were proposed later in the process of introducing the technology to local communities, for instance, tracking plant growth. The external expert worked with the local communities to develop Sapelli's pictorial decision tree and she captured additional requirements specific to this initiative, such as a zoom in function that was required so to help data collectors take better quality pictures without getting too close to the animals. Seven illiterate and low-literate people without any previous exposure to smartphones were first trained and then employed to collect data using Mann Zug 5S+ Rugged smartphones. Technological implications and the lack of additional resources, all of which we discuss in the following sections, did not allow an in-depth utilization of Sapelli in this initiative. It should be noted that it was further decided that due to privacy concerns, i.e. because of the sensitivity of the collected data, which may cause interpersonal conflicts and disputes, any future Sapelli training and use by local rangers should remain strictly confidential to protect rangers from cattle farmers.

R1 is a PhD student in anthropology at London School of Economics, UK. As a part of the above initiative, in 2015 she spent 14 months with the Ju'hoansi community in Namibia.

- **I2 – Mapping fishermen resources in Pantanal, Brazil**: Pantanal is the world's largest tropical wetland region, which covers an area of 160,000 square kilometers in Brazil (with parts of it also extending to Bolivia and Paraguay). The area is a rich natural ecosystem hosting several endangered species as well as indigenous populations. Policies and regulations for protected areas and broadly for natural resource management have been subject to controversies since they ignore the needs of local communities who rely on natural resources for their survival. In 2014, local communities approached a UCL anthropologist to support them with local natural resource management processes, looking especially at improving their understanding of local fishing practices and the local patterns of land tenure and access. Funded by Rolex Awards and World Wildlife Fund, the project relied on a Sapelli-based mobile application to capture local resources such as fish, wood, straw bait, hunting, fruits, honey, drinking water and wild rice. Participants of this initiative included two low literacy families who were somewhat exposed to smartphones prior to this extreme citizen science initiative. These users were provided with four Samsung X-cover smartphones, water and shock resistant devices running the Sapelli app.

R2 is a Brazilian researcher at Instituto de Pesquisas Ecologicas, Sao Paolo, Brazil. During his PhD work on local communities and conservation, he spent approximately one year living with the communities of the Pantanal wetland.

- **I3 – Reporting illegal poaching in Cameroon**: Led by Zoological Society London, together with Baka hunter-gatherers and Bantu agriculturalists, one of the extreme citizen science initiatives currently takes place in Cameroon, more specifically from Djoum to the Dja Biosphere reserve. The wider scope of the project involves the establishment of surveillance networks and the development of monitoring and evaluation systems where interventions can be assessed. The project, in collaboration with ExCiteS group at UCL, UK, involves two Baka hunter-gatherer and three Bantu farmer communities, with new communities slowly join the project, who are supported in monitoring and reporting illegal poaching in the area. The project involves up to eight monitors (i.e. people monitoring the area to collect data) in each of the five communities using Samsung X-cover 3 smartphones; with participants from Baka communities being non-literate and Bantu farmers being low-literate. It should be noted that due to privacy concerns, monitors are not allowed to talk about the project with any other community members for security and safety purpose. Although the project is still in progress, in this paper we provide information about preliminary observations in terms of interacting with technology in this initiative.

R3 is an anthropology PhD student with the ExCiteS group, UCL. He's previous education includes B.Sc. in Biology from the University of Leeds, two years studying zoology and anthropology, and working as a researcher in archaeology at Rhodes University and the University of Cape Town, South Africa, and M.Phil. in Biological Anthropology at the University of

Cambridge. Since 2017 He is actively working in the field with local Baka communities in Cameroon.

- **I4 – Supporting the Ashaninka with illegal hunting and fishing invasions**: Apiwtxa is a small Amazonian village in the border of Brazil and Peru. Since 2015 an anthropologist from ExCiteS group is working with local communities on reporting illegal fishing and hunting invasions within their indigenous territory. The goal of the project is to develop an integrated solution for reporting intrusion that supports photographing, geo tagging, digital data storage, and that can be used to contact the authorities. Participants of this initiative include 13 Ashaninka literate and illiterate monitors (12 male and one female) trained to use Samsung X-Cover 2 phones; some participants had prior experience interacting with smartphones. Together with the community, a Sapelli-based data collection app was developed. The initial results show that, due to technical deficiencies of the app, users revert to more versatile tools, such as WhatsApp messenger that they appropriated to the cause.

R4 is a Brazilian PhD student at the Anthropology Department, UCL, and a member of ExCiteS research group. She holds an MSc in Anthropology and Ecology of Development from UCL. Before her PhD work, she spent four years working for National Foundation for Indigenous Affairs in Brazil. Since 2015 she spent two years with Ashaninka working on resource preservation issues.

- **I5 – Supporting wildlife trackers in southern Africa**: Since the mid 1990s indigenous San communities in Namibia, Botswana, and South Africa have been working with a South African citizen scientist (himself a tracker) on designing a tool that would support tracking, wildlife poaching reporting, and natural resource mapping. The solution, initially developed in Karoo national park in South Africa with two illiterate trackers, have evolved into a mobile application that enables trackers to collect geo-tagged data by selecting among locally-relevant icons in a hierarchical menu. The application also supports note taking and sound recording. Within CyberTracker projects in southern Africa trackers are employed for data collection, often in national parks. They come from the traditional tracker societies, yet, most of the new generation had to be re-trained as they lost the traditional tracking skills.

R5 is a South African independent citizen scientist since 1980s. He is a wildlife tracker and a co-founder and an executive director of CyberTracker Conservation. He has more than two decades of fieldwork experience with indigenous South African communities of wildlife trackers.

- **I6 – Community forest monitoring in Brazil**: In 2007 the Surui community from the Amazon region of Brazil approached the Google Earth Outreach program in order to obtain help with forest protection. The project evolved into mapping forest resources for the visualization of carbon reserves, with the aim of participation in the global carbon credits market. A researcher worked with the community in designing an Open Data Kit (ODK) based mobile application for collecting geo-tagged data about forest resources.

R6 is a Brazilian researcher who has lived and worked in tropical South America for most of his life (Suriname, the rainforests of French Guiana, and the Brazilian Amazon). He holds a Masters of Science in Environmental and Political Sciences. He is the director and co-founder of the Brazilian NGO ECAM; previously, he worked with the Amazon Conservation Team (ACT) and coordinated the mapping of 18 million acres of indigenous lands in collaboration with the Brazilian government and 20 indigenous communities.

