FROM RADIO TO AI

African Community-driven Development of Sustainable Information Systems

VRIJE UNIVERSITEIT AMSTERDAM

FROM RADIO TO AI
African Community-driven Development of Sustainable Information Systems

ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad Doctor aan
de Vrije Universiteit Amsterdam,
op gezag van de rector magnificus
[Rector],
in het openbaar te verdedigen
ten overstaan van de promotiecommissie
van de Faculteit der Bètawetenschappen
op [Day] [Date] om [Time] uur
in [Venue] van de universiteit,
De Boelelaan 1105

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Keywords:

Printed by:

Cover:

The author set this thesis in LaTeX using the XY and YX fonts.

ISBN: xxxxx
An electronic version of this thesis is available at https://www.vu.nl/.

SIKS Dissertation Series No. XXXX-XX
The research reported in this thesis has been carried out under the auspices of SIKS, the Dutch Research School for Information and Knowledge Systems.

ISBN: xxxxx

DECLARATION OF AUTHORSHIP

I, Francis Saa-Dittoh, hereby declare that the thesis titled *"From Radio to AI: African Community-driven Development of Sustainable Information Systems "* and its content are the result of my own work.
I confirm that:

- This work was primarily conducted during my pursuit of a research degree at these universities.
- If any portion of this thesis has been previously submitted for an academic degree or any other qualification at these universities or any other educational institution, I have explicitly disclosed this information.
- I have consistently acknowledged the sources of published works by other authors that I consulted.
- In cases where I have included excerpts from the work of others, I have consistently provided proper source attributions. Aside from these quotations, the entirety of this thesis represents my independent effort.
- I have acknowledged all significant sources of assistance.
- In cases where this thesis draws upon collaborative efforts with others, I have provided a clear distinction between the contributions made by collaborators and my own individual contributions.

March 28, 2025

Dedicated to the loving memory of Dorothy Pornab Dittoh, a true rural developer.
1991 – 2017

But thou, O Daniel,
shut up the words,
and seal the book,
even to the time of the end:
many shall run to and fro,
and knowledge shall be increased

— Daniel 12:4

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ACRONYMS

2FA 2-Factor Authentication

3D Three Dimensional

3G Third-Generation Wireless

4D For Development

4G Fourth-Generation Wireless

5G Fifth-Generation Wireless

ACM Association for Computing Machinery

AI Artificial Intelligence

AI4D Artificial Intelligence for Development

AM Amplitude Modulation

API Application Programming Interface

ASR Automatic Speech Recognition

AT Advance Technology

CSIR-SARI Council for Scientific and Industrial Research - Savanna Agricultural Research Institute

CD Compact Disc

CNN Convolutional Neural Network

CPU Central Processing Unit

DIY Do-It-Yourself

DOS Disk Operating System

DRM Digital Rights Management

DTMF Dual-Tone Multi-Frequency

EDGE Enhanced Data rates for GSM Evolution

FGD Focus Group Discussions

FM Frequency Modulation

Gbps Gigabit per second

GHC Ghana Cedis

GILLBT Ghana Institute of Linguistics, Literacy and Bible Translation

GPIO General-Purpose Input/Output

GPU Graphics Processing Unit

GSM Global System for Mobile Communication

GSS Ghana Statistical Service

HCI Human-Computer Interaction

HTTP Hypertext Transfer Protocol

IBM International Business Machines Corporation

ICANN Internet Corporation for Assigned Names and Numbers

ICT Information and Communication Technology

ICTs Information and Communication Technologies

ICT4D Information and Communication Technologies for Development

IK Indigenous Knowledge

IO Input-Output

IoT Internet of Things

IS Information Science

IT Information Technology

ISOC Internet Society

IVR Interactive Voice Response

J2ME Java 2 Micro Edition

JSON JavaScript Object Notation

KB Kilobyte

KNUST Kwame Nkrumah University of Science and Technology

MB Megabyte

Mbps Megabit per second

MHz Megahertz

ML Machine Learning

MNIST Modified National Institute of Standards and Technology

MoFA Ministry of Food and Agriculture

MoSCoW Must have, should have, could have, would not have

MP3 MPEG-1 Audio Layer 3

NCA National Communications Authority

NGO Non-Governmental Organization

NGOs Non-Governmental Organizations

NLP Natural Language Processing

OTP One Time Password

PAR Participatory Action Research

PC Personal Computer

PDA Personal Digital Assistant

PhD Doctor of Philosophy

PS Personal System

PWM Pulse-Width Modulation

QBASIC Quick Beginners All-Purpose Symbolic Instruction Code

RAM Random Access Memory

RDS Radio Data System

SARI Savanna Agricultural Research Institute

SAT-3 South Atlantic Telecommunications cable no.3

SDG Sustainable Development Goals

SE Software Engineering

SK Scientific Knowledge

SUS System Usability Scale

SMS Short Message System

TPU Tensor Processing Units

TTS Text-to-Speech

UDS University for Development Studies, Ghana

UI University of Ibadan

UK United Kingdom

UN United Nations

UNIMAS University of Malaysia, Sarawak

USB Universal Serial Bus

USSD Unstructured Supplementary Service Data

UV Ultraviolet

VB Visual Basic

VHF Very High Frequency

VR Virtual Reality

VRA Volta River Authority

VSAT Very Small Aperture Terminal

VSDK Voice Service Development Kit

VU Vrije Universiteit Amsterdam

W4RA Web Alliance for Regreening in Africa

WASC West African Submarine Cable

WWW World Wide Web

ACKNOWLEDGMENTS

ToDO

1

THE DIGITAL DIVIDE

Chapter One introduces the background of the research and thesis. The Chapter first takes a look at Africa in its context as part of the Global South and the realities on the ground. For readers who may be unaware of or are inexperienced in the global issue of the digital divide, it is discussed into some detail. The issue of a rural-urban digital divide, which occurs in most (if not all) developing countries, is also explained. These two broad issues form the crux of the problem of digital information access in the developing world and therefore, to have an idea of what has been previously done to mitigate these divides, the chapter lays the background to later look at the idea of "Connecting the Unconnected" and the challenges associated with it.

The chapter also outlines the methodologies used in this research, and the research area; these are not trivial to the context of the issues at hand. The idea of a user-centric cum living-labs-like methodology combined with an interdisciplinary approach is also explained.

1.1 MYTHS VS REALITIES

Africa is the last place most people (including most Africans) will think about when you mention the Information Age, or the Fourth Industrial Revolution. There has been, and still is, a lot of misconception concerning the continent, and these myths are detrimental to the development of the continent whereas knowledge and attention to the realities would benefit the continent of Africa.

One of the main misconceptions is that Africa is a single, homogeneous entity and this, although being used in many jokes and comedies around the world, is not a trivial issue. Africa is a diverse continent with 54 countries, two independent states with limited or no recognition (Western Sahara and Somaliland), and several territories (mostly islands) controlled by non-African countries, each of these with its unique culture, history, and socio-economic situation. It is essential to recognize that the progress of the information age and the 4th industrial revolution varies across the continent (Chabal, 2009). Furthermore, within each African country exists a diverse number of regions and tribes who have varied cultures and languages. Also within each African country is typically a range cities, urban slums, towns, peri-urban communities and rural villages, all at varied stages of development ranging from highly developed communities in the cities, to highly impoverished rural areas.

Another myth is that Africa is technologically backward with many people around the world mistakenly believing that Africa lacks technological development and/or innovation. However, this is very far from the truth. Countries such as Nigeria, South Africa, Kenya, Rwanda, and Ghana have thriving technology ecosystems, with startups creating innovative solutions in sectors like fintech, e-commerce, renewable energy amongst others (GSMA, 2022). Issues like infrastructure, low digital literacy and low literacy may change the context of how these technologies need to be implemented (as will be seen in this thesis), but these technological advancements exist nonetheless. In addition, there is a wealth of indigenous knowledge which may not be fully documented or necessarily scientific by Western standards; it is common for Africans to see Western countries excited about some "new" technology that Africans have used for centuries. An example was the sudden African Net Sponge hype in 2024[1], which brought Western attention to an exfoliating product that has been in use in Africa for centuries. Linked to this myth is the notion that Africa is solely a consumer of technology, again this is false, because despite the many challenges, Africa has a growing number of entrepreneurs, software developers, and researchers contributing to the global technology landscape (Mawere et al., 2017).

A complicated reality of Africa, and indeed most countries in the Global South, is the issue of urbanization and development. Many non-Africans who have traveled to African countries often attest that these countries are highly developed. On the other hand, those who have never visited Africa but rely on media representations tend to believe that the continent is largely rural with little to no technological advancement. This discrepancy is as a result of a complicated situation I will attempt to explain. To understand this phenomenon, we must go back in history, when most of Africa (and the other countries in the current Global South) were divided into kingdoms and tribes which are far different from today. During the era of colonization, Western countries introduced (possibly, too early) certain advancements, which especially involved weapons of warfare, to some kingdom or tribes. At the time, since traversing continents was mostly by sea, most of these "advancements" were introduced in the coastal regions.

In Ghana, for example, most of the slave trade involved the capture of less developed tribes from the middle and north of the country, which were then sold to the Whites in the south and shipped off (Kankpeyeng, 2009). Due to this trend, most of the development; education, health care, weapons, etc., were introduced in the south, and also to the tribes which had collaborations with the colonizers. Fast forward to the various fights for independence and naturally the development afterward was centered in the already striving cities with higher literacy rates. A few leaders like Kwame Nkrumah[2] saw the need to spread development to various parts of the country; he even went as far as attempting same for the entire continent, however most did not share this view.

The result; we have some highly developed cities, highly developed neighbourhoods, and at the same time vastly contrasting underdeveloped rural and per-urban areas, sometimes not so far geographically from each other. This creates an internal socio-economic divide which in-turn leads to an internal digital divide as well. I explain the consequences (and opportunities) resulting from this in Section 1.3.

The last interesting myth I will mention has to do with language. Many people around the world believe that there are a lot of languages in Africa. A quick Google search will *claim* there are about 7000 languages in the world, 1500 to 2000 in Africa, 500 in Nigeria and 80 in Ghana. This is close to the truth but somewhat erroneous, especially when a bit

1 https://www.cnet.com/health/personal-care/what-is-african-net-sponge/
2 https://en.wikipedia.org/wiki/Kwame_Nkrumah (accessed 17-07-2024)

of context is understood. This error is as a result of referring to languages and ignoring dialects. Ghana alone has over 250 dialects and in context of development and culture, these must be considered as languages. Why? Because in terms of information access in resource-constrained communities, language is going to be the main barrier, not just because of literacy, but also because of acceptance. Systems that provide information in people's own languages will naturally be more accepted, but the interesting reality here is that a system providing information in what we may classify as the same "language" but a different dialect will most likely not be accepted due to various cultural and local contextual reasons. As such, regardless of how similar these so-called dialects may sound, we should be cautious to consider them as different languages.

Hopefully, this insight into these Global South-centered myths and realities gives us a deeper understanding of this research as we delve deeper.

1.2 A PERSONAL PERSPECTIVE

I was born in the same year the first Personal Computer (PC) arrived in Ghana. Around that time, what would later become the Internet was already being shaped through the collective work of engineers, researchers, and institutions across various countries. While figures such as Vinton Cerf and Robert Kahn are often credited with key protocols, the early Internet was a product of collaborative experimentation, including the work of people like Larry Roberts, Leonard Kleinrock, Paul Baran, and many others. The emergence of the World Wide Web (WWW) some years later, often attributed to Tim Berners-Lee and his colleagues at CERN, built upon this foundation of open protocols, distributed design, and academic cooperation.

As noted by Thomas and Wyatt Thomas et al., 1999, the Internet's development was far from inevitable. They describe a historical periodization in which the Internet passed through multiple stages: in the 1970s, it functioned as a testbed for technical experimentation; by the 1980s, it was home to an emerging community of computing professionals and students who co-created early services such as Usenet; in the early 1990s, it expanded as a general academic infrastructure; and from 1993 onward, it was rapidly commercialized, especially with the introduction of the Mosaic graphical browser. Each phase involved moments of provisional closure points where a certain vision temporarily stabilized, before being reopened and redefined by new actors and interests. What we now call the Internet could easily have evolved very differently.

My own life has moved in parallel with the development of ICTs and I was privileged to have access to most of these technologies and innovations as they were released. This section therefore gives a summary of how I came to be involved in ICT4D research and at the same time gives an idea of what was happening in Africa during those developmental years from one perspective (urban, literate) as opposed to the still unconnected population (rural, illiterate).

I had always wanted to be a Computer Scientist, even when I had no idea what exactly that was. I even wrote this in an exercise book in elementary school sometime around 1987. My first experience with a computer however was a few years later.

I consider myself privileged; my father was a lecturer at the University of Ibadan (UI) in Oyo State Nigeria with a Doctor of Philosophy (PhD) in Agricultural Economics and my mother was an elementary school teacher with a Diploma in Physical Education; having two parents with university degrees in that era was quite uncommon and led to me being exposed to quite a lot of new technologies (and sports!!) earlier than most in my environment. In addition, in those early days of computers, my father, somehow (and I am not so sure of exactly how until this day) had learnt to use them. He happened to pass by a new computer center with us (I believe they were early mainframe machines), and my senior brother and I came home to report proudly to my mum that my dad had sent us to a place with a lot of TVs.

Subsequently, his department acquired an International Business Machines Corporation (IBM) computer. This would most likely have been an IBM Advance Technology (AT) with Intel 80286 Processor[3] (8 Megahertz (MHz)), 256 Kilobyte (KB) – 16 Megabyte (MB) Random Access Memory (RAM), a 20 MB hard drive and 1.2 MB 5.25" (135 mm) floppy drive. This was placed in his office and I can vividly remember the excessive locks and metal door that was fixed to secure the office. He happened to take me there one day and being busy with something else, run some basic Disk Operating System (DOS) tutorial for me and left; on hind-sight this brought the (unclear) concept of AI to my young mind even then, because I assumed the interactive tutorial avatar (which was built like the early DOS games) actually understood everything I typed. Needless to say, this further solidified my intentions of being a Computer Scientist.

Also, being privileged to be exposed to the early days of hand-held computer games like the GameBoy by Nintendo, PC games (PacMan, Paratrooper) and early console games, helped shaped my focus because I wanted to understand how they worked and was fascinated at how they (programmers) managed to generate so many random events and outcomes.

Back in Ghana, in the year 1995, I experienced my first connection to the Internet!!; hooked up my Dad's laptop to a modem, connected to a phone line and got that heavenly (at the time) dial-up connection sound and proceeded to launch Netscape[4] and open up Yahoo! and their search engine, AltaVista[5] . My life was changed that day; seeing what the Internet was alone began to open up diverse possibilities in my mind. A couple of years later, after I had completed Junior High School (in 1997), my Dad gave me two things; one, a book titled "The Secret Guide to Computers" by Russ Walter (Walter, 1984), and two, access to his computer (an IBM Personal System (PS)/2 with an 8086 processor running at 8 MHz with 512 KB of RAM).

I began to learn myself with help from Russ Walter's book; understanding how computers work, the hardware behind it, DOS, Quick Beginners All-Purpose Symbolic Instruction Code (QBASIC), etc. I remember infecting his computer with a virus in my many explorations and had to figure out how to disinfect it with an antivirus scan; not so easy as it is now, in those days of DOS and Windows 95. By the end of 1997 when I started Senior High School, I was more knowledgeable that all my peers and most of my teachers.

3 https://en.wikipedia.org/wiki/Intel_80286 (accessed 17-07-2024)
4 https://en.wikipedia.org/wiki/Netscape_(web_browser) (accessed 17-07-2024)
5 https://en.wikipedia.org/wiki/AltaVista (accessed 17-07-2024)

I do not conclude with that statement to boast, but to show how all this personal history connects to the digital divide; it was at that stage in life that I realized how privileged I had been to have such exposure and knowledge, and to realize that most people around me were not privy to computers, let alone the Internet, because these technologies were not readily available to the general public. Note that mobile phones were not widely used then.

The history above explains my introduction to the ICT part, now let me explain how the For Development (4D) part came about. Growing up in a University community meant I was always privy to the practical side of research work and eventually began taking part in a number of them. I started out doing Data Entry in those days where paper questionnaires were used in the field and one would have to enter the data into applications like Epi Info and Microsoft Access forms. Eventually I got more involved in these developmental projects and started joining in the field for interviews and focus group discussions. Although the topics discussed were not my field of study, with time I became quite knowledgeable in the developmental issues around things like farming, food security, micro-finance, agricultural value-chain and the like.

In 2002, I finally got to University to study Computer Science at the best place I could hope for within Ghana; the Kwame Nkrumah University of Science and Technology (KNUST). Needless to say, my acquired computer knowledge was of great help and made me one of the best students. Within this time, I learnt the fundamentals of programming, program design, and languages like Java, Visual Basic (VB).NET and C# as well as the many other areas of Computer Science. Although we did a lot of "paper coding", at least we did have access to Computer Labs and I eventually got my own (custom built) PC in 2003.

Together with a friend, Eyram Akofa Tawia, by our final year, we came to the conclusion that a Three Dimensional (3D) Computer Game was the best culmination of all the Computer Science concepts that we had learnt, and so, with a lot of doubt from the department (took a lot of convincing to approve our project proposal) we set out to design Sword of Sygos[6] (Tawia, 2016). The project was a huge success and won Ghana Think Foundation's invitational programming contest in 2006[7]. In 2020, Jeff Glaspy, a PC games historian and archivist, in an ongoing research reached out to Eyram and myself because he found out that Sword of Sygos, released in 2005, is the first 3D Computer Game developed in Africa and is documented as such (Mark J. P. Wolf, 2015).

Figure 1: Sword of Sygos - First 3D Computer Game from Africa [Mark J. P. Wolf, 2015]

6 https://www.youtube.com/watch?v=QJ6hh_iBWuc (accessed 17-07-2024)
7 https://gamelmag.blogspot.com/2009/ (accessed 17-07-2024)

After graduating, I moved back to Tamale in 2007 to work with the University for Development Studies, Ghana (UDS). During this time I also started a company, DataWorks Ghana Limited, with Patrick Aalangdong because we immediately began to see the disparity in access to Information and Communication Technologies (ICTs) even between the south (where we studied) and the north of Ghana (where we hail from and lived). Our company provided ICT services to the numerous Non-Governmental Organizations (NGOs), institutions and individuals in Tamale, and most often involved providing Information Technology (IT) support for developmental projects.