- **I7 – Data collection usability study in a Brazilian slum**: Illiterate low-literate people from deprived areas of Curitiba, Brazil were selected for a study on the usability of a mobile mapping interface. The study, lead by a Universidade Federal do Parana researcher, consisted of a mapping exercise with Sapelli and involved 30 users, who despite being low-literate, quickly grasped the application due to their prior exposure to smartphones. The required tasks included selecting a point-of-interest (POI) category, taking a photo, GPS coordinates, confirming an entry, and returning to the main screen. While this use case significantly differs from the rest, not only because of its aims, but also because it is placed in an urban area, we still include it as it reveals details about the challenges and opportunities related to human-computer interaction in mobile data collection applications for extreme citizen science.

R7 is a Brazilian cartographic engineer. He obtained an MSc in computing engineering from University of the State of Rio de Janeiro and has 10 years of professional GIS experience. As a part of his PhD studies at the Federal University of Parana he collaborated with ExCiteS on the investigation of issues surrounding mobile data collection tool usage among low-literate urban users.

- **I8 – Data gathering tools usability studies with Pygmy hunter-gatherers in the Congo Basin**: Several opportunities for extreme citizen science have been investigated through the years in the wider area of the Congo Basin, to support local communities in various ways. For instance, Mbendjele community members approached the ExCiteS group in 2006, which resulted in the first anti-poaching application, the predecessor of Sapelli (for more information see (Vitos, Lewis, Stevens, & Haklay, 2013)). Further, the Tswa community experimented with Sapelli to address forest management issues with local logging companies, while the Bateke Plateau in the Lefini river communities also experimented with Sapelli to monitor animal populations and record hunting practices. Recently, the ExCiteS group worked with illiterate Pygmy hunter gatherers to assess the usability of initial Sapelli implementations focusing especially on the use of decision trees in data collection and “tap & map” interface re-design solution that was developed in the field to address the usability problems associated with decision tree implementations in the first experiment. Eighty local community members participated in the study using Samsung Galaxy X-cover 2 smartphones. None of the participants had used Sapelli before, had any experience with the use of similar technology, nor they they own mobile devices, although the participants were familiar with feature phones. Participants’ education levels varied to include non-literate, low-literate, and some people educated to high school level, although understanding of experiment instructions was not correlated to participant demographics. The stage of implementation of the described use case differs from the others we examine in this paper, still, we consider data about barriers and opportunities from our interviews with researchers who ran the usability experiments, since they shed light on issues related to Sapelli, a mobile technology used in most of the studies examined here.

R8 is a postdoctoral research assistant with ExCiteS with background in human-computer interaction and software engineering in participatory GIS and citizen science. As a part of his PhD (completed in 2017) he spent more than two months working with Pygmy hunter-gatherers in the Congo Basin exploring the appropriateness of pictorial decision trees as interaction style for capturing traditional ecological knowledge.

R9 is a postdoctoral research assistant with ExCiteS with background in geography and computer science. For her PhD (completed in 2018) she explored digital map creation and an evaluation of map understanding by non-literate hunter-gatherers in the Congo Basin, She spent more than two months working in the field with Congo Basin communities.

4. Methodology

The investigation presented in this paper is primarily based on a qualitative analysis of selected extreme citizen science projects based on in-depth interviews with nine researchers who have spent significant time (often measured in years) working directly with communities on the implementation, running and evaluation of extreme citizen science projects. To better contextualize interview data in each specific case study, we augment interview data, which includes anecdotal evidence, with relevant notes, blog posts, videos, mobile application interface analysis and other materials that may further refer to specific fieldwork experiences.

The goal of our research is to uncover factors surrounding the implementation of extreme citizen science projects in developing regions, with a particular emphasis on the role of mobile technology interaction issues. We first performed the examination of the related work with a particular emphasis on publications stemming from the selected initiatives, i.e. (Altenbuchner, 2018; E. H. Blake, 2002; Chiaravalloti, 2017a, 2017b; Chiaravalloti, Homewood, & Erikson, 2017; Liebenberg et al., 2017; Stevens et al., 2013, 2014; Vitos, 2018a; Vitos et al., 2017, 2013). From our goals and the related work examination the two authors individually extracted themes that were later refined in an internal discussion, as well as in a discussion that followed the workshop where the initial outline of our work was presented Workshop at UCL, London (2018). The themes we cover in our analysis include:

- **Background and context**, including the community organization, literacy, geographic location, available infrastructure, and other environmental factors.
- **Project organization**, including the details about the communication with the community, role and responsibility assignment, possible remuneration for data collectors, and similar.
- **Technological solution background**, including the details of the mobile software and hardware, as well as the auxiliary equipment needed (e.g. batteries, chargers, solar panels).
- **Technology interaction details**, such as the physical means of interaction (e.g. touchscreen, voice commands), users' conceptualization of the technology, as well as the issues related to data reporting and visualization. Since all the case studies involved mobile applications that used pictorial interfaces for data collection, we further investigated the organization of data representation items and categories within the application (e.g. linear or hierarchical) and visual interface design, including 2-D or 3-D icon design, icon colours, visualization style, and similar.
- **User feedback collection**, usage observation and (in)formal evaluation of data collection.
- **Reflections on the technology use**, including the researcher's vision of an ideal solution for the problem at hand.

Five interviews were done in person (with R1, R3, R4, R8, and R9), while four (R2, R5, R6, and R7) were performed via teleconferencing. Besides the interviewee, each interview included both of the paper's authors as interviewers. Interviews were semi structured and each interview lasted for approximately one hour, giving a total of nine hours of interviews. The two authors individually analyzed all the interviews and identified the most prominent and previously unreported organization, evaluation, and mobile interaction issues. Through a joint discussion and, when needed, reiteration with the interviewees, the authors distilled common issues shared across different case studies. Aspects that would diverge across different studies were juxtaposed to identify contextual differences that might explain the findings. In addition to the interviews the two authors individually analyzed the relevant blogs (Chiaravalotti, 2018; Comandulli, 2018; Conquest, 2015; Hoyte, 2018; Laws, 2015), video posts (PPGIS, 2009; TEDxUCL, 2012; Vitos, 2018b), and notes collected during researchers' presentations (Comandulli, 2017; Workshop at UCL, London, 2018). These were then merged in a single document by one of the authors along the previously defined themes (see above) and the evidence was then used to augment claims from the interviews.

5. Organizing extreme citizen science projects

Prior to conducting our interviews we were fully aware that extreme citizen science data collection initiatives in the developing world are often complex endeavors involving multiple stakeholders, such as local communities, government and non-government organizations, researchers who follow a long-term agenda, and who rely on voluntary participation under the assumption that it is for the communal benefit. In our attempt to understand the nature of interactions, the barriers and opportunities, we felt that it was needed to also shed some light on organizational practices employed in these initiatives. We were particularly interested in singling out factors that were crucial for successful implementation of each initiative. Such factors include mobilizing stakeholders, motivating participants, and identifying the necessary human capacity for successful project implementation.

5.1. *Local community involvement*

Local volunteers' time and effort are key assets of a citizen science initiative. Ensuring volunteers' participation can be challenging due to an often limited number of people who can be reached by the project, lack of interests and skills (above all, leadership skills) needed for the project completion, and a societal organization that requires a careful approach towards participant mobilization. In addition to those, interviewees suggested that local communities must be involved in such a way that the goals, benefits, and risks of the project are clearly communicated, and that participation is fully defined and agreed upon, while at the same providing the opportunity for the community to step out of the project, if desired.

For the initiatives we examined it was clearly demonstrated that they require careful matching of local community needs and skills with the interests and support offered by other stakeholders. In a preliminary phase of a project the match must be identified. For instance, the initiative on reporting illegal poaching in Cameroon (I3) was conceived from a long-term collaboration between the ExCiteS group and local Cameroonian communities. However, the implementation required the matching of particular communities that identified poaching as a problem with the group's experience in building mobile data collection and geospatial visualization applications. During this preliminary phase, R3 visited a number of these remote communities and discussed their grievances until five communities that identified poaching as a problem were isolated. Moreover, participants should also be clear about the long and short-term benefits of the initiatives they decide to participate in, especially if the communities expect some sort of compensation for their participation. While the majority of the interviewees explained that it is often preferred that compensation is not provided in the form of financial benefits, for reasons explained later in the text, I3 participants were reimbursed for their data collection efforts.

5.1.1. Free prior and informed consent (FPIC)

Most of the initiatives we examined are centered around aspects of key importance to local communities. These include the preservation of natural resources used for food or medical purposes, or protection of locations of cultural and religious importance to the communities. Further, participation, in terms of data collection, may carry significant obligations and risks for the volunteers and the community as a whole, when initiatives expose activities of organized criminal groups (either as a primary aim or as a side-effect). In other contexts, identification and data collection of TEK may lead to security implications, in terms of what data the community is ready to share with outsiders and what data they would like to protect. Communities need to be fully aware of the risks that an initiative would bring to the community itself and those who will collect the data. They further need to be fully aware of all aspects of project execution, and should give their explicit consent for the project to run. The consent should be achieved beforehand in a form agreed upon on the community grounds, and with full involvement of local population.

As noted in Section 2.3 many of the extreme citizen science initiatives that were included in our investigation use an FPIC tool to ensure a mutual understanding and agreement between external participants and local community and also as a tool to safeguard indigenous communities and their rights. In our interviews R3 explains how FPIC was used in the project related to illegal poaching prevention in Cameroon. First, the researcher, together with a local translator visits indigenous communities where the team has spent a few days living with local people to establish the necessary trust. It is important to note that at this phase the technology was not discussed nor brought into the village, in order not to distract from the main goals of FPIC. In the next step, a discussion about the needs and interests is initiated with the community. Researchers that we interviewed have worked with variously structured societies. Baka hunter-gatherers from I3 nurture an egalitarian society without a clear leader, required a broader community consensus before engaging in a project. Thus, R3 initial discussions require a dialog where the whole community is present and participates. This is in line with previous research arguing that participation through communal activities is much more appropriate than creating artificial individual settings for participation design when working with egalitarian societies (Winschiers-Theophilus et al., 2012). This, however, was not the case in I1 where the indigenous community fighting cattle invasion in Namibia is led by a chief, whose son organized the process of training and coordination of data collection volunteers, and who therefore represents the main point of contact with R1. The clear hierarchical organization in this case enables an one-stop access to the community, yet, it also means that the project's success is highly dependent on the engagement of those main actor(s), with the possible exclusion of others. Interesting observations were brought up by R5 who works with South African trackers. In 1950's these, otherwise egalitarian communities were obliged by the government to elect chiefs. Resulting changes in the social organization are also reflected in participant's behaviour within the initiative I5 – while the elder trackers advocate equal reimbursement for all data collectors, younger ones prefer a scheme that favours those with higher tracking skills. Finally, when (if at all) consent is achieved it is communicated and expressed in ways which are understandable for all involved parties. For instance, among certain Pygmy populations the achievement of consent is marked by a celebration.

5.1.2. Establishing a community protocol

Following the FPIC process, a community protocol is developed in most initiatives discussed herein. The protocol unfolds in parallel with participatory design processes (see Section 7) that also take place within the community. According to our interviews, the purpose of the community protocol is to formalize community's participation and to outline parties' contribution to the process. For instance, the protocol may specify who will be involved in data collection, how different data elements are handled (e.g. anonymity, privacy, secrecy), it defines possible remuneration for collected data, and other aspects of the initiative. The protocol specifies access to data collected – with the community deciding what, with whom, and to what extent to share their data. Such decisions have been found to impact the development of relevant technologies or add-ons and settings to address these needs (e.g. satellite image sharing and storage, data encryption mechanisms as currently being utilized by Sapelli implementations in such initiatives as I3)

In the majority of initiatives analysed here after FPIC, and in parallel to the process of participatory solution design (see Section 7), a *community protocol* was developed (see Figure 1). The community protocol formalises the community's participation and outside parties' contribution to the process. For instance, the protocol specifies who the data collectors are, how different data elements are handled (e.g. anonymity, privacy, secrecy), it defines possible remuneration for the

(a) FPIC.

(b) Community protocol.

Figure 1. Conducting the FPIC procedure with the Surui tribe (I6), courtesy of Vasco van Roosmalen; and building the community protocol with the Ashaninka (I4), courtesy of Carolina Comandulli.

collected data, and other aspects of the project. The protocol also specifies who has access to the collected data – with the community deciding what, with whom, and to what extent to share their data. Such decisions may influence the development of relevant technologies to address these needs (e.g. satellite image sharing and storage, data encryption mechanisms).

However, our interviewees explained the an agreed community protocol in practice might not often be adhered to. One possible reason is that data collection may significantly alter the daily lives of participants. R4 observes that Ashaninka people were often too busy with other chores and the use of the data collection software just did not fit in with their everyday activities. In other situations, the community protocol may also be ignored due to conflicting interests. For instance, despite the preliminary agreement, fishermen in I2 did not always record videos while collecting data to avoid being accused of catching fish that are too small. The protocol can also be ignored when participants fail to understand the concepts behind it. For example, Baka people live in a highly egalitarian society where secrets are unheard of. Thus, despite being briefed about the security risks, those involved in reporting illegal poachers had struggled to be secretive about the project and not talk about it with the rest of the community. Yet, one of the most challenging cases of protocol evasion was recorded by R3, who noted that community members intentionally ignored preparing their smartphones (i.e. charging, checking for updates etc.) before data collection trips because they noticed that the external researcher would eventually prepare and hand the phones to them, despite this not being agreed upon in the community protocol.