Sometime in 2009/2010 I met Hans Akkermans, Anna Bon and Wendeline Tuyp, who were from the Vrije Universiteit Amsterdam (VU), in the Netherlands. They were colleagues of my Dad and had visited Ghana and come to Tamale with Nana Gyan Baah, who was then a PhD Student. They organized a workshop to present their research work in ICT4D which involved voice technologies and local languages, and it didn't take too long to realize that these concepts connected the two halves of my life; the love and affinity for ICT, and the need and hope to bring development to resourced-constrained communities. This was perhaps the first time I realized that ICTs could realistically directly benefit resourced-constrained environments albeit with a lot of research first. Of course, I needed a Masters Degree before I could start proper research in this area and this also gave me the opportunity to learn more. I therefore went to Vrije Universiteit Amsterdam to study Computer Science with specialization in Internet and Web Technologies in 2011.

During this time, our research group, the Web Alliance for Regreening in Africa (W4RA) facilitated the start of an ICT4D course at the VU, one of the first world-wide in this subject area, and of which I was amongst the very first batch of students to take this course. The course pushed us as computer scientists to consider understanding the local ecosystem and end-user needs during development, as this is very vital in the development context, as we will see in abundant detail moving forward.

Naturally, for my Masters project I took up a rural development issue; the agricultural value-chain, investigated the underlying issues around it; rural farmers sell produce at very low prices, making little profit, only to have it extremely expensive at the consumer end. My thesis proposed how ICTs would go about solving this multi-faceted issue (Dittoh et al., 2013).

Between 27th April and 1st May, 2015, a collaborative workshop, ICT for Food and Water in Ghana - Collaborative Research by VU and the UDS, was organized in Walewale, Ghana by Vrije Universiteit's W4RA team, together with a team of researchers from the University for Development Studies, Tamale, Ghana (see Figure 7). The team consisted of a multi-disciplinary group of experts in rural economics, animal science, tropical agronomy, irrigation, microfinance, sustainable land management, gender, value chain development and ICT4D.

This team, of which I was part, brainstormed on the technological possibilities of information dissemination to communities related to food and security, looking at it from all angles based on their areas of expertise. We further visited Guabuliga, a rural community of about 2000 inhabitants east of Walewale, who live from rain-fed agriculture and livestock, where we had focus group discussions with members of the community in relation to the technological possibilities of digital information dissemination.

This adapted form of the living-labs approach is not trivial, as we will eventually come to see; involvement of end-users and stakeholders at the early stages of an ICT4D project is of utmost importance (N. B. Gyan, 2016).

Interestingly, during our discussions at Guabuliga, community members in their own words, brought up the issue of climate change as seen in their locality and even more interestingly, proposed the solution; providing them with localized weather information and forecasts through their mobile phones.

Subsequently, the Savanna Agricultural Research Institute (SARI), located in Tamale, Ghana, which works directly with local farmers in the northern sector of the country, provided further insight in the areas of meteorology, crop farming and livestock rearing, an understanding of climatic conditions, and communication; language and information dissemination in the local context.

This led to the start of my PhD work, which aims to, by way of practical research and fielded examples, teach us how to develop ICTs that will provide information to resource-constrained environments such as Guabuliga.

1.3 THE RURAL-URBAN DIVIDE

My first personal mobile phone was the Nokia 3310[8] in 2002; gifted by my Father to me when I was headed to University to study Computer Science. I upgraded to the Nokia 1100[9] a couple of years later and by the last year of my studies, necessity (being a Computer Science student) made me acquire a Sony Ericsson Xperia[10]; this was my first smart phone.

This short history of my early phone usage shows how quickly Africa adopted these technologies and tried (still try) to keep up with the times. Unfortunately, as this was taking place in urban Ghana, there was a different story in rural Ghana.

The first part (adoption of GSM phones) was basically the same as any urban area; the technology was simple, the hardware was affordable, the telecommunication companies did not need to install lines or devices in every house, perhaps not even every community, so GSM reception became widespread very quickly. It was more so when folk in rural areas began acquiring mobile phones in droves; this technology did not require learning a new language, spending too much; even spending nothing at all by way of usage costs because people could call you as opposed to you calling them, therefore the cost was paid by others (e.g. a more well to do relative and/or friend). Most importantly, it was a tool that greatly improved livelihood because it could be used to improve whatever aspect of life that was more relevant to the individual.

However, as we quickly moved on to smart phones with Internet access and a myriad of Apps, the rural folk got left behind. The smartphone required (and still does) much more learning, was more expensive to buy and to use, the Internet, perhaps its most advantageous feature, required the English language and unlike the voice-based GSM phones, this also required being able to read. The telecommunication companies of course correctly assessed this situation and the infrastructure needed for mobile Internet

8 https://en.wikipedia.org/wiki/Nokia_3310 (accessed 17-07-2024)
9 https://en.wikipedia.org/wiki/Nokia_1100 (accessed 17-07-2024)
10 https://en.wikipedia.org/wiki/List_of_Sony_Ericsson_products (accessed 17-07-2024)

access was for the most part restricted to urban areas, except by coincidence when spill over from main cities and towns reached these areas.

Fast-forward two decades later and this disparity still exists and is ever wider; even more than the disparity between the Global North and South.

As you have no doubt surmised from the above, the digital divide is not just a Global North versus Global South issue, but we find a vast difference *within* developing countries.

Let us use the Internet itself as an example; in Accra, the capital of Ghana, Internet access is available, mostly reliable, and up to median mobile speeds of 10.76 Megabit per second (Mbps) and fixed (Broadband) speeds of 27.06 Mbps[11]. In comparison, for Tamale, a city in the northern part of Ghana, I was unable to find Internet speed measurements anywhere online; which gives an indication of how sparse and unavailable Internet access is there. However from personal experience, Tamale has mobile speeds of about 8.5 Mbps. Move further from Tamale, to say a village in the Savannah Region, and there is no Fourth-Generation Wireless (4G) and very unreliable 3G connections and mostly GSM only.

Infrastructure might be able to fix the issue of Internet access, especially pertaining to a place like Tamale, which is also a city with middle and upper class workers, however, we run into a larger problem when it pertains to our rural areas; we'll take a look at these in Section 2.1

1.4 THE HISTORY OF INTERNET IN GHANA

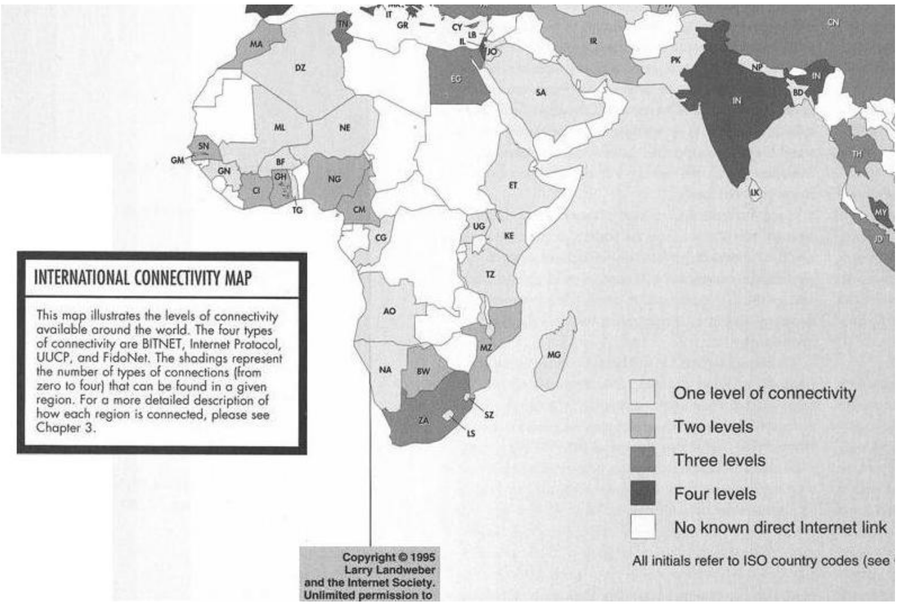

Figure 2: African nations with Internet, mid-late 1995. Copyright 1995 Larry Landweber and the Internet Society

Ghana was one of the first countries in sub-Saharan Africa to get connected to the Internet. Within Africa, aside from a few countries; Tunisia and South Africa in 1991, Eqypt in 1993, Algeria and Zambia in 1994 and Zimbabwe and Mozambique early in

11 https://www.speedtest.net/performance/ghana (accessed 17-07-2024)

1995, Ghana was connected August 21st 1995 (W. Foster et al., 2004).

This was largely through the work of one man; Professor Nii Quaynor. The Ghanaian professor is known as "Africa's father of the Internet," a web pioneer who helped establish some of the continent's first online connections[12]. He was the first African to be elected to the board of The Internet Corporation for Assigned Names and Numbers (ICANN), which is a multi-stakeholder group and non-profit organization responsible for coordinating the maintenance and procedures of several databases related to the namespaces and numerical spaces of the Internet, ensuring the network's stable and secure operation.

As of December 1995, there were only 205 connected accounts in Ghana and little did I know that the account I was using to connect at the time was 1 out of 205 in the country and 1 out of 4 in the whole northern Sector of the country. These connections were of course, at the time, through satellites, accessed via dial-up connection, very slow and very expensive; the cost of the Internet plus the cost of the phone connection.

Later in 2001, Ghana was connected through the South Atlantic Telecommunications cable no.3 (SAT-3) undersea cable, also known as West African Submarine Cable (WASC). The SAT-3/WASC is a 13000 KM submarine cable connecting South Africa, West Africa, to Europe. The SAT-3 cable system has a total capacity of 120 Gigabit per second (Gbps) and was owned by a consortium of 36 telecom operators including 11 African shareholders; Angola Telecom, Camtel, Cote d'Ivoire Telecom, Ghana Telecom, Maroc Telecom, Nitel, OPT Benin, OPT Gabon, Sonatel, Telecom Namibia and Telkom SA Ltd[13].

The result of this was an explosion in the Internet industry; Eight (8) Internet providers were established and licensed within the same year; Network Computer Systems, Africa Online, Internet Ghana, Africa Express (Christian Internet service providers), IDN, WWWPLUS, ESS LTD and Africanus.net. Also established were a multitude of Cyber Cafes especially in the capital, Accra. This gave a lot of people a chance to get access to the Internet although they didn't have the financial standing for a personal link nor obtaining the equipment needed; PC and modem.

The World Bank's data shows Ghana's Internet penetration for 2001 at 0.2%[14], but this figure is erroneous. I make such a bold claim because their data simply considered actual connections without catering for shared connections in the context of what was happening in Ghana at the time. Due to shared Internet connections- homes, offices, through friends and cyber cafes, there were over 500,000 people who used the Internet in 2001[15]. With an estimated population of 19 million at the time, this would put the Internet penetration at around 2.5%.

12 https://edition.cnn.com/2013/09/04/tech/web/africa-father-Internet-nii-quaynor/index.html (accessed 17-07-2024)
13 https://www.submarinenetworks.com/en/systems/euro-africa/sat-3 (accessed 17-07-2024)
14 https://data.worldbank.org/indicator/IT.NET.USER.ZS?end=2003&locations=GH&start=2001 (accessed 17-07-2024)
15 http://www.afrol.com/News2001/gha003_Internet_growth.htm (accessed 17-07-2024)

This is a recurring error in measurement of access to most things in most African countries; the culture of sharing is so prevalent that most communities do not see the need to, as it were, have duplicate resources. This is a contextual fact that we must always take note of. To give an example, in finding out how many people have mobile phones in a number of communities, we've often come across a few individuals (mostly women) who do not own their own phones. However, in other discussions/interviews, we find that the same individual makes and receives even more calls than those who own them. This individual may be statistically counted, and wrongly so, as not having access.

From 2001, Ghana's Internet penetration rose gradually and from 2005 saw a rapid increase due to the introduction of the first Enhanced Data rates for GSM Evolution (EDGE) network by Scancom Ltd (Spacefon)[16]. This, combined with the introduction of Java 2 Micro Edition (J2ME) phones and Blackberry phones, a sizable number of the upper and middle class began to use the Internet on their mobile devices.

Over the years, with the introduction of Android phones especially, Internet users on Ghana have remained predominantly mobile users, with an Internet penetration, as of 2023, of about 55.6%[17].

This however means that about 15,002,760 Ghanaians are not connected.

1.5 RESEARCH PROBLEM AND RESEARCH QUESTIONS

The traditional methods of technological advancement used in the Global North works to a certain degree in the urban areas of the Global South but have totally failed to solve the problems of the rural and suburban/peri-urban populations (Reidpath et al., 2019). This is in part due to the unavailability of researchers from the Global South and also in the failure of the current crop of available researchers to note that the existing problems are not always technological and cannot be solved by only throwing money and advanced technologies at the problem. An example is Google's Project Loon, which failed due to non-technological factors (Zhang et al., 2022).

In terms of information access, it is worth noting that the United Nations (UN) Sustainable Development Goals (SDG) only states digital information access and access to the Internet in passing; *"Significantly increase access to information and communications technology and strive to provide universal and affordable access to the Internet in least developed countries by 2020"*[18]. In my opinion, this is insufficient and totally fails to tackle the "how"; how exactly will this be achieved?; the notion of Internet access in the Global North is simply to "*provide wifi and get connected*". The specific local and contextual problems of many places makes this "non-solution" woefully insufficient for the Global South for the most part and especially so for areas that are particularly resource-constrained.

16 https://www.ghanaweb.com/GhanaHomePage/business/Ghana-to-gets-first-EDGE-network-in-Africa-54599 (accessed 17-07-2024)
17 https://nca.org.gh/wp-content/uploads/2023/10/NCA-RELEASES-REPORT-ON-HOUSEHOLD-SURVEY.pdf
18 SDG 9c - https://sdgs.un.org/goals/goal9#targets_and_indicators (accessed 17-07-2024)

In the course of this (and others') research over the years, three significant barriers have been repeatedly encountered in the attempt to increase digital information access in the Global South. These are the *(i) lack of infrastructure*, *(ii) low literacy* and the *(iii) lack of relevant (local) content* online. These barriers, as mentioned, are at the same time technical and social in nature, multifaceted and subtle; they may look straightforward and simplistic, but are multilayered and moreover intersect with each other.

In addition to the aforementioned barriers is the issue of sustainability. Sustainability in the context of this research is the creation of ICTs that are not only relevant to and therefore used by communities, but are also inherently cost-effective (both in setup and running costs) due to the design choices made. This is difficult to realize without a good understanding of the socio-economic contexts of stakeholders and especially end users.

The complexity of the problem then, lies in its entangled socio-technical and local-contextual nature. This leads me to formulate a number of Research Questions to help tackle this complexity:

1. In view of the existing barriers discussed above, can we overcome them and find practical and sustainable ways to improve digital information provisioning and communication access for rural and peri-urban communities in the Global South?
2. How can we ensure that such information and communication is locally relevant and truly fit the needs, priorities, as well as local context of communities?
3. What is the nature of the technological solutions involved, given that methods and results of technological advancement in the Global North often fail in the Global South?
4. Can cutting-edge technologies such as Artificial Intelligence be (made) useful in the resource-constrained environments of the Global South, and if so, how?
5. In view of the highly local and contextual specificity of use cases, systems and solutions, to what extent is it possible to draw more general lessons and conclusions about building and deploying information and communication systems in resource-constrained environments?

1.6 METHODOLOGY

Overall, as discussed above, I suggest that the solution for rural development lies not in (only) advanced technologies, which normally turn out to be unsustainable, but in a community-based, user-centric, inter-disciplinary approach to identifying the details of the extant issues on-the-ground and, on that basis, iteratively develop, field-deploy, evaluate and improve technological solutions in the field in collaboration with the respective rural and peri-urban communities.

Accordingly, the methodology I employ in this research has two main components:

1. Participatory Action Research (PAR)
2. Field work, research and experimentation

1.6.1 *Participatory Action Research*

The main methodology I employ in this research is Participatory Action Research (PAR). The key feature that sets PAR apart from other methodological approaches is that individuals and communities are conceived of as first-class partners in a co-creation approach. This is in contrast to certain social science approaches whereby people (whether called objects, subjects, or even research participants) are in fact considered as "observed entities" by a value-neutral academic "spectator" researcher, as for example is the case in empiricist variable-oriented hypothesis-testing (Robson et al., 2016; Johnson et al., 2022). A general overview of PAR is found, e.g., in Reason et al., 2006. As a methodological paradigm, PAR has a long history and tradition of emancipatory aims and roots (Freire, 2000; Borda, 1979) and so fits well into critical indigenous (Denzin, 2008) and decolonizing methodologies (Kovach, 2010; Smith, 2012). For own views of mine and colleagues on decolonizing technology and society see Bon et al., 2021. Within the PAR paradigm various kinds of Information Science (IS) and Software Engineering (SE) components are designed and deployed including AI tools. Here I follow the Design Science methodology for Information Systems and Software Engineering as explicated in Wieringa, 2014 that is concerned with constructing, testing and evaluating ICT/IS artefacts in interaction with their real-world context. In relation to ICT/IS, and in particular the socio-technical approach to systems, PAR has gained a long-standing reputation as a useful methodology (Checkland, 1990).

1.6.2 *Field work, research and experimentation*

The real-world context this research deals with are what I have generally termed "resource-constrained environments" in this thesis, more specifically in the rural dryland regions of the West African Sahel (this includes northern Ghana, but also countries such as Mali, Burkina Faso, Senegal, The Gambia). In my case I have done extensive field research and experiments in northern Ghana (see Figure 3).

Field work and field research refer to a family of scientific methodologies that have similarities but also differences across various disciplines. In anthropology and sociology, doing field work is an important component of ethnographic approaches and methodologies to research. Ethnography is, according to Fetterman (1997), "*the art and science of describing a group or culture*." An important methodological issue here concerns the processes of generation, organisation, curation and analysis of empirical data in and from the field: from raw "field notes" to research publication (Wolcott, 2004; Emerson et al., 2011). There is by the way an interesting analogy with similar issues related to the vast amount and diversity of data (cf. lab notes and journals) in laboratory experiment settings in physics, chemistry and the bio-sciences. Ethnographic approaches have more recently also come to influence computer science, in particular the field of Human-Computer Interaction (HCI), in relation to user-centric design of systems (see, e.g., Crabtree et al., 2012). Insights from these multi-disciplinary fields and approaches bear a direct relevance to my own field work, research and experiments as reported in this thesis.

The collaborative-iterative-adaptive PAR methodology approach to working in such field contexts has been developed in great detail in Bon et al. (2016) and Bon et al. (2020) in their ICT4D 3.0 approach. For the technical and software development, I have generally employed agile methodologies (Leffingwell, 2011) that fit well into an iterative, adaptive, and collaborative overall community-based approach.

This research therefore, with community and stakeholder involvement, designed, built and implemented a number of fielded experiments in (i) rural and peri-urban communities; Mr. Meteo (see Chapter 3), Tibaŋsim (see Chapter 4), (ii) industry; Sefarim (see Section 5.1.4), Woom (see Section 5.1.5), and (iii) the use of emerging technologies (namely AI) in resource-constrained environments; TIBaLLi Speak (see Section 6.3.1) and Crowd-Sourcing Rainfall with AI (see Section 6.3.2); two use-cases from an ongoing project named TIBaLLi (see Chapter 6).