5.2. Finding local champions

Kentaro Toyama, one of the leading scholars in ICT4D research, in his critical examination of both his own, as well as other efforts in the field postulates that technology can merely amplify the existing (positive or negative) potential for change (Toyama, 2015). The technology cannot, despite strong previous efforts, significantly impact societal matters without the underlying human capital, who would carry the necessary change out. The initiatives we examine are not an exception and their success is certainly conditioned on the level of motivation and skills of the people who participate in them. A significant majority of the projects we examine are conceived by the communities and directly address local needs, so a basic level of motivation is almost always present. Skills, especially the ones pertaining to solving societal issues, might or might not be present within the communities. In her blog Gill Conquest, an anthropologist who worked in the Congo-Basin with Pygmy hunter-gatherers, described how the presence of an already established local group of concerned volunteers gave her hope that a participatory mapping project can be a successful one (Conquest, 2015):

> “On the surface this project is much like the others – a logging company is about to begin cutting in the rainforest on which local Baka communities depend, but has indicated it would be open to incorporating a participatory mapping program within its management plan …
>
> But there’s something about this context that’s different … Ndima-Kali is a small group of Baka and Sangha-Sangha youth who come together three times a year, in workshops facilitated by independent NGO OrigiNations and funded by WWF Germany, to discuss and act on issues that concern them – the loss of traditional culture, drugs, alcohol and prostitution, discrimination, education and employment … Of course, even with the support of this group there are still individual and organizational agendas to navigate, ephemeral project funding regimes to negotiate, incompatibilities within technological ecosystems to overcome and capacity building needs that must be addressed. But for the first time in a long time, I feel that here I’ve found some allies who really get and support what ExCiteS is trying to do.”

5.3. Bootstrapping a project – stakeholder mobilisation

Getting support from all the relevant stakeholders has already been identified as a key requirement for successful ICT4D projects in general, thus, it remains a crucial aspect for data collection initiatives conducted in rural developing regions. Almost all initiatives we examine involve local indigenous communities, government bodies, and locally active industry players. However, the extent of stakeholder involvement varies. For example, while I2 examining land use in Pantanal, Brazil managed to sufficiently involve the government, so that data collected in the study indeed informed land use policies, officials in charge of preventing illegal poaching in the Congo Basin (I3) often failed to react even when data collected by the volunteers signaled a need for action. In a other rare cases, key parties can even be hostile to the project, as exemplified in the project with South African trackers, where a national park ranger objected the idea of giving non-white people access to mobile technology (I5).

Finally, although there are additional challenges that influence stakeholder involvement and, consequently, the success of a CS initiative (with some of these challenges being political in nature[1]) these should be studied separately within specific contexts of use and with the involvement of relevant stakeholders and we therefore choose to not analyze and discuss isolated incidents further. We just acknowledge that for most of the examined initiatives, the main organizational challenges that are mentioned by the interviewees refer to communication and coordination of volunteers in the field and the stakeholders in power, whose involvement is needed in order to close the loop from observations to actioning. As pointed out by R3, without the loop being closed, volunteers may abandon the project, since the their goals are not achieved. This, for instance, is the main reason why in I3 financial compensation is used to as a tool for ensuring sustained data collection.

6. Mobile computing for extreme citizen science – opportunities and challenges

Mobile computing solutions for data collection are utilized in all the initiatives we analyze in this paper. Wide availability and a relatively low price makes the smartphone a preferred choice, over the more traditional paper surveys, photo cameras, and other data gathering technologies. However, smartphone solutions for data collection, especially those targeting inexperienced users in rural developing regions, are scarce. The following three mobile application frameworks for data collection are used in the examined initiatives:

- **Sapelli** – a mobile data collection and sharing platform designed with a particular focus on non-literate users. The main part of the platform is a data collection app for Android devices which uses pictorial decision trees and icon-driven interfaces to guide low and non-literate users through data collection. Sapelli decision trees are defined in XML by nesting XML nodes, where the outermost node represents the first decision that must be made. Users navigate the decision space by repeatedly selecting a child node until they reach a leaf node, which represents a final selected value. This hierarchic description makes the structure of the decision space immediately apparent by looking at the XML code. The application also supports photo, audio, and location recording. A background service within the app automatically checks for connectivity at scheduled intervals. When there is data to be sent, the service autonomously decides what to transmit and how, depending on available networks, bandwidth and project-specific settings. Finally, the app features and optional Sapelli Launcher, a component that replaces the Android default launcher and only shows icons for a set of allowed apps, as per project requirements and user abilities (Stevens et al., 2013)
- **Cybertracker** – conceived in the 90s CyberTracker evolved from the initial attempts to preserve and improve indigenous wildlife tracking skills in Kalahari desert. The first version of the solution included wildlife observation recording software running on an Apple Newton PDA device hand-wired to an external Garmin GPS. This pioneering effort in developing icon-based user interface for non-literate data collectors was later ported to other PDAs and finally Android and Windows Mobile devices. CyberTracker applications are created as linked screens that are then shown on a mobile device. Each screen can host a set of elements, i.e. data items, that are represented by icons and textual descriptors. Further, screens can be organised in different kinds of list, can support numerical or textual entries, GPS location recording, etc. Besides for wildlife tracking in the Kalahari desert, CyberTracker was used in other areas, for instance in Australia where Aboriginal rangers use it for environmental monitoring and management (Ens, 2012), or in central Africa where wild animal ebola outbreaks were detected through wildlife monitoring alerting health authorities of imminent risk for human outbreaks weeks in advance (Rouquet et al., 2005).
- **Open Data Kit (ODK)** – is an extensive open-source modular toolkit that provides data collection and aggregation using resource-constrained devices (Hartung et al., 2010). ODK enables data collection through smartphone interaction but also through voice rendering of ODK applications through automated phone calls. Initially, ODK applications had to be written in a form of XForms code, which posed a significant burden for creating data collection campaigns. With later updates the toolkit now supports non-technical users with designing data collection forms, data collection through externally connected sensing devices, and managing data in the cloud (Brunette et al., 2013). ODK has a large user community and ODK applications have been deployed in a few dozen countries worldwide. Some examples of use include childhood illness diagnostics Tanzania (Hartung et al., 2010) and vaccine cold chain monitoring in Mozambique (Brunette et al., 2013).