These were fielded in four (4) rural and peri-urban communities in the Upper East Region (see Chapter 3), five (5) rural communities in the Savannah Region (see Chapter 4) and two (2) communities (one peri-urban and one rural) in the Northern Region (see Chapter 6).

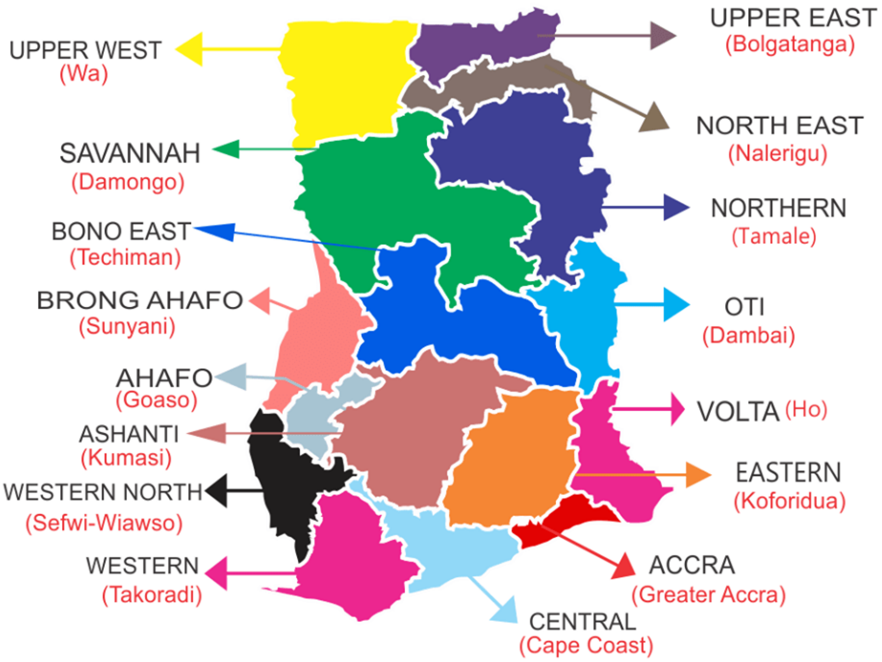

Figure 3: Map of Ghana showing Regions and their Capital Cities

Ghana currently has a population of 32 Million[19] and having recently attained middle-income status[20], has the potential of spearheading most of the technological advancements in Sub-Saharan Africa. Due to its relatively stable economy and absence of the unfortunately usual political and/or ethnic conflicts, it provided a suitable testing ground for this research. The northern sector of Ghana covers 143,019Km^2 (46.8% of the nation's

19 https://www.worldometers.info/world-population/ghana-population/ (accessed 17-07-2024)
20 https://www.worldbank.org/en/country/ghana (accessed 17-07-2024)

surface area)[21]. It is comprised of the Northern Regions, Savannah Region, North East Region, Upper East Region and Upper West Region (see Figure 3).

These Regions are significantly poorer, have less infrastructure, far lower literacy rates, with a larger population living in rural areas (the reasons for this were discussed in Section 1.1). However, these Regions are also predominantly agriculture-producing with farming (animal and crop) being the most prevalent occupation in the rural areas. In addition, the extreme increase of mobile telephony in Africa and its use in the rural areas of these Regions provides opportunities by way of voice-based solutions in ICT.

1.7 THE STRUCTURE OF THIS THESIS

This research utilized a community-based, user-centric, inter-disciplinary approach to produce practical solutions which were fielded in communities to obtain deeper insights into the best practical methods of overcoming the aforementioned barriers in the development of ICTs for the Global South, and drawing general conclusions about building and deploying information and communication systems in resource-constrained environments. This thesis outlines these use-cases, lessons and conclusions as follows;

Chapter 2 delves into the challenges of the Global South in the context of ICTs and the digital world by taking a look at the intentions of World Wide Web inventor Sir Tim Berners-Lee and contrast against what the World Wide Web is now. The Chapter gives some insight into the aforementioned barriers of literacy, infrastructure and lack of relevant information, but also outlines the various technologies in use in the Global South that can be possibly leveraged to circumvent these barriers. This Chapter, as well as parts of Chapter 1 are based on available literature, lessons learnt and empirical data gathered from the entirety of the research. The following publications are however especially relevant; *Dittoh, Francis et al., 2013. "Voice-based marketing for agricultural products: a case study in rural Northern Ghana."* Proceedings of the Sixth International Conference on Information and Communications Technologies and Development: Notes - Volume 2. *Pp. 21–24.* DOI: `10.1145/2517899.2517924`., *Bon, Anna et al., 2021. "Decolonizing Technology and Society: A Perspective from the Global South."* Perspectives on Digital Humanism. *Pp. 61–68.* DOI: `10.1007/978-3-030-86144-5_9`., *Saa-Dittoh, Francis, 2023. "Connecting the Unconnected: Decolonising ICTs for the Developing World."* Connected World: Insights from 100 Academics on How to Build Better Connections. URL: `https://vuuniversitypress.com/product/connected-world/`. and *Bon, Anna et al., 2024. "Bridging the Digital Divide."* Introduction to Digital Humanism: A Textbook. *Pp. 283–298.* DOI: `10.1007/978-3-031-45304-5_19`.

Chapter 3 introduces us to the early stages of this research, beginning with collaborative workshops and field visits; this is of utmost importance vis-à-vis the methodology employed in this research. The brainstorming in these workshops in conjunction with Focus Group Discussions in local communities resulted in the iterative design, and

21 https://en.wikipedia.org/wiki/List_of_Ghanaian_regions_by_area (accessed 17-07-2024)

piloting of Mr. Meteo; a GSM-based voice service that provides weather forecasts to communities in their local language. The service, built on low-cost hardware (Raspberry Pi with a Universal Serial Bus (USB) dongle for GSM access, is accessed by community members by simply placing a voice call to a phone number and hearing a 1-day forecast played back in their own language. *Chapter 3* details the design process and discusses the impressions by end-users and stakeholders as well as how this solution, together with its design process impacted the barriers of literacy, infrastructure and lack of relevant information. This Chapter is based on *Dittoh, Francis et al., 2020. "Mr. Meteo: Providing Climate Information for the Unconnected."* 12th ACM Conference on Web Science Companion. *DOI: 10.1145/3394332.3402824.*

Chapter 4 introduces us to a second use-case which is birthed from further collaboration with stakeholders and communities. Tibaŋsim (also RadioNet) is an award-winning solution to the need of "Connecting the Unconnected". The solution, built on the same hardware as the previous, flips the usage of the solution by rather allowing stakeholders (e.g. research institutions) to call into the device, which is now hosted in the rural community. Information meant for the community is then recorded over the voice call into the device which then begins to broadcast on a loop over an Frequency Modulation (FM) frequency thereby allowing anyone within range of the broadcast to receive it on their radios. The design process of this solution included automated hardware monitoring and user evaluations using the System Usability Scale (SUS). *Chapter 4* outlines the design process, the results of hardware monitoring and the user evaluation, and also discusses challenges and lessons learnt. This Chapter is based on *Dittoh, Francis et al., 2020. "Information Access for Low-Resource Environments."* Proceedings of the 3rd ACM SIGCAS Conference on Computing and Sustainable Societies. *DOI: 10.1145/3378393.3402506.* and *Dittoh, Francis et al., 2021. "Tibaŋsim: Information Access for Low-Resource Environments."* Proceedings of Sixth International Congress on Information and Communication Technology. *Pp. 675–683. DOI: 10.1007/978-981-16-2377-6_62.*

The design process and lessons learnt from the systems discussed in *Chapters 3 and 4*, utilized the PAR methodology (see Section 1.6) to give answers to the first three research questions (see Section 1.5); they show (i) two practical fielded experiments that improve digital information provisioning and communication access for rural and peri-urban communities in the Global South and yet circumvent all three barriers mentioned which of course include, (ii) providing information and communication that is locally relevant and truly fit the needs, priorities, as well as local context of communities and (iii) show the nature of the technological solutions involved; outlining the process (both social and technical).

Chapter 5 takes a look at more urbanized solutions. Even though this research was mainly targeted at rural and peri-urban communities, it is important to know if the same barriers hold and if so, if the same methodology can be employed in the urban Global South. The Chapter outlines the parallel barriers of *unreliable infrastructure*, *low digital literacy*, and *lack of local content* in the urban Global South setting. We then take a look at two ICT solutions (Sefarim and Woom) in different stages of development, alongside their design process, by employing the same methodology to the best degree possible for a more urbanized setting. The Chapter shows how we practically design two mobile applications based on the content needs of the urban population (see Appendix B; obtained by context analysis, and the resulting functional and non-functional requirements that are realized as a result, some of which can greatly differ from those in the Global North (e.g. Offline Access; see Section 5.2.7) and some of which differ from those in rural and peri-urban communities (e.g. Mobile (Smart) Apps; see Section 5.2.1). The design process and lessons learnt gives us an insight in our first three research questions albeit from an urban Global South point of view. This Chapter is based on the practical response to the issue of decolonisation of the Internet, as discussed in *Saa-Dittoh, Francis, 2023. "Connecting the Unconnected: Decolonising ICTs for the Developing World."* Connected World: Insights from 100 Academics on How to Build Better Connections. *URL:* `https://vuuniversitypress.com/product/connected-world/`.

Chapter 6 investigates the application of emerging technologies, namely AI, in resource-constrained environments. It is imperative that we know if (and how) AI methods like Machine Learning and Natural Language Processing are appropriate and can be used to build systems or facilitate access to information in the Global South and especially in resource-constrained (rural) settings. The Chapter introduces TIBaLLi, an ongoing project that asks if advanced AI methods be reconstructed so as to make the Internet more inclusive for communities in resource-constrained environments in the Global South. The project utilizes the PAR methodology to build Automatic Speech Recognition and Text-to-Speech tools for "small" resource-constrained languages. The Chapter outlines the project's development process, including context analysis and needs assessments that were done by way of collaborative stakeholder workshops, field visits and Focus Group Discussions, and the intermediary results gathered from this. Chapter 6 answers the fourth research by presenting two fielded experiments (see Sections 6.3.1 and 6.3.2) which show practically that AI *can* be used in resource-constrained environments and also show how it can be accomplished. This Chapter is based on on-going research and *Stan, George Vlad et al., 2022. "A Lightweight Downscaled Approach to Automatic Speech Recognition for Small Indigenous Languages."* 14th ACM Web Science Conference 2022. *Pp. 451–458. DOI:* `10.1145/3501247.3539017`., *Panayiotou, Antria et al., 2023. "Resourcing Small Indigenous Languages in the Field - Designing a user-centered data collection method for automatic speech recognition."* ICT Infrastructure and Computing: Proceedings of ICT4SD 2023, Volume 3. *URL:* `https://books.google.nl/books?id=oDfZEAAAQBAJ`. and *Saa-Dittoh, Francis et al. "Artificial Intelligence for Web Inclusion in the Global South."*

Chapter 7 first takes an overview of some failed and successful ICT4D projects, giving us some insight into some of the reasons for both failures and successes. The Chapter then presents The ICT4D Plug-in Principle, a conceptual framework for the building and deploying information and communication systems in resource-constrained environments, drawn from lessons and conclusions from the community-based, user-centric, inter-disciplinary fielded experiments (see Chapters 3, 4, 5 and 6). The Chapter concludes by outlining how exactly to utilize this principle in plugging in new ICTs into an existing ecosystem in resource-constrained environments. This Chapter is based on *Saa-Dittoh, Francis, 2024. "Information and Communication Technologies: The Plug-in Principle for ICT for Development."* The Plug-In Principle: Integrating Indigenous and Scientific Knowledge for Sustainable Food Systems in Africa.

Chapter 8 concludes the thesis with an overview of the research and the answers to our Research Questions (see Section 1.5). We end the Chapter (and Thesis) with a call to action to Computer Scientists to help close the Digital Divide by adhering to the prescribed methodologies and principles.

1.8 CONTRIBUTIONS

Firstly, this research contributes to the study of what is called the Digital Divide, that is, the contrast between places with access to ubiquitous broadband Internet, Big Data centers and massive computing facilities, on the one hand, and resource-constrained environments that struggle with poor energy and computing infrastructures, poor Internet access, and low literacy, on the other hand. Usually, the Digital Divide is thought of as a gap in Internet access possibilities between the Global North and the Global South (as suggested for example in the United Nations' Sustainable Development Goal SDG-9c). However, my analysis makes clear there is another and equally important dimension to the Digital Divide, namely, within the Global South itself; the gap between the (relatively rich) big cities and urban environments versus the vast resource-constrained and remote rural and peri-urban regions. The latter is the focus of the present work in particular in Africa and Ghana, but also in Burkina Faso, Mali and Malaysia. This thesis therefore analyses, in some depth, the technical as well as social ("sociotechnical") factors involved in the urban-rural Digital Divide of the Global South.

Second, the presented work offers an ICT4D approach that can help bridge or alleviate the urban-rural Digital Divide in the Global South. The thesis offers an account of an extensive program of community interaction, several ICT4D in the field applications, development, on-the-ground deployment and evaluation experiences. This practically demonstrates that a community-driven approach ("community first, then technology") stands a better chance for sustainable success than the technology-driven approach ("first technology, then community") that many technologists (even from Africa) in their thinking tend to adhere to, and that is also quite characteristic for many development and aid programs from the West.

As part of this research, I have designed and developed a number of ICT solutions that have real-world practical application and are currently in various stages of being scaled up for use in communities in northern Ghana; Mr. Meteo (see Chapter 3) provides an innovative system that retrieves climate information from online sources and makes these available for access by local communities in their own local languages in formats that they can understand and through channels they have access to (GSM). RadioNet (or Tibaŋsim)(see Chapter 4) provides a community-based information system built on low-cost hardware that gives community members access to information from the Internet or other sources (e.g. research institutes), not only in their own languages but over FM frequencies that are of course accessible via any radio receiver. Project TIBaLLi, which is an on-going project at the time of the writing of this thesis, seeks to enable rapid development of Automatic Speech Recognition (ASR) and Text-to-Speech (TTS) for small indigenous languages. The project has already resulted in two related applications for data collection of local language voice fragments from local communities (see Section 6.3.1) and AI assisted collection of rainfall data from local communities (see Section 6.3.2).

Fourth, my research provides an in-depth discussion, supported by fielded applications and experiences, of the place and potential for rural development of advanced ICT technologies, such as Artificial Intelligence (Machine Learning (ML) and Natural Language Processing (NLP)). It is not possible to usefully employ AI in resource-constrained environments in the same wholesale "BigTech" way of throwing loads of money at the problem, that is currently characteristic for the Global North, However, as this thesis shows, there are many valuable specific opportunities for cutting-edge technologies such as AI, but they must be tailored so as to properly take into account the local resource constraints that exist.

Finally, this work offers the contribution of a conceptual framework to the theory of ICT4D as a whole. By analyzing the commonalities and differences across the various use cases, systems, community contexts, and the development and deployment experiences, I come to a more general formulation of how one can integrate community (indigenous) knowledge, communication methods, information and communication priorities, existing technologies-in-use, and mix them with bits and pieces of advanced technologies, so as to come to useful and sustainable innovative technology solutions. This I call The Plug-In Principle for ICT4D: like Lego block configurations of different colours, forms and sizes, one can collaboratively "plug-in" the right technology pieces into the right community "pieces" in the specific context at hand.

1.9 PUBLICATIONS

This thesis is the culmination of research done over a number of years. It is therefore based on the following publications from said research:

Saa-Dittoh, Francis, Hans Akkermans, Anna Bon, and Andre Baart (2024a). “Artificial Intelligence for Web Inclusion in the Global South.” In: under review.
CRediT - credit=Francis Saa-Dittoh: Conceptualization, Validation, Investigation, Data Curation, Writing - Original Draft, Visualization, Funding acquisition. Hans Akkermans: Methodology, Investigation, Writing - Review & Editing, Supervision. Anna Bon: Methodology, Investigation, Writing - Review & Editing, Project administration. Andre Baart: Software, Validation, Formal analysis, Writing - Review & Editing
Chapter(s) - 6.

Saa-Dittoh, Francis (2024). “Information and Communication Technologies: The Plug-in Principle for ICT for Development.” In: *The Plug-In Principle: Integrating Indigenous and Scientific Knowledge for Sustainable Food Systems in Africa*. Ed. by Saa Dittoh, Anna Bon, and Hans Akkermans. under review. Springer.
CRediT - credit=Francis Saa-Dittoh: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Visualization, Funding acquisition
Chapter(s) - 7.

Saa-Dittoh, Francis, Tingoli, and Nyankpala Communities of the Northern Region of Ghana (Aug. 2024b). *Recordings of spoken Dagbani for the letters zero to ten and the words yes and no*. Zenodo. DOI: 10.5281/zenodo.13284005. URL: https://doi.org/10.5281/zenodo.13284005.
CRediT - credit=Francis Saa-Dittoh: Conceptualization, Methodology, Investigation, Funding acquisition, Project administration, Validation, Investigation, Data Curation, Supervision.
Chapter(s) - 6.

Bon, Anna, Francis Saa-Dittoh, and Hans Akkermans (2024). "Bridging the Digital Divide." In: *Introduction to Digital Humanism: A Textbook*. Ed. by Hannes Werthner, Carlo Ghezzi, Jeff Kramer, Julian Nida-Rümelin, Bashar Nuseibeh, Erich Prem, and Allison Stanger. Cham: Springer Nature Switzerland, pp. 283–298. ISBN: 978-3-031-45304-5. DOI: 10.1007/978-3-031-45304-5_19.
CRediT - credit=Anna Bon: Conceptualization, Methodology, Investigation, Writing - Original Draft, Project administration. Francis Saa-Dittoh: Conceptualization, Validation, Investigation, Data Curation, Writing - Review & Editing. Hans Akkermans: Conceptualization, Methodology, Investigation, Writing - Review & Editing, Supervision.
Chapter(s) - 1, 2.

Panayiotou, Antria, Francis Saa-Dittoh, and Anna Bon (Aug. 2023). "Resourcing Small Indigenous Languages in the Field - Designing a user-centered data collection method for automatic speech recognition." In: *ICT Infrastructure and Computing: Proceedings of ICT4SD 2023, Volume 3*. ICT4SD '23. Goa, India. URL: https://books.google.nl/books?id=oDfZEAAAQBAJ.
CRediT - credit=Antria Panayiotou: Conceptualization, Software, Investigation, Data Curation, Writing - Original Draft, Visualization. Francis Saa-Dittoh: Conceptualization, Validation, Investigation, Data Curation, Writing - Review & Editing, Supervision, Funding acquisition. Anna Bon: Methodology, Project administration, Supervision.
Chapter(s) - 6.

Saa-Dittoh, Francis (2023). "Connecting the Unconnected: Decolonising ICTs for the Developing World." In: *Connected World: Insights from 100 Academics on How to Build Better Connections*. Ed. by Ivan Vermeulen. Amsterdam: VU University Press. URL: https://vuuniversitypress.com/product/connected-world/.
CRediT - credit=Francis Saa-Dittoh: Conceptualization, Investigation, Writing - Original Draft.
Chapter(s) - 1, 2, 5.

Stan, George Vlad, André Baart, Francis Dittoh, Hans Akkermans, and Anna Bon (June 2022). "A Lightweight Downscaled Approach to Automatic Speech Recognition for Small Indigenous Languages." In: *14th ACM Web Science Conference 2022*. WebSci '22. Barcelona, Spain: Association for Computing Machinery, pp. 451–458. ISBN: 9781450391917. DOI: 10.1145/3501247.3539017.
CRediT - credit=George Vlad Stan: Conceptualization, Software, Validation, Formal analysis, Investigation, Writing - Original Draft, Visualization. André Baart: Conceptualization, Software, Validation, Formal analysis, Writing - Review & Editing. Francis Dittoh: Conceptualization, Methodology, Investigation, Resources, Data Curation, Writing - Review & Editing, Supervision. Hans Akkermans: Methodology,

Investigation, Writing - Review & Editing, Supervision, Project administration. Anna Bon: Methodology, Investigation, Writing - Review & Editing, Supervision, Project administration.
Chapter(s) - 6.

Bon, Anna, Francis Dittoh, Gossa Lô, Mónica Pini, Robert Bwana, Cheah WaiShiang, Narayanan Kulathuramaiyer, and André Baart (Nov. 2021). "Decolonizing Technology and Society: A Perspective from the Global South." In: *Perspectives on Digital Humanism*. Springer International Publishing, pp. 61–68. DOI: 10.1007/978-3-030-86144-5_9.
CRediT - credit=Anna Bon: Conceptualization, Methodology, Investigation, Writing - Original Draft. Francis Dittoh: Conceptualization, Investigation, Writing - Review & Editing. Gossa Lô: Conceptualization, Investigation, Writing - Review & Editing. Mónica Pini: Conceptualization, Investigation, Writing - Review & Editing. Robert Bwana: Conceptualization, Investigation, Writing - Review & Editing. Cheah WaiShiang: Conceptualization, Investigation, Writing - Review & Editing. Narayanan Kulathuramaiyer: Conceptualization, Investigation, Writing - Review & Editing. André Baart: Conceptualization, Investigation, Writing - Review & Editing.
Chapter(s) - 1, 2.

Dittoh, Francis, Hans Akkermans, Victor de Boer, Anna Bon, Wendelien Tuyp, and André Baart (Sept. 2021). "Tibaŋsim: Information Access for Low-Resource Environments." In: *Proceedings of Sixth International Congress on Information and Communication Technology*. Springer Singapore, pp. 675–683. DOI: 10.1007/978-981-16-2377-6_62.
CRediT - credit=Francis Dittoh: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Visualization, Project administration, Funding acquisition. Hans Akkermans: Methodology, Supervision. Victor de Boer: Methodology, Writing - Review & Editing, Supervision. Anna Bon: Methodology, Writing - Review & Editing, Supervision. Wendelien Tuyp: Methodology, Writing - Review & Editing. André Baart: Software, Validation, Writing - Review & Editing, Visualization.
Chapter(s) - 4.

Dittoh, Francis, Victor de Boer, Anna Bon, Wendelien Tuyp, and André Baart (July 2020a). "Mr. Meteo: Providing Climate Information for the Unconnected." In: *12th ACM Conference on Web Science Companion*. ACM. ACM. DOI: 10.1145/3394332.3402824.
CRediT - credit=Francis Dittoh: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Visualization, Project administration, Funding acquisition. Victor de Boer: Methodology, Writing - Review & Editing, Supervision. Anna Bon: Methodology, Writing - Review & Editing, Supervision. Wendelien Tuyp: Methodology, Writing - Review & Editing. André Baart: Software, Validation, Writing - Review & Editing, Visualization.
Chapter(s) - 3.

Dittoh, Francis, Hans Akkermans, Victor de Boer, Anna Bon, Wendeline Tuyp, and André Baart (June 2020b). "Information Access for Low-Resource Environments." In: *Proceedings of the 3rd ACM SIGCAS Conference on Computing and Sustainable Societies*. ACM. DOI: 10.1145/3378393.3402506.
CRediT - credit=Francis Dittoh: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Visualization, Project administration, Funding acquisition. Hans Akkermans: Methodology,

Supervision. Victor de Boer: Methodology, Writing - Review & Editing, Supervision. Anna Bon: Methodology, Writing - Review & Editing, Supervision. Wendelien Tuyp: Methodology, Writing - Review & Editing. André Baart: Software, Validation, Writing - Review & Editing, Visualization.
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CRediT - credit=André Baart: Conceptualization, Methodology, Software, Validation, Investigation, Writing - Original Draft, Visualization. Anna Bon: Conceptualization, Methodology, Validation, Investigation, Resources, Writing - Review & Editing, Visualization, Supervision. Victor de Boer: Investigation, Writing - Review & Editing, Supervision. Francis Dittoh: Data Curation, Validation, Investigation, Writing - Review & Editing, Visualization. Wendelien Tuyp: Investigation, Writing - Review & Editing, Supervision. Hans Akkermans: Conceptualization, Methodology, Investigation, Writing - Review & Editing, Supervision.
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CRediT - credit=Francis Dittoh: Conceptualization, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Visualization. Chris van Aart: Methodology, Supervision, Writing - Review & Editing, Funding acquisition. Victor de Boer: Methodology, Writing - Review & Editing, Supervision.
Chapter(s) - 1, 2.

2 CONNECTING THE UNCONNECTED

In Chapter two, we step into the current trends of ICT4D, and into the context of resource-constrained environments to see the prevailing challenges, including a look at the urgent need to decolonize the Internet. We will discuss the occurrence of these challenges generally in resource-constrained environments and more contextually in our research area.

Juxtaposed against the above will be the available technologies prevalent and/or possible in most countries in the Global South, but also, specifically in the selected research area. These are the most likely go-to areas technology-wise in decolonizing the Internet and achieving digital information access for resource-constrained environments. In contrast, we also take a look at one emerging technology and consider how it can be leveraged for use in resource-constrained environments considering the cost and complexities of such advanced technologies. This chapter is based on available literature, lessons learnt and empirical data gathered from the entirety of the research. However, the following publications are especially relevant; Dittoh, Francis et al., 2013. "Voice-based marketing for agricultural products: a case study in rural Northern Ghana." Proceedings of the Sixth International Conference on Information and Communications Technologies and Development: Notes - Volume 2. *Pp. 21–24.* DOI: 10.1145/2517899.2517924.*, Dittoh, Francis et al., 2021. "Tibaŋsim: Information Access for Low-Resource Environments."* Proceedings of Sixth International Congress on Information and Communication Technology. *Pp. 675–683.* DOI: 10.1007/978-981-16-2377-6_62.*, Bon, Anna et al., 2021. "Decolonizing Technology and Society: A Perspective from the Global South."* Perspectives on Digital Humanism. *Pp. 61–68.* DOI: 10.1007/978-3-030-86144-5_9.*, Saa-Dittoh, Francis, 2023. "Connecting the Unconnected: Decolonising ICTs for the Developing World."* Connected World: Insights from 100 Academics on How to Build Better Connections. URL: https://vuuniversitypress.com/product/connected-world/. *and Bon, Anna et al., 2024. "Bridging the Digital Divide."* Introduction to Digital Humanism: A Textbook. *Pp. 283–298.* DOI: 10.1007/978-3-031-45304-5_19.

2.1 CHALLENGES

2.1.1 *A Colonized Internet*

People from the Global South are not often included in debates about the digital society (Bon et al., 2021). However, the current trends in the digital society worldwide have perhaps a greater impact on the Global South. The phrase "Global South" refers broadly to the regions of Latin America, Asia, Africa, and Oceania (see Figure 4). It is one of a family of terms, including "Third World" and "Periphery", that denote regions outside Europe and North America, mostly (though not all) low-income and often politically or culturally marginalized. The use of the phrase Global South marks a shift from a central focus on development or cultural differences toward an emphasis on geopolitical relations of power (Dados et al., 2012).

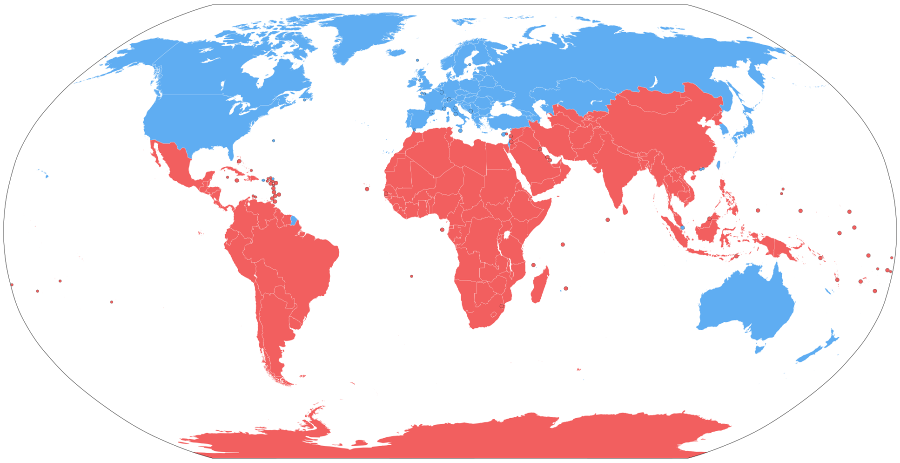

Figure 4: World map showing a definition of the North–South divide (red countries in this map are grouped as 'Global South') Wikipedia contributors, 2023

Since the advent of technology, humans have attempted to define technologies and adapt them, as opposed to technologies changing us (Lee, 2020), and of course we have failed in certain aspects of that, but perhaps sometimes for the better. More importantly, however, is the question of exactly who "humans" is referring to. Who is defining technology, and who has the knowledge, the assets, and the decision-making power? (Bon et al., 2021)

On 29th of May 2018, I had the privilege of meeting Sir Tim Berners-Lee, widely credited as the inventor of the World Wide Web, whose contributions, along with those of other pioneers, shaped the Internet as we know it (see Figure 5). Sir Tim had just delivered his Turing Award Lecture at the Association for Computing Machinery (ACM) Web Science Conference in Amsterdam, titled "What is the World Wide Web and what is its future? What could it be, what should it be? What is the Web we want?" During this lecture, he talked about how the Web was originally built as a decentralized system (and I think *he* would know best), but how the Big Tech[1] industry has over the years created a centralized system due to their focus on making money.

This has resulted in a situation where a few large companies dominate online spaces, deciding what people can access, how data is used, and who benefits the most; similar to how powerful nations once controlled vast territories and resources and where power is skewed and inequalities exist. The World Wide Web was designed as "*an open platform that would allow everyone, everywhere, to share information, access opportunities and collaborate across geographic and cultural boundaries*" (Berners-Lee, 2017), but unfortunately the World Wide Web that we have now, and, in effect, access to information, follows this trend of colonization; *access and especially control belong to a select few*. This commercialization and centralization of ICTs and information results in any and all ICT innovations in the Global South having to put a large chunk of its profits into the accounts of Big Tech, control over what can be installed in mobile devices sits in the hands of Big Tech and bound by the

1 Big Tech, also known as the Tech Giants refers to a grouping of the most dominant companies in the information technology industry, mostly centered in the United States

Figure 5: Ambushing Sir. Tim Berners-Lee (British computer scientist, generally credited as the inventor of the World Wide Web) to discuss decentralizing the Internet in the Global South Context

norms, culture, and beliefs of the Global North (Bon et al., 2021).

In Bon et al., 2021, we referred to the fact that the digital society has inherited patterns from the physical society and some of these patterns may be discriminatory and/or colonial. Some patterns are hidden in the data and some are part of human behavior, including all its biases and positives and negatives. If we consider the digital society to be an image of the physical world, it may have inherited, along with many other aspects, historical patterns of inequality. These patterns are very generally referred to as "coloniality" by various scholars (Mendoza, 2021; Mignolo et al., 2018; Quijano, 2016). Decolonial theory helps to uncover the tacit patterns of power in the social fabric, and also in the technologies.

This concern lies at the heart of what is advocated for in the decolonization of computational sciences. Birhane, 2021 also argue that acAI and data sciences are not neutral but are built on a foundation shaped by Western, white, male-dominated worldviews. These systems replicate systemic exclusions by design, especially for Black women and minoritized communities (Birhane, 2021).

The call to decolonize the internet, then, goes beyond simply expanding access—it involves asking critical questions about control: who owns the infrastructure, who sets the standards, who collects and defines the data, and who ultimately benefits. As Iliadis et al. (2023) argue, the politics of colonialism persist in digital spaces, with multinational tech giants acting as new colonizing forces that reshape the world in their own image. Digital infrastructures, far from being neutral, are entangled in historical and ongoing forms of domination that reproduce inequality on a global scale. This is data colonialism

Figure 6: Vinton Gray Cerf (American Internet pioneer, recognized as one of "the fathers of the Internet" and Founder of Internet Society) and I after our discussion on my project work and thesis

in action, a term proposed by Couldry et al. (2018) to describe how Big Tech replicates extractive logics of empire through digital means.

Birhane (2021) also critiques "tokenistic" inclusion efforts, such as "diversity boards" that do not dismantle the structures of inequality but rather serve to maintain the status quo under the guise of reform. For her and others, decolonizing is about reimagining knowledge systems and computational methods from the ground up, centered around historically marginalized voices. This extends into the realm of epistemic governance, where even the questions that can be asked, and answered, by AI systems are bounded by the data and classifications deemed important by the North.

In more concrete terms, decolonizing the internet would involve, among other things:

- Reclaiming digital governance by involving communities of the Global South in infrastructure and protocol design.
- Challenging extractive data practices by developing local data sovereignty models and culturally grounded ethical frameworks.
- Investing in autonomous infrastructures, hardware, software, and platforms that are owned and controlled by local communities.
- Rejecting universalist models of intelligence and instead cultivating pluralistic, contextual approaches to computation.

In September 2023, I was again privileged to meet Vinton Gray Cerf, who, together with others such as Robert Kahn, are accredited with the invention of the Internet. We had two separate discussions (one alone and the other with a few other young Computer Scientists) centered around my project work and thesis. He concluded with a statement I will paraphrase; he said he wished people like me (*from* the Global South, working on connectivity *for* the Global South) had been there when they were having discussions (some years before I was born) on how the Internet should be structured. He suggested it (the Internet) would have been very different. This is one of the driving reasons behind his founding of the Internet Society[2]; to fix this problem. You are more likely to be offline if you are female, poor, live in a rural area or a low-income country, or some combination of the above (Berners-Lee, 2019) and from personal experience, as an IT innovator in the Global South, you are more likely to pay Big Tech (cloud space, storage space, server space, web hosting, app hosting, plus a myriad of other things) much more than what you get yourself from your innovations. This, in my opinion, is the biggest challenge in the quest to close the digital divide and aid the Global South in development through ICTs.

2.1.2 *Infrastructure*

Part of the issue of this "colonization" of the Internet comes from the lack of infrastructure in the Global South. The development of digital technologies in Africa came quite late compared to many other places in the world, and for that reason, infrastructure development has not progressed as quickly as needed (World Bank, 2024). In terms of communication, the telecommunication companies in countries like Ghana naturally run a business-modeled system which necessitates that they look at the profits making margins in terms of hardware installation. For this reason, these companies would install the hardware required for Internet access and call services only at places that would generally use these services in sufficient numbers to generate a profit (Koi-Akrofi, 2013; Ecofin Agency, 2024).

Ghana being a developing country has the development of cities at very different levels. A city like Accra (its capital) has highly developed areas, a high proportion of people per square meter, a higher number and higher caliber of jobs salary-wise, and a higher number of middle- to upper-class citizens with some very high earners at par with their European peers. In contrast, in a city like Kumasi in the Ashanti Region of Ghana, we see a drastic decrease in the various factors mentioned. Furthermore, if you move northward, farther from Accra to cities like Tamale, Bolgatanga, and Wa, you will find even far fewer numbers in terms of the metrics discussed (Adarkwa, 2012).

As would be expected, infrastructure development generally follows these metrics discussed above as well, and therefore these communities that have fewer people per square meter and have less spending capacity tend to have less infrastructure (Adarkwa, 2012). Over the years, telecommunication companies have tried to improve infrastructure, as some towns and cities have developed gradually (World Bank, 2011). However, we are not there yet; ICT infrastructure remains inadequate, especially when moving further

2 https://www.internetsociety.org/

from the urban areas to the rural areas (Adomako et al., 2022).

Ghana generally uses 4G Internet services, but in most of these rural communities, you may only get a 3G connection or none at all due to the number of service masts per square kilometer, which is very lacking in these areas but more concentrated in the urban areas (Weplan Analytics, 2023). GSM on the other hand is a bit more widespread and more readily available (GSMA, 2021). However, there are still rural communities where GSM is unavailable (except in specific locations within the community) or very unreliable. (Telecom Review Africa, 2024).

The other area of infrastructure that has a direct bearing on ICTs would be electricity. With regard to electricity, Ghana probably is better off than most other West African countries, the reason being that there is a hydroelectric power plant and artificially created dam (the Akosombo dam) that was created decades ago by the first President, Kwame Nkrumah (Miescher, 2022). This has served Ghana and even neighboring countries for decades now. In addition, sometime in the past, one of the country's presidents embarked on what was known as a village electrification project, which was to ensure that all villages had access to the electrical grid (World Bank, 1995). This, of course, in turn ensured that power lines pass through almost everywhere, thereby extending power to the entire country. As such, there are very few communities that do not have access to the electrical grid in Ghana.

However, the fact that the population has increased to about 30 million people currently with almost all connected to this grid plus the increased populations being served in Burkina Faso, Togo and the Ivory Coast means there is a massive load on this power grid (World Bank, 2021; Reuters, 2023). This has resulted in unreliable power in some places, and power cuts occur once in a while in most places.

2.1.3 *Literacy*

Let us start this section with the assumption that we have provided all the kinds of infrastructure required for Fifth-Generation Wireless (5G) connections in Africa, using Ghana as an example once again, set up all the hardware that is required and people have access to all the devices that are required to access these networks, we would still not have solved the problem.

There is still a problem of literacy. At its last Census of Population and Housing (2021), Ghana's literacy rate was about 69. 8%. This means that there are about 8 million people who are not literate. By literacy we are referring to the ability to read and write English, since the official language of Ghana is English and generally any person who can read or write a local language would have learnt this through formal education (Amoah et al., 2021). As seen in the area of infrastructure, the same trend of there being a vast difference when moving to the north and also to rural areas also reflects in the issue of literacy. In the Northern Region of Ghana, for example, the literacy rate is about 41.3% and 32.8% in the Savannah Region (Ghana Statistical Service, 2023).