Despite the warnings that information and communication technology is not designed to be suitable for underdeveloped and rural environments (Brewer et al., 2005), modern computing devices are increasingly imposing very high energy, connectivity, and user proficiency requirements. In the following paragraphs we summarise the usability issues that are the most prominent across the nine initiatives that we explore:

- **Energy requirements**: Smartphones require daily charging due to high energy consumption of the touchscreen, sensor chips (especially GPS), and communication interfaces. Congo-Basin hunter gatherers from I3 and I8 live in forest environments without access to grid connectivity and where alternative means of energy harvesting, such as solar panels, are of little use due to thick foliage, which prevents sunlight penetration.
- **Access to infrastructure**: Technical solutions involving smartphones and laptops are highly reliant on a whole technological ecosystem that is in urban developed world taken for granted. Devices need suitable chargers, cables, correct power plugs or converters. Due to the site's remoteness and the lack of local infrastructure, these issues are particularly prominent in the project with the Ashaninka people in west Brazil (I4)
- **Software updates**: Smartphones assume constant wireless connectivity. In areas with patchy connectivity automatic updates lead to unstable software states and buggy performance. The problem was especially prominent in I4.
- **Screen brightness**: Ju'hoansi community from I1 resides in planes of eastern Namibia characterized by low vegetation and climate with a high number of sunshine hours. Using smartphone touchscreens in such bright outdoor environments can be challenging due to insufficient screen contrast.
- **Inappropriate interaction interface**: Smartphone interaction is designed around different on-screen gestures (e.g. short tap, long tap, swipe, pinch, etc.). As reported by R3, unfamiliarity

with these gestures may frustrate and prevent certain rural users from using the smartphone. In addition, a touchscreen might fail to detect gestures conducted by a rural dweller's rough finger calluses.

- **Perceived value issues**: Perceived value of a smartphone can also repel certain users. R9 reports reluctance to use the phone among Congo Basin forest dwellers, as they were afraid of breaking an expensive device. Similarly, in I7, conducted in a high-crime urban area, users were concerned both about their own devices being stolen, as well as about their personal responsibility for project-supplied phones that get lost or stolen. In the end, I7 was conducted in a sheltered environment of a school courtyard, which although acceptable for an explorative study of participatory mapping, raises questions about the ethical issues with citizen science projects that rely on relatively expensive technological solutions.

Still, the smartphone is becoming ubiquitous and recognized in some of the most remote areas of the world. It carries an inevitable "cool" factor with it and, as shown in the study conducted in an informal urban settlement in Brazil (I7), even the most impoverished users are eager to hop on the bandwagon. Smartphone's versatility is an important factor, thus, among the Ashaninka community (I4) users were quick to embrace not the specially developed Sapelli-based data collection app, but WhatsApp, a globally popular messaging solution. Besides the utility, the adoption is also driven by a simple desire to collect new gadgets (R1). Smartphone's popularity might help researchers engage citizen scientists in remote areas. However, premature introduction of the technology might steer users away from the true goals of the project (R3), thus, as explained in the previous subsection, the technology should most probably be left untouched before the user needs and expectations are fully understood.

Finally, when introducing new technology, whether it is a never before seen device or a new smartphone application, a researcher should not forget that for a user this represents yet another thing to learn. The data collection tool usability study in a Brazilian slum (I7) demonstrates that the usage frequency/ease of re-learning is another important factor. Here, users were initially trained to map POIs using the mobile application, yet, depending on the time spent without using the tool, users were more or less successful in correctly using the application by themselves. As it is the case with other technologies and a general interaction design principle, when designing for a data collection solution in the developing world, care should be taken that concepts can be quickly re-learned. Learnability is an integral usability characteristic; the easier it is to learn an interface the easier it will subsequently become to use it. With that in mind it is not surprising that intuitive solutions allow even those who were not the intended users to pick it it up and contribute to data collection. For example, in several initiatives, such as I1 and I4, children in the community managed to used the data collection application even without previous training. The tension between the professional and personal usage of mobile devices in ICT4D settings has been reported before (Schwartz, Bhavsar, Cutrell, Donner, & Densmore, 2013); yet, intermediated technology use opens up opportunities for less skilled or non-literate to benefit from the technology via a proxy user, usually younger and better educated (Sambasivan, Cutrell, Toyama, & Nardi, 2010).

7. Designing mobile-based data collection

Distributed volunteered data collection is central to each of the initiatives we have examined. Due to the initiatives' focus on local resources preservation, data collection often entails indigenous knowledge gathering. This takes form in collecting information about the presence and location of natural resources as well as potential threats (Stevens et al., 2014).

Drawing from the interfviews conducted with expert researchers in this section we present key issues in data collection design that are most common in the initiatives we examine. We first discuss the participatory design process applied in the majority of the examined initiatives and we then review how particular issues of item and knowledge organization design were solved by our interviewees. It is worth mentioning that our analysis remains limited to mobile computing technologies (with mainly pictorial interfaces, which target non-literate and low-literate users) as it was the method of choice for data collection in all the studies we examined. The most common tool we encountered was Sapelli (Stevens et al., 2013), followed by Cybertracker (Liebenberg et al., 2017) and Open Data Kit (Hartung et al., 2010) (see Table 1). However, other tools, either alone or in combination with mobile apps, such as paper surveys, maps, special sensing equipment and others, may be used in extreme citizen science projects.

7.1. Ethnographic design

The interfaces of the data collection tools used in the examined initiatives have been either partially or in full co-designed with the intended users, evaluated through ethnographic interviews, and in a couple of cases refined after direct usability testing conducted according to contextual characteristics as further discussed in Section 7.4. Ethnographic interviewing assumes both immersive ethnographic observation and directed one-on-one interviews.[2] The former is necessary in order to understand the everyday life and the culture surrounding the intended users, the latter is needed for the local community to be actively involved in shaping the tools they will be using. The core of the process is defined by Holtzblatt and Beyer as *contextual design* (Beyer & Holtzblatt, 1997).

Contextual design requires that the interface developer observes the users working with the technology in its actual context of use, as opposed to develop a solution in the lab according to a predefined specification. Through iterative participatory design is a solution then tailored to user needs and the actual contextual characteristics. When a software solution is refined through participatory design there are additional benefits of demystifying the solution development process. The users can understand the malleability of software, which allows them to, instead of taking it for granted, request their own changes and additions to the solution (Figure 2(a)).

(a) Participatory design. (b) Locally relevant visualization.

Figure 2. In a) a user from I3 draws the desired representation on the ground (courtesy of Gill Conquest); b) the border of the map designed by Surui from I6 featured additional visual elements that among others symbolize territorial claims, ancestors, and resource preservation (courtesy of Vasco van Roosmalen).

In the initiatives we analyzed the most common form of adaptation was the pictorial icon design (further discussed in Section 7.2). Researchers would typically start with paper prototypes containing initial drawings, which would then be discussed with the community to solicit comments on design ambiguity, preferred means of depicting objects, and to obtain suggestions for design improvements. An iterative approach ensured that icons (which would represent the data to be collected) are redrawn until fully understood by the community and that irrelevant icons are discarded, thus, that any potential for errors in data collection is minimized. The participatory design process also enabled a community to embrace a solution as “their own”. For instance, R6 reports that fishermen and bait catchers required that the initially designed application is split into two – one for fishermen, the other for bait catchers, so that each community has its own app. Similarly, even when icons were recognized accurately, the hunter-gatherer community in the Congo Basin (I8) requested that the depiction is changed, if they find the original drawing diverged from their vision of an object. Participatory design also allows for local metaphors to be used – maps generated by the Surui tribe (I6) feature additional visual elements that indicate the maps’ utility for cultural, historical, territorial, and resource-preservation purposes (Figure 2(b)).