Furthermore, because the Internet is mainly in English (W3Techs, 2025), people who are able to access the Internet, who are not literate, would find it very difficult to make use of the content they find online. Most websites have their information in text, and people who cannot read can therefore not be able to make sense of it. Even if that text could be read out in English, since we do have technologies for text-to-speech for their languages, it would still remain a challenge for most of our rural communities.

There are about 250 languages in Ghana and close to 8000 languages in Africa. These are normally referred to as dialects; however, the complexities of Natural Language Processing become increasing relevant in that difference between languages and dialects (Joshi et al., 2020) since in building NLP tools, one would have to consider nuances in each unique "dialect". Most of these languages would be considered small languages spoken by just a few million people or even less (Ethnologue, 2022). This daunting task of producing systems that will cater for so many languages may make one consider rather educating everyone in English and/or the other major, resourced languages. However, this proves to be an even more daunting task.

Generally, literacy levels in rural areas in Africa do not change (Menashe-Oren et al., 2021). This is mainly because as younger generations become educated, there is a massive rural-urban migration that, in turn, creates a situation where there are very few literate in rural areas (Teye et al., 2019). The older generation who make up the bulk of the non-literate population is not about to go back to school to learn English anytime soon and would therefore stick to their own languages (Miller et al., 2006).

2.1.4 *Content*

Now let us assume that 1) infrastructure is available and 2) literacy is somewhat circumvented either by everyone being literate or for example, we are targeting a more urban population with whatever solution we are deploying (see Chapter 5). The issue of relevant content remains.

Through, perhaps the fault of no one, the Internet is generally dominated by content from the Global North (Curran, 2012). Websites are mainly from Europe or America, as most organizations with information online are from these countries; Europe and North America alone have an estimated web hosting market share of more than 70% worldwide[3] [4] [5]. Social Media, which is primarily open to wider populations of people around the world, are also dominated by Asia, North America and Europe, with Africa constituting 4% and below on all Social Media platforms [6] [7] [8]. The overall result of this is that the content you find online is skewed away from what most Africans would be

3 https://www.wpbeginner.com/research/ultimate-web-hosting-statistics-and-market-share-report/ (accessed 17-07-2024)
4 https://www.demandsage.com/web-hosting-statistics/ (accessed 17-07-2024)
5 https://www.hostingadvice.com/how-to/web-hosting-services-market-share/ (accessed 17-07-2024)
6 https://prioridata.com/data/social-media-usage/ (accessed 17-07-2024)
7 https://www.demandsage.com/social-media-users/ (accessed 17-07-2024)
8 https://www.smartinsights.com/social-media-marketing/social-media-strategy/new-global-social-media-research/ (accessed 17-07-2024)

searching for, especially rural Africans, if given the opportunity.

Most citizens in rural areas of Ghana (and Africa in general) are predominantly farmers (crop and animal farmers), and also a bit of marketing and processing of produce (Horlu, 2024). The kind of information that these farmers would seek would therefore be related to farming practices, climate, price of commodities, price of seed, and the like (Dittoh et al., 2021). However, this is the kind of information that you would hardly find on the Internet (N. B. Gyan, 2016). The price of commodities in Africa, the price of agricultural implements, the climatic conditions of communities in West Africa, especially the tropics, where the climate is very location-specific (Nicholson, 2013), is very missing or sparse information when searched on the Internet. This, of course, is in part because Africans have not generated enough information which would be shared with the world (Makinde et al., 2024).

Whereas there is a higher probability for an urban teenage anywhere in the world to be interested in The Weeknd's new album, from personal experience and from research in rural Africa, farmers are far less likely to be interested in foreign music in general. The content they would care about is the aforementioned (Mbagwu, 2017; Phiri et al., 2018).

We wish to connect the unconnected but once we are able to circumvent the challenges we have previously outlined and have connected communities in the rural Global South, they should be able to get into a system where they will find content that is relevant to them.

2.2 TECHNOLOGIES (FROM RADIO TO AI)

In this section, we take a look at the most prevalent and available technologies in the Global South, using Ghana as a case study. These technologies represent the primary go-to technologies we should consider in circumventing the aforementioned issues. We also acknowledge that we must begin to look at emerging technologies in context of the Global South and see how to effectively leverage them for use.

2.2.1 *Radio*

Radio was once the go-to communication system in the days of Amplitude Modulation (AM) and FM frequencies and all information was basically shared via radio waves to radio sets all over the world (Sterling, 2004). In Africa, Radio broadcasting still reigns supreme over other forms of mass media channels[9], and although this may seem like it is due to backwardness in technology, I have come to realize in the course of this research that this is not the case. It is more due to the culture of speech as the major method of communication which has made radio a very widely used system of communication in Africa (Mytton, 2023).

9 https://news.un.org/en/story/2022/02/1111882 (accessed 17-07-2024)

In Ghana there are over 500 radio stations in operation[10] and these cover a wide range of topics, adverts and programs that reach almost everyone in the country. Most of the rural and non-literate population rely on these radio stations for information. One interesting occurrence I have encountered has to do with feature phones (the very old type of mobile phones) having FM receivers as part of their systems and being able to receive radio, while most of newer smartphones do not have this functionality. This may be one of the reasons people in the rural areas in countries like Ghana stick to their feature phones. There is the possibility (but this needs more research) that the use of smartphones might not be impossible for these rural folk, but they may actually want to have these feature phones due to these radio services which will give them information in their own languages.

This opens up a big possibility of using radio frequencies to transmit information. We do not necessarily have to stick to the traditional methods of radio programs and broadcasting, but inculcating newer technology with the older technology can enable us utilize radio frequencies, but in a new way to be able to transmit information to rural communities and enable them have access up-to-date information on various topics.

Radio is one of the technologies that I believe will always be helpful and as such should not be allowed to fade off into the past due to reduced use in more developed countries. For the purposes of connecting the unconnected, radio is simply another form of communication technology that can get information from one place to another, and for the sake of the unconnected, who mostly have a culture of vocal transference of information (Minc, 1986; Rubin, 1995), radio should not be downplayed because this, as we would see in this work, can be the center of the solution to connect the unconnected (see Chapter 4).

2.2.2 *Mobile Telephony*

As mentioned on our list of challenges, infrastructure is a prominent problem in Africa. Telecommunication infrastructure especially is not readily available and in the advent of the telephone system which ran on masts and copper wires, there was simply not enough resources or know-how in most African countries to lay lines that would be available to every city, town and village (Empower Africa, 2018). As such, there was little by way of telephone lines and the few that could afford were mostly organizations and a very few individual homes.

Due to this, for a long time there was very little use of personal telephony except in the case of phone-booths that were placed in various locations within cities and people made calls to other places, mostly to other phone booths at prearranged times. However, the advent of the mobile phone and GSM saw a huge change in usage of telephones, reason being that the mobile technology enabled the telecommunication companies to invest in infrastructure with far less revenue than they would have needed to do if they had had to wire entire countries (GSMA, 2021).

10 https://nca.org.gh/authorised-radio (accessed 17-07-2024)

It did not take users long to realize the usefulness of mobile telephony and especially when the mobile phone prices dropped drastically as a result of mass production of cheap mobile phones from China. This resulted in an explosion of the use of mobile telephones where every adult was eager to get one because there was a direct impact on the livelihood of people, people were able to communicate directly, and speak in their own languages without having to resort to any other form of communication (Acheampong, 2021). This supports my assertion that the technologies of radio and mobile telephony are not archaic or defunct technologies, but rather different forms of technologies that our target users in rural areas tend to prefer due to their innate nature of being vocal. As such, every single adult statistically has a mobile phone and in a country like Ghana, the mobile phone penetration increased drastically to its current value of 113%[11].

2.2.3 *SMS*

Short Message System (SMS) originated from radio telegraphy in radio memo pagers that used standardized phone protocols. Radio telegraphy is transmission of text messages by radio waves, analogous to electrical telegraphy using cables, which in turn originated from Telegraph which used morsecode. Adding text messaging functionality to mobile devices began in the early 1980s and the mobile phone revolution came along with SMS functionality (Hillebrand et al., 1985).

In Ghana, and most other places in the Global South, SMS remained woefully under-utilized due to the then costly nature of sending one message and the low levels of literacy. As the years went by, the use of SMS increased slightly, mostly in urban areas due to necessity, but remained generally unused for sending information in the rural and peri-urban areas even until now (Dittoh et al., 2021). Telecommunication companies and other companies and institutions however have since then used SMS for advertising and for other forms of information dissemination (Statista, 2025).

At the end of 2010, the launch of WhatsApp, which utilized 3G for messaging saw the figurative death of SMS for any viable messaging by people with smartphones, while those without smartphones were generally the illiterate; this pushed SMS into the background and for the most part now remains a tool for companies to send information and for purposes of One Time Password (OTP).

Some ICT solutions in the Global South have attempted the use of SMS for information dissemination to rural and peri-urban areas, mostly targeting farmers (e.g. Esoko). These projects, for reasons we will come to see, failed in this regards and most realigned themselves to provide information for the more urbanized medium to large scale farmers (A. D. Foster et al., 2016).

This is not to say that SMS is useless for ICTs in resource-constrained environments, especially since it is now very inexpensive due to the lack of use. We can leverage on SMS in other innovative ways that may not necessarily involve end-users reading; e.g. the use of symbols that can easily be interpreted, communication between devices where there is

11 https://datareportal.com/reports/digital-2024-ghana (accessed 17-07-2024)

a lack of internet access, for transfer of information in small chunks from the internet to a device with no internet access.

2.2.4 *Artificial Intelligence*

Artificial Intelligence (AI) is probably one of the last technologies that comes to mind when thinking of rural Africa, however it is worth exploring AI, and other emerging technologies to determine what innovation can be built using these advanced technologies (Mhlanga et al., 2023).

Artificial Intelligence is is a branch of Computer Science that aims to build machines capable of mimicking human intelligence. In more technical terms, AI refers to systems or machines that exhibit capabilities traditionally associated with the human mind, such as learning, understanding, problem solving, decision making, and language processing (IBM, 2024).

One of the first examples of AI-driven gameplay is the computerized game of Nim[12], implemented in 1951 with the Nimrod machine. Although it did not learn or adapt, it demonstrated early AI principles using predefined search algorithms rather than Machine Learning or symbolic reasoning (Mitchell, 2020)). AI research initially focused on logic-based approaches, such as the Logic Theorist and General Problem Solver (Newell et al., 1959). The 1970s and 1980s saw expert systems such as MYCIN for medical diagnosis, and in the 1990s, Machine Learning gained momentum. Deep learning breakthroughs in the 2010s (Krizhevsky et al., 2012) significantly increased AI adoption. Today, AI is regarded a transformative technology with applications in multiple industries, including healthcare, finance, and manufacturing (Brynjolfsson et al., 2017; Marcus et al., 2019) although its adoption and impact vary according to sector-specific challenges (Bathaee, 2018).

2.2.4.1 *AI and the Global South: Challenges and Debates*

The fast development of AI has started to stir discussions about whether it is even possible for developing countries to adopt this technology. Although some researchers are optimistic that AI can provide answers to some of the most pressing challenges in the Global South, such as agriculture, healthcare and education (Odume, 2024), others are skeptical and believe adoption is extremely unlikely. These experts point to a number of issues; AI needs data, AI needs talent and AI needs resources.

1. Data and Representation Data availability and representation are two critical problems for AI deployment in the Global South. Most AI models are trained on datasets that come from high-resource environments. This means that they tend to perform very well in high-resource settings but they perform poorly when you apply them in low-resource contexts. Now, take Natural Language Processing as an example. The NLP models that we have today do very well not only because the model architectures are good but also because we have good datasets on which to train these models. The problem is that the datasets available for African languages are simply not enough. And we require

12 https://en.wikipedia.org/wiki/Nim (accessed 17-07-2024)

sufficient data (in this case, annotated data) in order to have a robust NLP model that can do anything useful (Orife et al., 2020; Hovy et al., 2016).

2. Cost and Infrastructure Barriers Implementing AI costs a lot of money. It requires high-end server systems with Graphics Processing Unit (GPU)s and Tensor Processing Units (TPU)s (Strubell et al., 2019). It also requires a strong and steady supply of energy; otherwise, you cannot expect your fancy AI to work regionally, if at all. Most of the basic computer hardware and energy supply (if any) are located in cities, where the high-speed Internet is also more reliable and available. Once you have developed an AI system, you should expect to continue investing money in it for a long time.

3. Technological Dependency and AI Colonialism Technological dependency is another concern. AI development, just as most digital development, takes place in a handful of global centers, predominantly in the United States and China, but also in some European countries. Most of the Global South has no choice but to use AI systems built in these hubs. Critics of this arrangement charge that it is a kind of economic neocolonialism, since the values and priorities that inform the construction of the AI systems are those of the Global North. (Bastion et al., 2020; Birhane, 2021)

4. AI for Development: What is feasible? Even with these difficulties, AI does offer prospects for growth when it is fine-tuned for regional situations. Some of the most exciting prospects for AI in the Global South entail:

- Farming – Using AI for detecting pests, forecasting weather, and predicting yields in a manner tailored to small farmers (Kamilaris et al., 2018).
- Low-resource environment diagnostics and therapies (Esteva et al., 2017).
- Education – Support for initiatives in multilingual global education and literacy through AI-driven translation tools (Lakew et al., 2018)
- Natural Language Processing (NLP) - Text-to-Speech and Automatic Speech Recognition models for small rural languages

2.2.4.2 *Leveraging AI for Resource-Constrained Environments*

Given these limitations, researchers in the Global South must explore how to adapt AI to local realities. Some strategies include:

- Decentralized AI development – Encouraging local data collection and AI model training to ensure ownership and relevance (Abbasi et al., 2022)
- Offline AI capabilities – Developing lightweight AI models that do not require Internet connectivity for core functionality (Ruder et al., 2019)
- Community-centered AI – Engaging local users in co-designing AI solutions to ensure usability and adoption (Hecht et al., 2021).

In this thesis, AI is explored through the TIBaLLi project, which investigates Automatic Speech Recognition models for African languages (see Chapter 6). The project investigates the potential of AI to improve access to digital information for small language speakers with respect to challenges in the Global South.

2.3 Chapter Summary

This chapter explored the challenges and technologies relevant to bridging the digital divide in the Global South, particularly in resource-constrained environments. We first identified the barriers, particularly socio-technical ones, that impede access to digital information and then discussed the kinds of technologies that can help to mitigate those barriers. This is a necessary chapter for understanding why the common traditional ICT solutions from the Global North often fail in the Global South context and sets the stage for the practical solutions discussed in later chapters.

The chapter begins by addressing the "colonized internet", how the Internet, which was meant to be global and decentralized, has in fact been reined in by a few corporate players and has become, in many ways, an electronic version of the old, bad centralized, top-down, command-economy model. The chapter then shifts to the technologies that can be used to bridge these gaps. Radio, despite being an older technology, is still one of the main technology tools available for communication in Africa. It is accessible and well suited to the oral underpinning of many African cultures where information is disseminated. Mobile telephony, particularly GSM-based phones, are now a key technology for voice-based communication in Africa. Even in rural areas where landlines are few or non-existent, mobile phones are a suitable option for communicating and sharing information. While SMS seems to have missed the boat for simple communication in rural areas where low literacy is an issue, there is still potential for its use in innovative and novel ways. Finally, the chapter looks at the potential of Artificial Intelligence (AI) in the Global South, though its implementation must consider the high costs, lack of data, and infrastructure challenges.

This chapter is foundational for understanding the barriers to digital information access in the Global South and the technologies that can be used to overcome these barriers. It provides the necessary context for the practical solutions and case studies presented in subsequent chapters, such as Tibaŋsim (see Chapter 4), and TIBaLLi (see Chapter 6) which utilize Radio and AI respectively.

3 MR. METEO: CLIMATE INFORMATION FOR THE UNCONNECTED

In this chapter, we discuss the first use case, Mr. Meteo, as a proof of concept. Mr. Meteo was built to provide community-specific weather information via voice calls (GSM) in local languages to rural farmers in Ghana (Dittoh et al., 2020b). We see the practical steps taken as we developed this ICT4D solution for low-resource environments. The user-centered and interdisciplinary approach is immediately evident in the nature of the local context analysis, the need assessment, and the requirement analysis. We further explain how the prototype was engineered, deployed, and evaluated, and conclude on the lessons learnt from this use case and how it contributes to the general study. This chapter is based on Dittoh, Francis et al., 2020. "Mr. Meteo: Providing Climate Information for the Unconnected." 12th ACM Conference on Web Science Companion. *DOI: 10.1145/3394332.3402824.*

3.1 CONTEXT ANALYSIS & NEEDS ASSESSMENT

There has been overwhelming evidence of climate change in recent years; increasing global temperatures, rising sea levels, increased ocean acidity and increase in extreme natural events are but a few obvious indicators (Lewis, 2014). Moreover, local farmers are aware of climate change and have attested to the need for modern scientific knowledge to augment their indigenous climate knowledge (Mahoo et al., 2015). About northern Ghana, Akudugu et al., 2012 found that food insecurity at the household level triggered by climate change negatively impacts on general livelihoods and thus has the potential to put families permanently poor or trapped in the poverty cycle. This is because of the fact that climate change causes crop yields in the study area to decline as a result of erratic rainfall patterns (Adesete et al., 2022; IPCC, 2023). In Ghana, fairly accurate seasonal (regional) rainfall forecast is available from the National Meteorological Services mostly online and during Television Weather Reports (in English)[1]. Less accurate, but usable daily and weekly local forecasts are also available through a combination of satellite data and local weather stations which feed open weather sources online (Gbangou et al., 2020).

Mr. Meteo was built to provide community-specific weather information via voice calls (GSM) in local languages to rural farmers in Ghana. Between 27th April and 1st May, 2015, a collaborative workshop, ICT for Food and Water in Ghana - Collaborative Research by VU and the UDS, was organized in Walewale, Ghana by Vrije Universiteit's W4RA team, together with a team of researchers from the University for Development Studies, Tamale, Ghana (see Figure 7). The team consisted of a multi-disciplinary group of experts in rural economics, animal science, tropical agronomy, irrigation, microfinance, sustainable land management, gender, value chain development and ICT4D. This team brainstormed on the technological possibilities of information dissemination to communities related to food and security, looking at it from all angles based on their areas of expertise. The team further visited Guabuliga, a rural community of about 2000 inhabitants east of Walewale,

1 https://www.meteo.gov.gh/Services/weather/ (accessed 17-07-2024)

Figure 7: ICT for Food and Water Workshop, Walewale, Ghana

who live from rain-fed agriculture and livestock, where they had focus group discussions with members of the community in relation to the technological possibilities of digital information dissemination. This adapted form of the living-labs approach is not trivial, as we will eventually come to see; involvement of end-users and stakeholders at the early stages of an ICT4D project is of utmost importance (N. Gyan et al., 2011). Interestingly, during discussions at Guabuliga, community members in their own words, brought up the issue of climate change as seen in their locality and even more interestingly, proposed the solution; *providing them with localized weather information and forecasts through their mobile phones*. Subsequently, the Council for Scientific and Industrial Research - Savanna Agricultural Research Institute (CSIR-SARI), located in Tamale, Ghana, which works directly with local farmers in the northern sector of the country, provided further insight in the areas of meteorology, crop farming and livestock rearing, an understanding of climatic conditions, and communication; language and information dissemination in the local context.