We note, however, that participatory design is not without its drawbacks. It is an expensive and a long-lasting endeavor, having in mind that often multiple trips to difficult-to-reach regions are needed. Furthermore, sometimes, as reported by R3, users forget the meaning of the designs they co-develop and ask for changes, which puts an additional burden on the solution development. But probably the most striking limitation our interviewees report is the problem of running through “what if” scenarios with inexperienced users. R8 and R9 report that when they asked their users to comment on how the application is (or could be) used in imaginary scenarios and for tasks not already supported by the solution, the users struggled to grasp the meaning of a “hypothetical situation” and therefore failed to effectively answer these questions. Testing multiple potential solutions (even minor interface tweaks) using participatory design with inexperienced users would require creating and introducing to the users all these very specific situations, which significantly increases the time, effort and resources required for solution development.

7.2. Picture-based interface design

At the interface level, technologies aiming to support data collection in extreme citizen science have to face two challenges: 1) how to communicate the meaning of data object representations to non-literate and low-literate users, who in their majority are also inexperienced in interacting with mobile computing devices, and 2) how to organize knowledge concepts so that users without formal education successfully navigate through hierarchical structures incorporating these data object using appropriate abstraction levels. All of the initiatives we have analyzed utilize mobile phones loaded with data collection applications requiring users’ input through a touchscreen. For low-literate users picture-based interfaces are often the most effective way of interaction with mobile computing technology (e.g. (Frommberger & Waidyanatha, 2017; Medhi et al., 2007; Parikh et al., 2003) and further in Section 2.2).

Mobile computing solutions are to a large extent still built by and for urban developed users. Visual interface of mobile apps is driven by design guidelines (e.g. Android “Materials”) supplied with major mobile operating systems. However, many of the extreme citizen science initiatives examined here represented the first opportunity for participants to interact with smartphones. Consequently, visual designs, cues, and other metaphors commonly used in urban developed settings, are here rendered unusable, as the populations have not had a chance to previously familiarize themselves with – and even build some intuition in terms of using – these interaction concepts. This is true for both visual representations of real-world objects and actions (i.e. icons), as well as for the organization of data collection items (discussed in the following subsection). For instance, participants from the Congo Basin (I8) requested more realistically drawn icons, while fishermen in rural Brazil (I2) requested that the actual photos of fish species are used (Figure 3(a)). However, it should be acknowledged that the digital literacy skills of the latter were different than those of the former, as most of the fishermen in this initiative have previously interacted with mobile devices and have therefore been more familiar with digital photography visualizations.

In line with previous research (Lalji & Good, 2008; Medhi et al., 2006)f, the participants also requested that

(a) Photorealistic images. (b) Local metaphors.

Figure 3. Realistic images used in a data collection app from I2 (courtesy of Rafael Chiaravalloti); Local metaphor "thumbs up" used instead of the "check" sign in I3 (courtesy of Simon Hoyte).

representations are stripped of symbolics and, where possible, also show the context in which the objects and actions are commonly found. Thus, R8 reports that users in the Congo Basin required that certain icons depicting forest-based objects feature a forest in the background. Participants in I4 requested for more color in the drawings. In addition, the participatory design process often resulted in locally relevant metaphors getting embedded in the visual representations. Thus, wildlife trackers in southern Africa (I5) depicted a specific plant with a wheelbarrow icon, as the name of the species sounds like the word "wheelbarrow" in a local language. In another example, Cameroonian hunter gatherers from I3 understood a local "thumbs up" sign better than an imported "check" as an indicator of a successful data collection session (Figure 3(b)). Local meanings were also attached to icons used in I7 where slum dwellers saw shopping malls as places of entertainment (and depicted them with an escalator icon), as high prices prohibit them to actually do the shopping there. Yet, many symbols surprisingly cross literacy barriers. For example, irrespective of being unable to read, urban Brazilian users correctly recognized written trademark logos as they were exposed to them on a daily basis (I7).

Some of the examined extreme citizen science initiatives make use of both textual and symbolic representations on their interface design (e.g. I5 and I6). However, interviewees suggested that one should be careful not to overburden low-literate users with visuals and/or text. R7 leading the research in urban Brazil for instance, reported that mixed text-picture interfaces negatively affected data collection times, as users kept switching to "reading the app" mode, de-prioritizing the main data collection task. Another modality that can enhance data collection applications is sound. For example, as noted in some of the related work (Medhi et al., 2006), when the goal of the data collection is to identify activities, icons representing actions are better received than icons representing objects utilized in such actions. Yet, drawing such icons may be challenging. In I1 the same effect was achieved through overlying voice instructions – a spoken description of the action was played whenever a user clicked on an icon.

7.3. Knowledge organization concepts in mobile data collection apps

The organization of knowledge, for example in hierarchies, is something that it is taught in formal education programs. Difficulties in navigating hierarchies have been observed by a number of researchers we have interviewed (R3, R4, R8, R9), which is in line with previous research findings on mobile phone interface use among low-literate users (Section 2.2). Problems ranged from not being able to abstract a group from a particular instance drawn on the icon (e.g. "animals" from "gorilla") to not understanding that the selection process must finish at a leaf node. In their study of low-income users in India Medhi et al. demonstrate a correlation between the level of formal education and a user's ability to navigate hierarchies (Medhi, Lakshmanan, Toyama, & Cutrell, 2013). Yet, in a mapping study among non-literate urban users in Brazil (I7) there was no confusion with how a pictorial decision tree is used, despite the lack of formal education among the users. Most of these users, however, although non- or low-literate, had already used smartphones before the study. We hypothesize that exposure to the smartphone, and its often hierarchically designed apps, equips users with an understanding of hierarchical navigation structures, which is otherwise acquired through formal education.