3.2 USE-CASE AND REQUIREMENT ANALYSIS

In this section, we take a look at how we arrived at the resulting use-case based on the understanding of the context and needs of the end-users and stakeholders. Note that the interaction with these parties does not end, but continues in an iterative fashion. From interactions with stakeholders and field visits to various communities, it was clear that there was a fundamental lack of certain infrastructure needed for dissemination of digital information. Internet access in the rural areas of northern Ghana was found to be unreliable and slow at best, and most often, unavailable (Dittoh et al., 2020b). In contrast to the above, mobile telephony and radio reception was not only found to be available and reliable, but also widely used by members of rural communities. Empirical data showed a 100% usage of both technologies in all communities investigated (Dittoh et al., 2020b); Ghana had an mobile penetration of 132.8% as at January 2021 (NCA, 2021). The high usage of these technologies is perhaps due to the indigenous oral nature of information dissemination for the past millenniums in these cultures (Ayensu, 2003). An investigation of other related technologies have found the lack of use of SMS, and the lack of use of smartphones in the rural areas of northern Ghana (Dittoh et al., 2013; Dittoh et al., 2020a). This is not a trivial issue, and is due to the low levels of formal literacy; the inability to read and write in the rural areas. In contrast to the south, the north of Ghana has low literacy rates; 35% literacy among females aged 15 to 49, and 53% among males aged 15 to 49 (Statistical Service (GSS) et al., 2015). Furthermore, the reason for the lack of significant change in literacy rates over a five (5) to seven (7) year period, despite a very high youth literacy rate of over 93% nationally (Bank, 2020), is the constant rural-urban migration of the (educated) youth (Kwegyir Tsiboe, 2020).

Armed with this knowledge, it became clear that certain solutions would not be feasible. The issue of infrastructure required the use of what is readily available, as opposed to the design of grand ideas that would never be implemented due to their high cost. As such we arrive at a requirement of using non-smart mobile phones and radio; GSM and FM/AM. The levels of literacy also made it clear that a text-based solution would not work; perhaps a symbol-based SMS system could work, but that would require some basic training for communities to understand each symbol which would drastically affect scalability; both to other communities and for other forms of information. As such, we have a requirement for the use of voice-based technologies, in local languages.
Finally, it was necessary to determine if the need for weather information was a general concern in rural areas in northern Ghana and not just an isolated incident. The relevance of information to the end-user is a powerful incentive for them to access it (Schmida et al., 2017). Based on this, information was gathered from stakeholders (namely the CSIR-SARI and the Ministry of Food and Agriculture (MoFA)), and from various rural communities on the relevance of climate information to their livelihood. It turned out that over 90% of adults in rural areas of northern Ghana are crop farmers, and combined with the current issues resulting from climate change (see Section 3.1), climate information was of utmost importance to them, especially in determining the right time to begin cultivation at the start of the farming season.

3.2.1 *Key Idea*

From the requirements gathered, the key idea of this solution was to build a system that provides weather information via voice prompts in local languages over voice calls to rural communities in northern Ghana. Members of rural communities will be able to call in to a local mobile number, upon which the system will answer and read out the weather forecast in their own local language (see Figure 8).

3.2.2 *Actors and Goals*

It is important to identify the various actors (individuals, groups and organizations) that have a part to play in the system. It gives a clear indication of how to technically facilitate their involvement in the system. Table 1 outlines the actors for Mr. Meteo with their goals

3.2.3 *Key Requirements*

In combination with the requirements already gathered in Section 3.2, we further solicited for more specific requirements pertaining to the specific operations of the system and

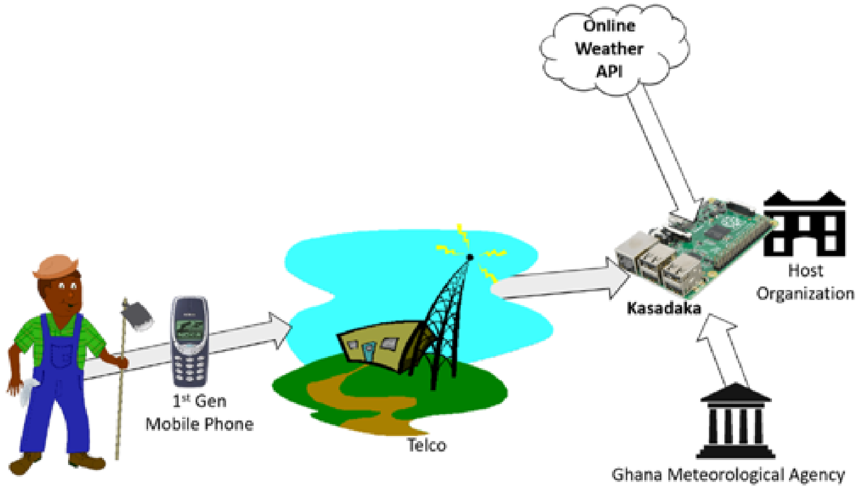

Figure 8: Mr. Meteo System

ID	Actor	Description
1	User	Call phone number to get weather forecast
2	Weather Source	Relay Weather Forecasts
3	NGO/Company/Institution	Manage Users
4	NGO/Company/Institution	Record Voice Fragments for new languages
5	Tech Support	Monitor system; Maintenance

Table 1: Mr. Meteo Actors and their Goals

specific information required by the end-users. Using the MoSCoW Method (Clegg et al., 1994), these requirements are outlined below;

- Must Have
  - Weather forecast source
  - Localized forecast data
  - Rainfall forecast data
  - Seasonal forecast data
  - Interactive Voice Response
  - Local Language(s)
  - Regular Weather Updates
- Should Have
  - Precipitation data
  - Temperature data
  - Wind speed data

Humidity data

- Could Have

  Subscription-based service

  Short-Range Radio (FM) Transmission of information

3.2.4 *Non-Functional Requirements*

There are also non-functional requirements to consider. As opposed to the functional requirements that specifies behaviour, non-functional requirements specify criteria that can be used to judge the operation of a system. These are mostly realized from the context analysis with some requirements from the more technical issues.

- Maintainability - Tech support should be able to maintain, adapt and replicate the system with ease. This technology will not only be used locally, but formed into a locally-run system, as such it must be maintained by whichever local-based innovators that adopt it. They should also be able to modify, re-adapt it to their local context and replicate the system as required with relative ease.

- Availability - Users should be able to reach the system at all times. Barring GSM network issues, the system must be hosted on a platform that will be available at all times. In both developed Nations and developing ones, users are quickly disinclined to utilize a system that is not available when they need it. It is more so in low-resource areas where we argue that users are only interested in specific-context information that aids their livelihood directly (Dittoh et al., 2020b) ; if this cannot be obtained as and when needed, users are likely not to use the system.

- Scalability - The system must have the ability to scale to different locations (and languages) and for any number of subscribers. Low-Resource environments in developing countries often have similar problems while having varied local-contextual situations. The success of any ICT system in these regions should be that it can improve the livelihood of many. As such the system needs to reach more people that need it in these different contexts. Scaling the application to reach more people should therefore be an integral aspect of the application's design

- Reliability - The system must ensure that forecasts are as accurate as possible. The basis of this system was a fundamental need for accurate weather forecasts, needed due to the reduced accuracy of indigenous methods (see Section 3.1). This means that it is of utmost importance that forecasts given through the system are as accurate as possible. This, we will see later on, it not trivial in the least

- Usability - The targeted user group creates a requirement of simplicity in the user interface We have already established the low levels of literacy in the area of interest; digital literacy is even lower (Adarkwah, 2020). This necessitates that the UI for the system be either very simple and/or familiar to the end-users.

- Cost-Effectiveness - The whole system must work together to be financially sustainable Affordability of goods and services is a major problem in developing countries for most of the population (Baart et al., 2019). However, it is not reasonable to expect continued funding from any agency in perpetuity. As such, it is expedient to develop not only a low-cost solution but also a financially sustainable system. There are numerous "grand" solutions that are often proposed in response to solving the information needs of low-resources regions; most of these never work mostly due to their high-cost nature.

3.3 ENGINEERING

Once the functional and non-functional requirements were realized and/or catered for in our design, we could proceed to building the actual prototype.

3.3.1 *Kasadaka*

Mr. Meteo was built on the Kasadaka using its Voice Service Development Kit (VSDK). The VSDK allows rapid development of a voice service (prototypes) in a web-based development environment. The VSDK also generates VoiceXML files, which describe the possible interactions in a voice service. To serve these interactions in a phone call, Kasadaka runs a stack of open-source applications that provide the different functions that are required for voice-based interactions. Asterisk, an open-source telephony exchange application is used in conjunction with chan_dongle (an interface to phone modems) and VXI (a VoiceXML interpreter), to provide the voice-based interactions through the local GSM network (Baart et al., 2019).

Figure 9: Kasadaka on RaspberryPi

In terms of hardware, we used the Raspberry Pi 3B+ (see Figure 9), which is a low-resource computer based on an ARM processor. The Raspberry Pi runs a Debian-based Linux distribution. To provide the Raspberry Pi with connectivity to the local mobile phone network, a USB 3G modem is used. The total costs of the hardware was around 560 Ghana Cedis (GHC) (about $90).

3.3.2 *Development and Testing*

Preparation for development on the Kasadaka VSDK involved recording various audio fragments in local languages. This is a brief illustration of how this works; Consider the following text as separate audio files; 'There will be', 'Light', 'Medium', 'Wind', 'Rain', 'Storm', 'Heavy', 'Today', 'Tomorrow' and 'The Day After'. Consider the following (edited)

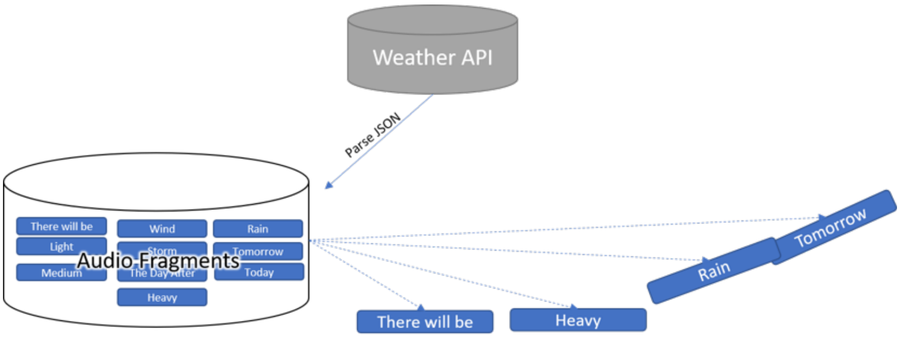

Figure 10: Concatenating Audio Fragments based on Parsed Data from Weather API

result of a 24hr weather forecast API call from Weather API;

```
"location": {
        "name": "Guabuliga",
        "region": "West Africa",
        "country": "Ghana",
        "lat": 10.42,
         "lon": -0.71,
        "tz_id": "Africa/Accra",
"forecastday": [{
"time_hr":24,
"date": "2019-11-03",
"date_epoch": 1572739200,
"day":
  {
  "maxtemp_c": 35.2,
  "mintemp_c": 21.2,
  "avgtemp_c": 28.9,
  "maxwind_mph": 12.1,
  "maxwind_kph": 19.4,
  "totalprecip_mm": 9.1,
  "totalprecip_in": 0.36,
  "avghumidity": 83,
  "condition": {
  "text": "Heavy Rain",
  "icon": "//cdn.weatherapi.com/weather/64x64/day/305.png",
  "code": 1192 },
```

Mr. Meteo parses the available data from the API call that determines the nature of the climate information we require (namely rainfall; refer to our "Must Haves" in Section 3.2.3), and concatenates the corresponding local language audio files to form the audio information needed by the end-user. In other words, the system does the following;

1. Makes a call to the Weather API for the desired location, using its geographical coordinates (In this example, Latitude 10.42, Longitude -0.71 (the coordinates for Guabuliga)). The call is an Hypertext Transfer Protocol (HTTP) GET in the format; http://api.weatherapi.com/v1/current.json?key=APIKEY&q=10.42,-0.71
   Where q is the location and key is an API key provided by Weather API. The call returns a JavaScript Object Notation (JSON) response (see above)

2. Determines the forecast day by looking at the time_hr variable under forecastday; 24 being tomorrow, 48 being the day after.

3. Looks at the text variable, under forecastday>day>condition which has been conveniently provided by the Weather API; alternatively, calculations could be done using Precipitation (totalprecip_mm) and Humidity (avghumidity) to determine the likelihood of rain over the forecast duration. The text variable from Weather API is more extensive than what was required, and so variables with unrequired conditions were ignored (e.g. snow, sleet) and the remaining were parsed to further simplify them (e.g. variables with "light" or "patchy" were simplified to just "light", some text like "at times" were ignored). The parsing therefore resulted in two variables; quantity ("light", "moderate" or "heavy") and event ("rain")

4. Based on the variables ("heavy" and "rain" for quantity and event respectively), the appropriate audio fragments are selected consisting of the preamble (which is always "there will be"), the forecast; quantity ("heavy" in this example) and event ("rain" in this example) and time ("tomorrow" in this example). The resulting fragments selected (in order will therefore be);

   - There will be
   - Heavy
   - Rain
   - Tomorrow

   Mr. Meteo then "instructs" the Kasadaka system to point to these fragments, in this order, for all incoming calls (after an initial welcome message). Note that these audio fragments are in the local language of the caller and only in English here for obvious reasons. The resulting system is a Raspberry Pi with a USB Dongle, hosted in an institution, with internet access, that end-users in the community call via normal 1st generation, non-smart mobile phones to immediately hear the weather forecast for the next 24 hours in their own language. To improve simplicity, one number was designated to one location so that users would not need to use Dual-Tone Multi-Frequency (DTMF); pressing keys on your phone in response to questions during an Interactive Voice Response (IVR) call.

3.4 DEPLOYING AND EVALUATING

Mr. Meteo was initially piloted to over 50 farmers from 4 communities in the Upper East Region of Ghana. Based on informal interviews of farmers involved in the project, carried out during the requirements elicitation, 100% owned mobile phones which they used regularly to make calls and 50% of those calls were said to be related to farming. All farmers also owned radio sets; those who did not have separate radio sets mostly had an FM feature on their phones which they used to tune into radio programs. On the other hand, although aware of a SMS function, none of the farmers had ever used it. Due to the fact that most of these farmers had been involved in the requirement elicitation from the very beginning, and the stakeholders involved, namely CowTribe and CSIR-SARI, had frequent interactions with them, they needed little to no introduction to the system to begin testing. Once a number was provided, they made calls in to assess the system, with those who could not or did not make calls, listening in to other's calls. Focus Group Discussions and individual interviews were conducted with the 50 farmers involved in the deployment, after they had become familiar with the use of the system. This was meant to get some in-depth knowledge as to their impressions of the system.

The Focus Group Discussions dealt with five key areas:

1. User Experience and Usability - Farmers were queried about their general experience with the Mr. Meteo system, the convenience of using it, the obstacles encountered while working with it, and if they were able to gain immediate access to the weather report when required.

2. Language and Content Relevance - The clarity and understandability of the information offered were probed in the queries to find out how easy it was to grasp the content being given as a forecast and in the local language (Frafra in this case). questions also explored difficulties with any specific weather terms or phrases.

3. Accessibility and Adoption - The farmers were asked about how easy it was using their phones to access the system, what kind of network-related problems (if any) they encountered, how likely they were to keep using it (or not), and whether they would recommend the system to anyone else in their community.

4. Impact and Decision Making - The dialogue centered on whether they felt the predictions would influence their life, farm, business, or daily decision making. They were asked to share instances where they thought the system would, in fact, help them better plan things.

5. Suggestions for Improvement Farmers were urged to give their thoughts on how the system could be made better, whether they liked to get updates at a set time every day or whenever they wanted, and what could be done to make the service reach and help more people in their communities.

The Individual Interviews worked with the Focus Group Discussions (FGD)s to provide more depth and detail on the use of the system. These interviews touched on the following points:

1. User Background and Context - Participants were asked if they had used any system for weather information previously, and how they typically used (or would use) weather forecasts in their daily activities.

2. System Usability and Accessibility - The inquiries evaluated the simplicity of accessing weather forecasts and the nature of the experiences associated with calling into the system. This was to determine obstacles that may have cropped up when interacting with the IVR or delays or network issues encountered during use.

3. Language and Understanding - Participants were queried about the clarity of the forecasts. Was it understandable? Were any words or phrases potentially problematic?

4. Impact and Decision Making - Same as with the FGDs, questions centered on how the predictions would influence their livelihood and daily decision making

5. Future Adoption and Improvement - The likelihood of continued use was probed along with the willingness to pay a small fee for access to the system on an ongoing basis. Also explored were features that might be added to make the system more useful.

These discussions and interviews provided a comprehensive assessment of farmers' experiences, challenges, and recommendations regarding Mr. Meteo, ensuring that user feedback could inform further refinements and potential expansions of the system.

3.4.1 *Farmers Impressions*

3.4.1.1 *Climate*

From the onset of this study, farmers in various rural communities had made mention of how their indigenous methods of determining climatic conditions were increasingly problematic in recent years; we suspect this to be due to the drastic change in world-wide climate. As such, this became the most impressive "selling point" for farmers who were introduced to the system; they would have the ability to finally get the climate information they had been looking for. As it has a direct impact on their farming activities and subsequently their livelihoods, they found this to be a much needed solution that would be extremely useful. Farmers however indicated that they would be more inclined to use this service towards the end of the dry season and during the rainy season, as opposed to the dry season; the north of Ghana has two seasons, one during which there is rainfall, and the other when it's totally dry (no rain at all) (Atiah et al., 2021). The reason for this inclination in when they need the service, is that climate information becomes irrelevant to them when there are no rains and becomes increasingly relevant as the rainy season nears; knowing when the season will start gives them an indication of when to prepare their farms for seeding. This goes back to the argument of the need for relevancy for the end-users in ICTs for low-resource environments (see Section 2.1.4)

3.4.1.2 *Local Language*

In Section 3.1, we refer to the nature of the current weather forecasting that is available and how it is often in English. It was therefore refreshing for farmers to see a system built that "spoke" their own language and more importantly useful in the sense that it allows them to understand (in proper context) the forecast being given without 3rd-party interpretation (prone to errors) and/or ambiguity.

3.4.1.3 *Usability*

Some farmers, during the development phase of this project had talked about other systems they had heard of, or been introduced to, and one of their major concerns had been the usability of the system; primarily which medium they would use to access the information and in what format said information would be in. They were therefore glad to have a system that they could access through technologies they were already abreast with (mobile phones) and in a format that, although they had not really encountered before in such modern solutions, was natural to them and didn't require literacy in

English. The simplicity of simply calling a number and not having to figure out any "advanced" features was appealing to them.

3.4.1.4 *Cost*

In terms of the cost of using the system, most farmers were willing and able to spend (airtime) to make calls into the system (0.2960 GHC (5 US cents) per minute), however a few did show some reluctance due to the cost of calling in. We have previously mentioned the need for a financially sustainable system, which would require some form of payment from end-users and it was therefore positively surprising that the more preferable option, as suggested by the farmers, was a subscription-based system with toll-free calls. This potentially can be modelled into a self-sustaining system while maintaining the low-cost of subscription for end-users.

3.4.1.5 *Other forms of Information*

In addition, farmers inquired of the possibility of other forms of information via the system. Information of note that they requested were; disease outbreaks, human and animal health, farming practices and information on their children's schooling. The addition of other relevant information, they noted, would increase the likelihood and number of subscribers and also possibly change the lack of usage they perceived in the dry season (see Section 3.4.1.1)

3.4.2 *Other Stakeholders' Impressions*

In addition to the impressions outlined above, other stakeholders, namely Cowtribe (an animal health startup) and CSIR-SARI (an agricultural research institute), were, as expected, interested in some more technical aspects.

3.4.2.1 *Scaling Up*

Stakeholders were interested in a scale up of the system with additional languages (impressions from CSIR-SARI) and with other relevant content (impressions from CSIR-SARI and Cowtribe), especially animal health. They had already realized, from being involved in the design process, that the above scale-ups proposed would not only be feasible but simple to achieve, based on the design choices we had made as a result of requirements (see Section 3.2.4). This gives a good indication that the broader concept of getting general information to rural communities has already been realized by the stakeholders and end-users.

3.4.2.2 *Future Modifications*

Post-pilot discussions with stakeholders went on and we delved into the future plans of the project. Aside from simple scaling-up, stakeholders were interested in what other possibilities they were to improve and/or augment the system. Further brainstorming brought up a new idea of a future plugin system related to community (HAM[2]) radio

2 https://en.wikipedia.org/wiki/Amateur_radio (accessed 17-07-2024)

transmission (see Chapter 4). This was seen as simply another iterative step in the design process, working with the stakeholders and end-users to provide an even better solution.

3.5 Challenges

There are some notable challenges that were faced, not necessarily during the design and development of the system, but in the evaluation of its real-world use. It should be noted however that subsequent iterations tackled these challenges (see Chapters 4 and 6

3.5.1 *Cost of Calls*

One of the main challenges noted was the expense of making phone calls to access weather forecasts. Farmers had to pay for calls, which, although relatively inexpensive at a cost of 0.296 GHC per minute (about 5 US cents), were still a concern for some users. The average farmer did not have too much trouble covering the price of the calls, but some farmers balked at the idea of paying to make a call for a weather forecast. Discussions were held with various stakeholders on what some alternative pricing strategies might look like, and some ideas emerged that could potentially allow farmers to access the service without paying for calls.

3.5.2 *Concurrent Calls*

Another limitation was the system's inability to handle multiple calls at the same time. The GSM module used to host the service could only accommodate one call at a time, which meant that users had to wait if another farmer was already using the system. This issue became more evident during testing when multiple farmers were accessing the system at the same time. This pointed to a need for scalability solutions that would still adhere to the contextual situation.

3.5.3 *Accuracy of Weather Information*

Perhaps the most significant challenge was the accuracy of the weather information provided by Mr. Meteo. Mr. Meteo relied on Open Weather APIs, which, while broadly reliable, failed to offer hyperlocal forecasts for some fairly remote rural regions. Farmers reported that the weather predicted by the system did not always match their actual conditions, leading some to less trust the system. This situation made clear how necessary it was to couple the system with local meteorological stations and to explore hybrid models that would allow the system to incorporate more of the indigenous knowledge that its rural users have about their specific regions.

Although significant, these challenges provided valuable insights on how to improve voice-based ICT systems to better serve rural communities. It showed the need to tackle these problems and concerns in three big areas: cost optimization, system scalability (can we serve even more people as the system gets better?), and better accuracy in the actual predictions of the weather, or alternative, but equally important and accurate information.

3.6 DISCUSSION

As the first implementation of the various concepts discussed so far and of the methodology, Mr. Meteo formed a basis upon which successes, challenges, and failures could be assessed. It also provided the first proof of concept in the field; of the adapted living-labs, iterative and interdisciplinary methodology proposed. From this implementation, we immediately see how the context had a direct consequence on several choices made in the design process;

3.6.1 *Literacy*

Literacy, as mentioned, is a major contextual issue, as most formal information online or offline will be in English or in one of the major languages in the world. These low-resource regions have very minor languages spoken by a small population of people (maximum of 2 million; often much smaller). Members of these communities often cannot read or write (Dittoh et al., 2020a), and as such, by implication, any information they must access should be in their own language and in a format that is easily understood (diagrams, pictures, symbols, oral). This context drove the choice of technologies to voice (oral), which can combine the two above requirements of a local language and an understood delivery format. Furthermore, in order that the project will benefit numerous communities in any low-resource environment, the design was not made for *a* local language, but for *any* local language, allowing easy scaling in terms of language.

3.6.2 *Infrastructure*

ICT Infrastructure is severely lacking in most of the Global South and Ghana, although better positioned than most in its region, has a huge lack, especially in rural areas. This is most likely due to expected business choices made by communication companies due to the general lack of digital (specifically, Internet-enabled) devices in those areas. This makes the use of the internet (3G or 4G) unfeasible for any communication in and out of such communities. On the other hand, due to the extremely high mobile penetration (note; not internet penetration) in Ghana, GSM often works in all communities. This context led to the choice of network access to GSM for communication in and out of rural areas to ensure that it is indeed accessible to these communities. It is of utmost importance in building a sustainable ICT system to use the technologies that are available as opposed to introducing new technologies (Heeks, 2002) and as such, the system utilises the already existing and available mobile telephony.

3.6.3 *Relevant Information*

It has been mentioned that the originating idea for Mr. Meteo came from members of rural communities during various focus group discussions and surveys (see Section 3.1).

As such, from the onset it was obvious that climate information was relevant to rural communities, especially for crop and animal farmers. Furthermore, during the iterative design process, it became evident (from farmers) that certain climate information was far more relevant (e.g. rainfall, wind), others far less relevant (e.g. humidity, temperature) and some not relevant at all (e.g. Ultraviolet (UV) radiation). This information on relevance of specific climate information was therefore taken into consideration in the data being parsed by the system (see Section 3.3.2), and subsequently the information being passed by the system to the end-user. As such, the system only delivers forecasts on rain and wind.

3.7 CHAPTER SUMMARY

In this chapter we have seen the various steps taken that resulted in the implementation of the Mr. Meteo prototype, a voice-based information dissemination system that provides climate information to rural communities in the northern part of Ghana by providing a system they can call-in with 1st generation (non-smart) mobile phones via GSM.

One of the most interesting things about Mr. Meteo was that we (the researchers) had this idea in mind prior to our visit to the communities, and without any leading from us, members of these communities also proposed the same idea. Naturally, this is because climate change is a serious and noticeable issue in farming and since this is the major occupation of these communities, it is therefore one of the most pressing needs to them (remember; relevant content).

On the other hand, they originally suggested some form of symbol-based SMS prompts as the means of delivering this information to them. This was because they had previously seen all other ICT4D projects in the region that attempted this form of information delivery and although it was not the best (or even good for that matter), it was the only thing they could think of.

The suggestion (and demonstration) of a call-based system that speaks their language causes quite a stir in every community I have been to; they are used to hearing their languages on radio and from others on the phone, but usually not in automated systems. The sudden realization that this is possible is a wonder to see, as they are suddenly bursting with ideas on what else this system can do for them, sometimes beyond what we can (currently) provide.

This speaks to the need for systems such as this and the fact that this community-orient methodology, alongside voice technologies, is a step in the right direction.

In the next chapter, we see the development of another system based on the successes, challenges, and lessons learnt from the first prototype.

4

TIBAηSIM (RADIONET): INFORMATION ACCESS FOR RESOURCE-CONSTRAINED ENVIRONMENTS

In this Chapter, we discuss a second use-case, Tibaŋsim (RadioNet), which delves even deeper into, not only the local context, but also the use of multiple available technologies (as discussed in Section 3.6.2), a more elaborate engineering phase, a wider deployment within the research area, and a more detailed evaluation with empirical data to measure both technical (hardware and software) usage and the usability of the system from the user perspective. This evaluation shows, by way of empirical data, the success of the user-centric approach and the feasibility of hardware deployments in resource-constrained environments. This chapter is based on Dittoh, Francis et al., 2020. "Information Access for Low-Resource Environments." Proceedings of the 3rd ACM SIGCAS Conference on Computing and Sustainable Societies. *DOI:* `10.1145/3378393.3402506`*. and Dittoh, Francis et al., 2021. "Tibaŋsim: Information Access for Low-Resource Environments."* Proceedings of Sixth International Congress on Information and Communication Technology. *Pp. 675–683. DOI:* `10.1007/978-981-16-2377-6_62`*.*

4.1 CONTEXT ANALYSIS & NEEDS ASSESSMENT

Using an iterative process in the follow-up to Mr. Meteo (see Chapter 3) insights from stakeholders and end-users were further gleaned to obtain the needs of an improved system. Most of the requirements therefore remain the same; however, some new requirements, which are not trivial in terms of design and implementation were realized from this process.

The local infrastructure was re-assessed, by field visits and interviews with CSIR-SARI and other organizations, taking a deeper look into the availability and/or reliability of certain information communication technologies that could have been in consideration for the project. The rural areas of the Salaga District, just like the previous research area for Mr. Meteo, were found to have unreliable internet at best, and in most communities often slow or unavailable access. In contrast, and again similar to the previous research area, GSM was found to be available and often reliable, as well as Radio; which is vital for the new innovation that was being considered.

4.1.1 *Research Area*

The research focused on East Gonja District of the newly formed Savannah Region of Ghana. The Savannah Region covers about 11.7% (35,862 km^2)[1] of the nation's surface area. It has a total population of about 653,266[2] and has the lowest literacy rate in the country (32.8%) which is significantly different from the then national rate of 69.8% (Ghana Statistical Service, 2021). This area is selected for the case study because its rural

1 https://en.wikipedia.org/wiki/List_of_Ghanaian_regions_by_area (accessed 17-07-2024)
2 https://en.wikipedia.org/wiki/List_of_Ghanaian_regions_by_population (accessed 17-07-2024)

areas fit the target group of a resource-constrained environment; being an agriculture production region, having impact on the nation's food security and therefore in dire need of up-to-date information, but being more deprived of infrastructure, and with higher illiteracy rates. Five (5) communities were selected from the East Gonja District of the Savannah Region of Ghana, namely *Kpandu*, *Dabogshei*, *Wulanyili*, *Dalogyili* and *Daashei*. These are typically small communities with about 20 to 30 households with roughly 200 to 250 people per community.

4.1.2 *Pre-Analysis and Findings*

4.1.2.1 *Demographics*

A structured interview (see Appendix A) was carried out with 106 community members in the five (5) communities of the East Gonja District of the Savannah Region of Ghana, to obtain empirical data on the rural context. There were a total of 61 males (57.5%) and 45 females (42.5%) of which 97.2% are married. This gives an indication of some appreciable balance in the gender ratio for this project, which in turn is helpful to ensure equality. 84% of survey participants had no education, with only 5.6% having reached beyond elementary school. In addition, *only 1.6% speak English*. This indicates the low levels of literacy and thus the need for the system to be in local languages understood by members of the community and also not based on text. In terms of occupation, 82.3% were found to be *farmers (crop and/or animal)*, 5.3% *traders*, 5.3% *producers (mainly shea butter)* and 6.2% *artisans*. This is important especially after deployment, giving information providers an idea of the people they are serving.

4.1.2.2 *Technologies*

Out of 106 end-users interviewed, 74 (69.8%) owned mobile phones and 99% had access to a mobile phone (Ghana has a mobile penetration of 130.85% (NCA, 2021). With regards to radio, end-users owned radio sets or had FM radio on their mobile phones (71.7%), or had access to a radio set (97.2%). Using the analysis of a Likert scale (Likert, 1932), which assigns numerical values to ordinal data by giving each a value (Not at all, Seldomly, Normally, Regularly and Frequently) on a scale (the most common scale is 1 to 5). As seen in Figure 11, the mean frequency of end-users listening to radio was 3.58, with a median of 4 (Regularly) while the median score for making phone calls is 3 (Normally). Other research has found very little to no use of SMS and little to no use of smartphones in the rural areas of northern Ghana (Dittoh et al., 2013) and this is further confirmed in this research where the analysis of a Likert Scale on the usage of SMS (sending SMS) shows a mean of 1.44 and a median of 1 (Not at all). This has been found to be due to the inability to read and write.

4.1.2.3 *Information Needs*

As part of the survey, members of the communities were asked what type of information they would like to receive on a regular basis. From a multiple response analysis, *Farming Practices* is the highest mentioned by 98.1% of respondents, followed by *Market Prices* (43.8% of respondents), *Seeds* (37.1% of respondents) and *Weather* (35.2% of respondents).

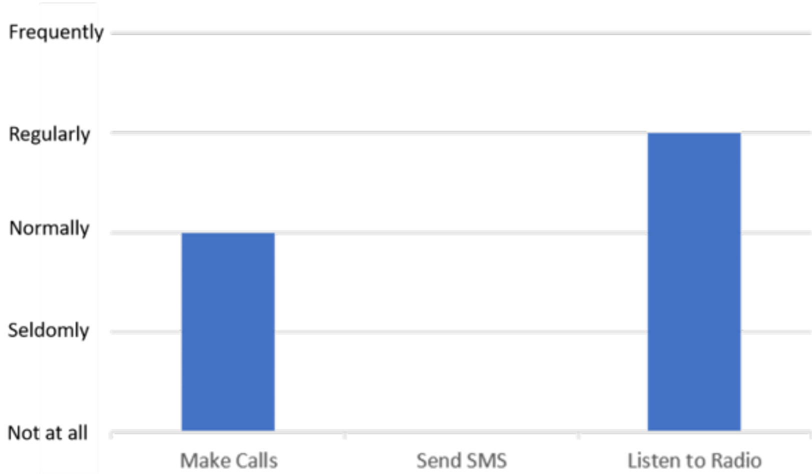

Figure 11: Median frequency of use of mobile phones (calls and SMS), and radio among rural end-users (n = 106), based on a 5-point Likert scale (1 = Not at all; 5 = Frequently)

Other information types of note are; *Health* (25.7%), *Adverts for sale of produce* (22.9%), *Plant disease, animal farming and animal disease* (mentioned by 19.0%, 18.1% and 16.2% of respondents respectively).

This gives information providers a good indication of the relevant (from an end-user stand-point) information that would have to be obtained and translated for the service.

4.2 use-case and requirement analysis

Based on the above context analysis, from stakeholders and end-users, we begin to build on the use-case.

4.2.1 *Key Idea*

To create a digital information access system for local communities by designing a short-range FM broadcast system. This will enable rural communities to get access to relevant voice-based information in their own language(s). It will involve the design of a low-cost system, built on a plug-computer with solar power-banks, that stores recorded voice fragments over GSM calls and broadcasts it over FM (see Figure 12).

4.2.2 *Actors and Goals*

The following actors were identified for the system, along with their intended/required goals within the system

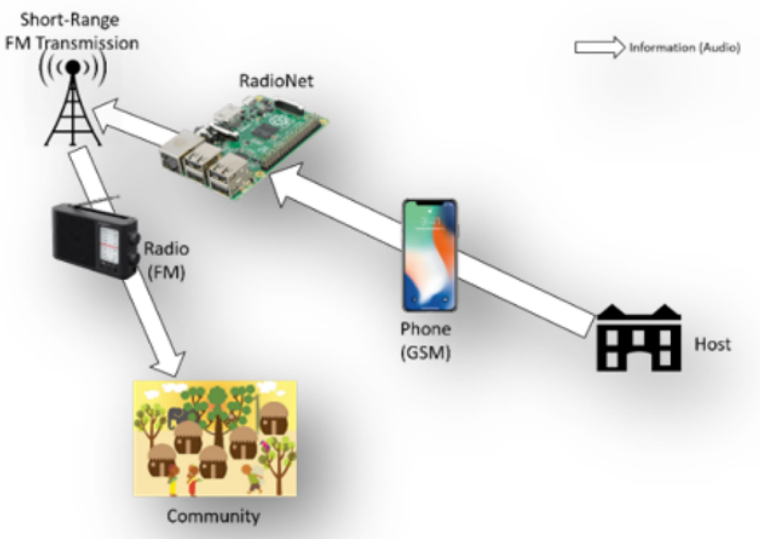

Figure 12: Tibaŋsim System Design Showing Information (Audio) Flow

ID	Actor	Description
1	User	Tune to FM Frequency on Radio Set to get information
2	Community Leader(s)	Host Hardware in appropriate location
3	NGO/Institution	Obtain, translate and call into system to record relevant/requested information
4	Support	Monitoring/Maintenance

Table 2: Actors and Goals identified for Tibaŋsim

4.2.3 *Key Requirements*

Following an understanding of the context and the needs analysis, as well as considering the technologies available, the following are the key requirements of the system;

Must Have	Interactive Voice Response
	Local Language(s)
	Regular Information Updates
	Short-Range Radio (FM) Transmission of information
	Monitoring
Should Have	Uninterrupted power supply
Could Have	Community-level Subscription-based service
	Wide-Range Radio (FM) Transmission of information

Table 3: MoSCoW Requirements for Tibaŋsim

4.2.4 *Non-Functional Requirements*

- Maintainability - NGOs/Companies and Institutions should have the ability to maintain the system and update information with ease
- Availability - Users should have the ability to reach the system at all times. As such, barring mobile network issues, the system should be hosted on a platform that will be available at all times
- Scalability - The system must have the ability to scale to different locations and for any number of subscribers and the system should be easily replicable
- Reliability - The system must ensure that information is as accurate as possible
- Usability - The targeted user group creates a requirement of simplicity in the user interface
- Cost-Effectiveness - The whole system must work together to be financially sustainable

4.2.4.1 *Feasibility and Sustainability Assessment*

It is important that the system outlasts the initial project so as to be truly beneficial to the communities. As such, we *assess the sustainability* by considering the technical and business/socio-economic feasibility as well as possible goal conflicts, dependencies and preconditions required for the system to function as a whole (Bon et al., 2016).