In the conventional mobile application design the hierarchical organization is preferred as it efficiently uses the limited screen real estate – subcategories can be adjusted so that at each navigation point a user has a good overview of the items within the subcategory. An alternative, simple linear representation with only one level composed of all the items, would, for an experienced user, increase the interaction time, as one needs to scroll over a possibly large number of items before the desired one is identified. However, for users unfamiliar with hierarchies such a design might lead to fewer errors and abandoned data entry sessions. To increase data reporting accuracy from around 75% to 95%, our interviewees from I8 developed Tap & Map – a linear mixed physical/digital interface for data collection based on NFC-enabled printed cards depicting data collection objects (Vitos et al., 2017) (see Figure 4). A user would select a card

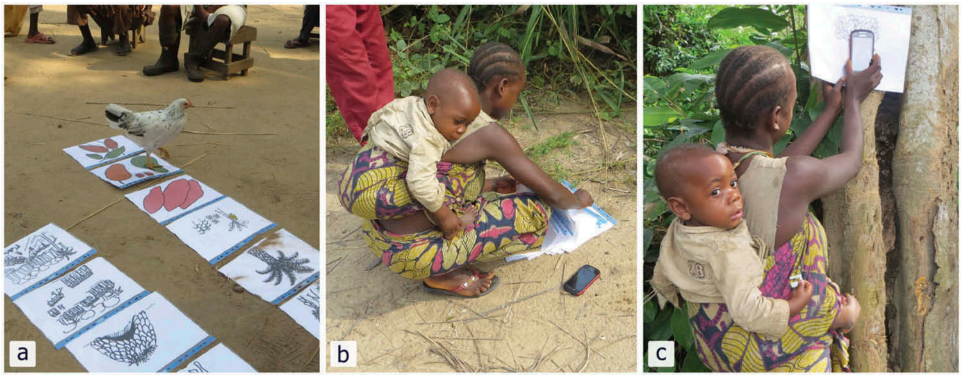

Figure 4. Tap & Map mixed physical/digital data collection: a) printed cards depicting natural resources; b) selecting the appropriate card; c) mapping a resource with a combination of a phone and a card. Photos courtesy of Michalis Vitos.

showing a desired object and report it by tapping the card with a mobile phone. Despite increased reporting accuracy and being preferred by the community in I8, Tap & Map has obvious scalability issues (need to physically make the cards). A middle ground between fully linear and hierarchical interfaces could be, as suggested by R4, an adaptive item bank that would be shown in a reconfigurable view according to the number of items relevant for the situation at hand. Thus, the system would arrange icons in a scrollable page, adjust their size, split them in different pages, depending on the number of items and their mutual relationship. Finally, to the best of our knowledge, none of the data collection tools supports context-aware interface adaptation. Hierarchical menus could be further simplified if the ontological relationship between the data items and the context are taken into account. For instance, a user mapping both fish and tree species would be shown only the latter, if the GPS location would indicate that she is in the middle of a forest.

One means of information organization proved to be easy to comprehend to all the involved parties, irrespective of their level of formal education, literacy, and cultural background. Throughout all the initiatives analyzed in this paper *geographic maps* have transcended barriers and provided a common ground for indigenous communities and foreigners alike (Lewis, 2014); 14 millenia old maps found in caves further support maps' universality (Utrilla, Mazo, Sopena, Martínez-Bea, & Domingo, 2009). This opens significant opportunities for the future development of data collection tools targeting extreme citizen science initiatives, especially in terms of visualizing the information collected, which is an essential user requirement. Spatial information remains not only relevant for a number of pressing issues that vulnerable communities face, including natural resource protection, cultural heritage preservation and similar, but also, when collected via digital means, local information easily integrates into geographic information systems of outside researchers, governments, and industry stakeholders, allowing stronger involvement of these actors.

7.4. Evaluating mobile designs with inexperienced users

Usability testing, perhaps the most popular and widely used evaluation method in the developed world, is used to identify usability problems through the provision of a selection of well-defined tasks and observation of how participants are trying to accomplish them. Previous research has already shown concerns about the difficulties in applying the method in an HCI4D context and our interviewees have also commented that struggled in understanding these hypothetical situations, which are introduced by usability testing tasks, and providing the feedback the research were seeking. To overcome this problem in some situations, such as in I8, the researchers had to be creative organizing treasure hunt games in the forest to understand how geographical data collection prototypes are being used.

Apart from methodological issues, evaluating usability aspects with remote communities might be challenging due to other issues; e.g. several of our interviewees mention the lack of honest and constructive feedback from their users as this is not in line with the way their societies and belief systems work. Users lacking formal education seldom criticize projects. Within this context, and as already noted in the literature (Dell, Vaidyanathan, Medhi, Cutrell, & Thies, 2012), there is a bias towards whichever solution users think the interviewer has designed. Feedback in most situations is positive, even when the observed behaviour indicates otherwise (R8). As suggested by R4, the criticism is avoided as it goes against the principles of the egalitarian society that these users belong to. Another barrier to effective evaluation, poses the lack of vocabulary and experience to comment on the UI and propose alternatives, as noted by R8. In initiatives such as I5 where R5 have gotten deeply integrated in the community, getting honest feedback was more likely than in other studies.

8. Providing data collection feedback and closing the loop

Volunteers motivation for participation in citizen science projects includes factors such as personal interest in the topic, sense of belonging to a community, acknowledgement and attribution of the efforts, and others (Rotman et al., 2014). The role of feedback for sustaining participant motivation is recognized in other types of altruistic efforts (Zhu, Zhang, He, Kraut, & Kittur, 2013) and is certainly important in citizen science initiatives explored in this paper as well. Most of these initiatives are driven by communities and individuals desire to address their local concerns. Yet, we observed that for the initiatives discussed herein closing the loop and providing feedback about the amount and the quality of the gathered data, displaying aggregate data points in an intuitive way, as well as exposing the link between the collected data and the induced changes in, for instance, public policies, has proved to be extremely challenging due to different technological or social issues.

The difficulties in showing the results of data collection back to the users are evident in the experiences of R2, who describes the situation as follows[3]:

> "The visualizations were very well received by the community. The discussion and ongoing visualization of their datasets helped to build and strengthen relationships of trust with the participants who had rarely worked with researchers before. However, often they would have to wait for months to actually see the data collection results. The location where the data was collected was out of the wireless signal coverage, so the data was transferred to a laptop during [R2's] occasional visits, taken to London, where [R2] would load the data into ARCGIS to create the maps that would be brought back to Brazil …
>
> … giving feedback to data collectors is crucial, but it cannot be done with the current tools, neither ODK nor Sapelli. Data retrieval should be easy to do even on-site with all the heat, mosquitoes, and time constraints imposed."

Even when a locally-deployed equipment is used to bypass the need for wireless connectivity, the challenge of generating the visualizations on the ground remains, as witnessed by R4:

> "No immediate visualization of the data was available for the participants through the app, although later the visualization would be done using QGIS on a local PC. The participants were excited about data collection once they could see the data on a PC. Additionally, users who collected the data were happy to see it for themselves and show it to others, which might motivate data collection further. However, getting data from the devices to a PC and visualizing the data proved to be too challenging, so the four community members who were appointed to do this simply stopped the training process at one point."

Finally, R5 summarizes an indigenous wildlife tracker's motivation as:

> "CyberTracker motivated him to record all his observations, because he knew that one day his children will be able to see his work."

Technical issues that surround participatory data collection aggregation and visualization include: i) intermittent wireless connectivity; ii) limitations of data visualization on a resource-constrained device such as a smartphone; iii) lack of easy-to-use visualization tools geared towards inexperienced users. The lack of Internet connectivity has spawned a plethora of research solutions that rely on ad-hoc delay-tolerant networks created among wireless devices within a community (Pentland, Fletcher, & Hasson, 2004), or on locally deployed wireless networks and protocols facilitating local content generation and sharing (Johnson, Pejovic, Belding, & van Stam, 2012). However, modern smartphones run operating systems and applications that practically assume always-on connectivity. Supporting users from remote regions to both use commodity phones and apps, and implementing delay tolerant solutions on the same devices would be extremely challenging from the engineering side. Furthermore, the solution needs to be fully transparent to the user, as R5 explains:

> "Trackers should be able to quickly view the data on an iPad and be independent from the stuff with wires. Also, as soon as in the range of connection, data should go to the cloud and back."

The lack of data visualization tools that are intuitive to novice, perhaps low-literate users, is a major challenge that the extreme citizen science research community should focus on. Tools such as ODK, CyberTracker, and Sapelli have successfully tackled the data collection part, and lessons from their development, for instance, engaging the users though the participatory design, could prove useful for the visualisation tool development as well. Yet, further research is necessary to understand how people perceive the space in which data are collected, to identify effective spatial representations, and to employ these in the design of highly-functional visualizations.

9. Conclusions and guidelines for future work

In the presented study we have gather experiences from nine experts who work with extreme citizen science initiatives for data collection purposes and who have spent considerable time in developing regions working directly with low-literate communities to establish the methods and solutions which are tailored to users' unique needs and contextual characteristics. We have, for the first time, aggregated in-depth observations and anecdotes from such a varied set of extreme citizen science projects. This allowed us to extract common issues across all the projects, but also to identify factors that might explain some of the observed differences among projects. Having in mind that extreme citizen science initiatives take tremendous implementation time and effort, and seldom allow controlled experimentation, we believe that the juxtaposition of projects in this paper is particularly valuable for the research community and it is equally important in terms of guiding and inspiring future research.

Our work further emphasizes one of the most highly cited methodological challenges in HCI4D research – there are no 'one-size-fits-all' solutions. In the same way it is wrong to make assumptions about user needs, it is also wrong to make assumptions about contextual characteristics purely based on our western value systems and knowledge structures (Winschiers-Theophilus et al., 2012). Cultural, political and the wider socio-economic landscape needs to be well-understood to inform the design of culturally-appropriate methodological protocols. For example, in specific contexts data collection may impose dangers to those collecting them and risks to the wider community. These implications need to be uncovered early and with the consent of the community and its support to identify effective solutions – an FPIC process has been effective in achieving this goal. Being open, honest and respectful during this process, and building on trust and personal relationships with local community members, is also highlighted both by our interviewees, as well as in related studies (Winschiers-Theophilus et al., 2012; Winters & Toyama, 2009).

The final goal of our study was to derive practical guidelines for future endeavors. Guidelines are dispersed throughout the text in thematically organized sections in order to preserve the background on the observations that led towards the formulation of specific recommendations. In terms of upcoming research, below we propose a set of solutions that we believe should guide the evolution of mobile computing solutions for extreme citizen science:

- Despite ever-increasing penetration rates, mobile technologies are either not present or perform poorly in some rural developing regions. Efforts should be focused on devising resource-efficient solutions portable across a range of old and new devices that may be found in rural developing regions.

- Item organization in mobile data collection applications should adapt to both user expertise (e.g. hierarchical organization can be confusing for novice users without formal education), as well as the task at hand. Context awareness brought by mobile sensing and ontological relationship between data items and the context are potential enablers of such adaptation.

- Mobile data collection tools should be complemented with tools that enable participants to quickly and easily visualize the collected individual and aggregate data, should have the capacity to do so even in poor connectivity settings and without requiring substantial support from external experts.

- The lack of honest feedback about the technological solutions developed for these projects calls for more subtle ways of assessing usability, that might be based on fine-grain application usage logging and tools that would allow researchers to quickly identify issues from the collected logs.

- A deeper collaboration of HCI experts with (digital) anthropologists who use ethnography to study the same communities for periods as long as several years and who can give insights into cultural aspects that would influence interaction and testing, can improve understanding and allow for improved technology design.

Finally, often overlooked is the question of programming and maintenance. Despite ODK, Sapelli and similar frameworks that aim to reduce the entry barrier for building mobile data collection applications, support from mobile application and backend programmers is often necessary. Success of citizen science initiatives, especially grassroots initiatives in rural developing world, is threatened by the inability to hire programmers, which are at current times highly sought for by well-paying companies. Our hope is that this article sparks discussion about consolidating efforts and engaging a wider open-source software community into supporting extreme citizen science initiatives, as these promise to address some of the key societal challenges of the 21st century.

Notes

1. Design – especially as a participatory process that brings together people from all walks of life to support and enable some form of change – is highly political; it may be used to pursue and nourish democracy, empowerment and similar values and principles which are tied to western socio-political structures (Smith, Bossen, & Kanstrup, 2017). In doing so and planning for some future change, there are several pragmatic and ethical arguments, which are associated with the rationales, epistemological and methodological frameworks and practices (Light, 2015), which may as well be relevant to both citizen science and ICT4D initiatives. For example, in his chapter "A Tale of Two Logoi" (Wynn, 2017) Wynn looks into the influence of citizen science in public policy arguments, by examining a case that is very similar to the initiatives described here, in that it is used "to empower community members to improve their lives and counter agendas of the powerful"(p. 129) and that members of London's Pepys Estate community participate in all stages of the participatory process. Understanding how participation influences extreme citizen science practices, the change achieved or could potentially be achieved, and the politics that surround these processes, although a very interesting research question, goes well beyond uncovering and reflecting on common interaction barriers that influence the successful utilization of these tools, which is the main focus of our work. This is due to several reasons: not all initiatives explored herein are at the same level of maturity in terms of experiencing and providing the necessary evidence to support such discussion, the structures of some of these societies and the activities during FPIC have their challenges in terms of uncovering those political differences one would expect, and finally, our interviews did not focus on uncovering any political challenges, neither we tried to include all actors involved or understand their agendas, which would be absolutely essential in capturing and discussing these issues.
2. However, our interviewees report that with tightly knit egalitarian societies ethnographic interviews have to be done on one-to-many basis.
3. Quotes in this section are not necessarily verbatim, but adapted from the interviewers' notes.

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