The project also focused on the system being fit for the rural context. As such, technically, the design is as simplistic as possible, focusing on affordable hardware, open-source software and not requiring additional hardware and/or skills from the end-users.

Discussions with stakeholders showed that information delivery to and from rural areas is often an issue and as such a system that aids this is economically viable provides them with a way of not only saving time, but also delivering information they would have before now not been able to.

A further analysis of costs pertaining to financial sustainability of the system are as follows;

4.2.4.2 *Hardware Costs*

Tibaŋsim was built on low-cost hardware. The system runs on a Raspberry Pi 3B+ and requires an SD-Card, a Huawei 3G Modem and a GSM Sim Card. A power bank was also added to the package. At the approximate costs of $40 for a Raspberry Pi 3B+, $40 for a powerbank, $17 for a 3G Modem and $7.50 for 32GB SDHC Card, the total hardware cost for a single deployment stands at $104.50.

4.2.4.3 *Open-Source Software*

Tibaŋsim was developed on top of the Kasadaka Platform (see Section 3.3.1). The main software component that enables the development of voice services is called the Voice Service Development Kit VSDK which runs a stack of (mostly open-source) applications that provide the different functions that are required for voice-based interactions. Asterisk,an open-source telephony exchange application is used in conjunction with chan_dongle (an interface to phone modems) and VXI (a VoiceXML interpreter), to provide the voice-based interactions through the local GSM network (Baart et al., 2019).

The FM Broadcast Module of Tibaŋsim was developed using Pi-FM-RDS[3], which is an open-source module that generates an FM modulation, with Radio Data System (RDS) data generated in real time. It can include monophonic or stereophonic audio. It is based on the FM transmitter created by Oliver Mattos and Oskar Weigl[4]. It is compatible with both the Raspberry Pi 1 (the original one) and the Raspberry Pi 2, 3 and 4.

Finally, Bash-Over-SMS, the monitoring/updating module of Tibaŋsim, was developed using Gammu[5]. Gammu is an open-source command line utility that provides access to wide range of phone features including SMS retrieval, backup and sending.

4.2.4.4 *Setup Costs*

Tibaŋsim is built with rapid deployment in mind. As such, the process of setting up involves writing the Tibaŋsim Image to an SD Card (ETA; 2 to 5 minutes), obtaining a SIM Card with its corresponding phone number, connecting all these peripherals together and turning the system on. First boot may take up to 20 minute, making a maximum of about 30 minutes required for setup. As such, the setup process even during a scaled up deployment will incur little to no cost.

4.2.4.5 *Running Costs*

Regardless of how effective cost reduction is, there are unavoidable costs (however small) that any information delivery system will incur during its operational phase. Tibaŋsim requires power supply and access to the local telephone network. The host, a selected community member, is responsible for this. The information providers are also required

3 https://github.com/ChristopheJacquet/PiFmRds (accessed 17-07-2024)
4 http://www.icrobotics.co.uk/wiki/index.php/Turning_the_Raspberry_Pi_Into_an_FM_Transmitter (accessed 17-07-2024)
5 https://wammu.eu/gammu/ (accessed 17-07-2024)

to make calls into the system to leave messages, and the monitoring system requires the use of SMS through the local telephone network. Through the use of low-cost hardware and technologies, the running cost is firstly distributed and also minimal. Based on discussions with stakeholders, we however propose a business model for the running of Tibaŋsim.

4.2.4.6 *Proposed Business Model*

A subscription-based service is proposed, where the information providers (in this case, the CSIR-SARI) are able to keep the system sustainable by funding information updates as well as monitoring and maintenance, from funds generated from subscriptions per community.

Some funds are also required for the hosting of the hardware (mainly cost of power and the hosting service). Note that the hardware is hosted within the community by a selected community member. To further validate/formalize this model, we use the

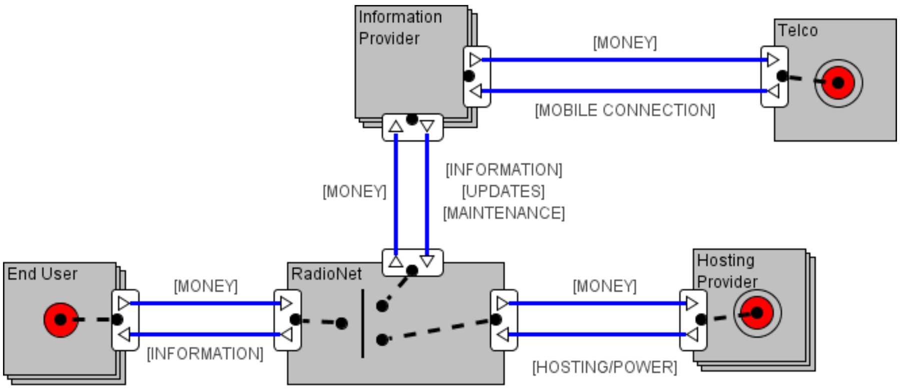

Figure 13: Proposed Business Model - e^{3}value for Tibaŋsim

e^{3}value modelling language. Containing a small set of concepts and relations, this allows us to do easily apply it in out iterative step with changes which aids rapid development. The e^{3}value methodology represents networked business models in terms of end users and enterprises, as well as the things of economic value they exchange with each other.

e^{3}value assigns economic value to the things exchanged, set pricing models, the number of customer needs, the actors involved and required investments. Actors are profit-loss responsible entities, such as organizations, customers and intermediaries. A Market segment is used to represent a group of similar actors (such as a pool of users), Value transfers are transfers of value objects, such as a payment or the delivery of a service, and Value objects are things of economic value which can be exchanged, such as money, services, products, knowledge or experiences(Gordijn et al., 2021).

The e^{3}value system proposed for Tibaŋsim (see Figure 13), has the Information Provider (e.g. CSIR-SARI) as an example of a market segment, exchanging information, maintenance and updates of the system for money (a value object) which in turn is used to pay for mobile services from the Telecommunications Provider (an actor). The information uploaded into the system by the Information Provider, using the services of the Telecommunications Provider is accessed by the end-user in exchange for a flat-rate community subscription which provides the funds needed for the Information Provider and for the Hosting

Service	Cost/Month (GHC)	Cost/Month ($)
Call Tariffs	17.97	3.41
SMS Bundle	20.00	3.80
Call Service	150.00	28.50
Hardware Hosting	50.00	9.50
TOTAL	**237.97**	**45.21**

Table 4: Tibaŋsim Expenditure (Running costs)

Provider, who will provide services that ensure the uptime and upkeep of the hardware system.

Call rates for MTN Ghana[6] (the most widely used Telecommunications Provider) stands at GHC 0.1198/min ($0.022/min) for a local call. A typical voice segment from the Information Provider (based on durations from the pilot phase) is about 5 mins. Using an estimation of one voice segment per day, call costs will be at GHC 0.599/day ($0.11/day) or GHC 17.97 per month ($3.41 per month). An addition of GHC 5 per call can be made as incentive to the personnel that will make these calls daily. This could help with the creation of controlled crowd-sourcing for translation and recording of the daily voice segments; this will result in a total of GHC 150 per Month ($28.50 per month). An estimate of GHC 50 per month ($9.50 per month) can also be made for the Hosting Provider. Maintenance and Monitoring of the system requires the use of SMS, which is estimated at 5 GHC per month (SMS Bundle of 1800 SMSes).

This will put total running cost of the system at about GHC 237.97 ($45.21) per month. The proposed subscription cost, based on discussions with stakeholders and end-users is GHC 10.00 ($1.90) per month. With a lower estimate of 50 farmers per community, that puts income at GHC 500.00 ($95.00). The profits made will then cater for monitoring and maintenance (see Table 4).

The above proposed financial model using the e^{3}value methodology provides a detailed model that can ensure the economic sustainability of the project.

4.3 ENGINEERING

Based on the Context Analysis and Needs Assessment (see Section 4.1), Use-Case and Requirement Analysis (see Section 4.2) and the Feasibility and Sustainability Assessment (see Section 4.2.4.1), the various components of the system were engineered, deployed and evaluated in multiple iterations with adaptations in a Agile approach coupled with an adapted living lab approach.

4.3.1 *Hardware*

Tibaŋsim was built on the Raspberry Pi 3B+ 10, tiny credit card size computer that was designed in the United Kingdom (UK) by the Raspberry Pi Foundation. Originally

6 https://mtn.com.gh/insight/tariffs/ (accessed 17-07-2024)

intended to assist in teaching computer science, the Pi's accessible price makes it popular with hobbyists/makers/hackers who use it to create everything from Living Room PCs to Robotics Projects, and now, rural ICT4D Projects. The Raspberry Pi 3B+ runs a Quad Core 1.4GHz Broadcom BCM2837 64bit Central Processing Unit (CPU), with 1GB RAM (2GB and 4GB RAM versions available) and requires a power supply of 2.5A.

It also has a 40-pin extended General-Purpose Input/Output (GPIO), of which, vital to this project, GPIO Pin 4 transmits its FM signals. The Raspberry Pi 3B+ requires an SD-Card to run its Operating System.

Tibaŋsim also required a Huawei 3G Modem that is chan_dongle capable and a GSM Sim Card. A power bank was also added to the package to ensure uninterrupted power supply.

4.3.1.1 *Voice Input: Kasadaka*

The Kasadaka platform was used for the system's audio input module. Kasadaka enables the development and hosting of voice-based information services, targeted at resource-constrained environments (see Section 3.3.1).

The Voice Input Module of Tibaŋsim is the user interface for the Information Provider. On calling into the system through the use of any mobile phone, from anywhere with GSM coverage, the Information Provider encounters a prerecorded voice prompt welcoming them to Tibaŋsim and immediately allowing them to record a message. After recording the system will then play back the message and ask for a confirmation or a do-over.

At the backend, on confirmation, the audio fragment is stored in Tibaŋsim's file storage

4.3.2 *Broadcast System: Pi-FM-RDS*

The Tibaŋsim FM Broadcast System was built using Pi-FM-RDS. Pi-FM-RDS generates an FM modulation, with RDS data generated in real time. It can include monophonic or stereophonic audio. The transmitter uses the Raspberry Pi's Pulse-Width Modulation (PWM) generator to produce Very High Frequency (VHF) signals[7].

Pi-FM-RDS generates its audio from an audio stream or file. It will automatically filter and sample audio formats including WAV and Ogg/Vorbis (among others) but not MP3. It is however possible to pipe the output of a program into Pi-FM-RDS. For instance, this can be used to read MP3 files using Sox.

The Broadcast System of Tibaŋsim is the main user interface for the End-User. The system reads the audio files from the file storage system of the Voice Input Module and broadcasts them on a loop on FM at 107.9MHz. This frequency was chosen because, firstly, it is at the very end of the used frequencies for FM Stations and also because it was

7 http://www.icrobotics.co.uk/wiki/index.php/Turning_the_Raspberry_Pi_Into_an_FM_Transmitter (accessed 17-07-2024)

found to be the least close frequency to the registered twelve (12) FM Stations in Northern Ghana.

4.3.3 *Monitoring System: Bash Over SMS (BOS)*

Monitoring of deployed ICT Systems can be difficult but at the same time, it is very necessary to keep track of its operation status (Dostál, 2012). Many monitoring tools exist, some even designed with rural deployments in mind, but in some resource-constrained environments, it becomes impossible to implement these, as they rely on internet connections (Cai et al., 2009).

The Monitoring System of Tibaŋsim (codenamed BOS) uses the existing GSM connection to send internal measurements/information to a pre-selected number for monitoring purposes. The information, which includes device temperature, CPU and Input-Output (IO)-utilisation, number of running processes, uptime and the names of the available recordings from the Tibaŋsim file system, is sent at 30 minute intervals.

An analysis of these results give an indication to the average and highest temperature of the device (critical due to the climate of the region), the software load on the device (will inform on future adaptations) and keeping track of recorded voice fragments.

In addition, BOS receives commands sent from a pre-selected number and executes them on the system. This gives the ability to remotely make software-based system changes, modify the measurements (device) and information being sent, delete outdated voice fragments, among other things.

4.3.4 *Setup and Testing*

Setup and testing was carried out at the University for Development Studies, Ghana in conjunction with experts from the CSIR-SARI and Internet Society, Ghana Chapter. Setup involved the assembling of the hardware components and installation of the developed system. Testing involved call-ins by stakeholders to test the Voice Input, tuning in on various radio-enabled devices to test the Broadcast System (quality and range) and test of the Monitoring System by retrieving the various measurements over SMS and also sending commands via the BOS module.

4.4 DEPLOYING AND EVALUATING

4.4.1 *Deployment*

Deployment entailed a road-trip to 5 communities in the Salaga District of Ghana. CSIR-SARI, together with an Agricultural Extension Agent from the Ministry of Food and Agriculture had pre-informed the selected communities of the deployment visits.

At each community, the system (as a whole) was re-introduced to community members. Most were aware of the system due to collaborations in the context analysis and user-centred design process. A community member (pre-selected by community members) worked with the team to place the hardware in the most optimal location (with respect to safety, GSM reception and FM Broadcast coverage).

Community members then tuned in on their various FM-enabled devices to hear the broadcasts. This was used as a Beta test where more data was collected to inform on further changes. The devices, from that point on, remained in the respective communities.

4.4.2 *User Evaluation*

User evaluation was carried out by way of a System Usability Scale (SUS) Test. The results are presented in this Section.

4.4.2.1 *SUS*

The SUS is designed to obtain subjective feedback on overall usability and user satisfaction (Brooke, 1996).

The SUS involved the administering of the test to all 106 participants following their use of the system. The following questions were asked and participants responded on a scale of 1 (strongly disagree) to 5 (strongly agree);

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well intergrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

It is important to note that translations (in the right context) were necessary to effectively administer the SUS as it has been found that there is a possibility of a lack of comprehension in some of the SUS questionnaire items for non-Native English speakers (Finstad, 2006).

Items 1, 3, 5, 7, and 9 are positively worded and items 2, 4, 6, 8, and 10 are negatively worded. Apart from the 10-item SUS Score, using factor analysis, the SUS is able to provide additional information via two sub-scales: an 8-item "Usability" and 2-item "Learnability" scale (Finstad, 2006)(Sauro, 2011).

4.4.2.2 *SUS Results*

For reliability analyses of the data, the absolute ratings (Questions 2, 4, 6, 8, and 10 were re-coded so that all scales had 1 as the negative and 5 as the positive) for the 10 statements were used to calculate Cronbach's alpha(Gliem et al., 2003). The SUS showed good internal consistency (alpha = 0.743)

SUS Score	80.50
Learnability	71.90
Usability	82.60
Standard Deviation	16.08
Cronbach's Alpha	0.74
Adjective Rating	Excellent

Table 5: System Usability Scale Score

For every odd-numbered item above, we subtracted one from the user response (x - 1). For every even-numbered item above, we subtracted the user response from 5 (5 - x). This scales all values from 0 to 4 (with four being the most positive response). We then multiply each response by 25; this converts the range to a 0 to 100 scale. The average score of the averages of all calculated responses gives us an SUS Score of 80.52 (an Adjective Rating (Bangor et al., 2009) of "Excellent") with a Standard Deviation of 16.08. We also calculate Learnability from Questions 4 and 10, giving a value of 71.93, and Usability from the remaining 8 questions, giving a value of 82.67 (see Table 5).

The high scores for SUS, Learnability and Usability, indicates a high quality of end-user's experience with Tibaŋsim and the ability to utilize it with little to no prior training or help.

4.4.3 *Monitoring (Device Evaluation)*

The Monitoring System of Tibaŋsim provided data on device temperature, CPU and IO utilization, number of running processes and uptime of the five (5) deployed systems. We present data collated from the Monitoring System for a period of 20 days (average of one SMS every hour), from the 23rd of October, 2019 to the 11th of November, 2019

Community		R1	R2	R3	R4	R5
Device Temp (°C)	Mean	63.64	63.66	63.99	63.56	63.67
	Max	81.70	80.60	81.10	77.40	80.60
CPU/IO Utilization	Mean	0.41	0.40	0.41	0.39	0.38
	Max	1.54	2.03	2.03	1.46	1.89
Processes	Mean	7.53	7.40	7.62	7.49	7.47
	Max	13	13	13	12	12
Average Uptime/Day (Hrs)	Mean	16.83	17.16	16.59	16.39	17.01
	%	70.10	71.51	69.11	68.28	70.89

Table 6: Analysis of Monitoring System Data

4.4.3.1 *Device Temperature*

The average atmospheric temperature in northern Ghana in October is about a min of 22°C to a max of 30.6°C, rising by March to an average of 25°C (min) to 39.7°C [8]. These high temperature values makes device heating a large concern with regards to hosting in a rural setting.

All Raspberry Pi models perform a degree of thermal management to avoid overheating under heavy load. The System on a chip (SoCs) have an internal temperature sensor, which software on the GPU polls to ensure that temperatures do not exceed a predefined limit; this is 85°C on all models. For Raspberry Pi 3 Model B+, the PCB technology has been changed to provide better heat dissipation and increased thermal mass [9]; one vital reason for the use of this model over its predecessor (Raspberry Pi 3 Model B). Heatsinks were also installed on each device, but no fans.

The Monitoring System uses a command that can provide an accurate and instantaneous reading of the current SoC temperature, as it communicates with the GPU directly, *vcgencmd measure_temp*, to retrieve the device temperature. For the period of 20 days, from hourly measurements, we recorded an average temperature of 63.64°C, 63.66°C, 63.99°C, 63.56°C and 63.67°C respectively for each community, with a maximum device temperature of 81.7°C, 80.6°C, 81.1°C, 77.4°C and 80.6°C (see Table 6).

The average and maximum temperatures measured from the devices indicate no thermal issues and are well below the high of 85°C.

CPU AND IO-UTILISATION On Linux, load averages are (or try to be) "system load averages", for the system as a whole, measuring the number of threads that are working and waiting to work (CPU, disk, uninterruptible locks). In short, it measures the number of threads that aren't completely idle with the advantage that this includes demand for all resources [10].

In a Single-Core CPU, a load of 0.0 means there is no utilization of resources at all and a load of 1.0 means utilization is at full capacity. Beyond 1.0 would indicate a backlog of

8 https://www.darksky.net/ (accessed 17-07-2024)
9 https://www.raspberrypi.org/documentation/hardware/raspberrypi/frequency-management.md (accessed 17-07-2024)
10 http://www.brendangregg.com/blog/2017-08-08/linux-load-averages.html (accessed 17-07-2024)

processes waiting to run. However, in a Quad-core CPU (like the Raspberry Pi B+), the load is relative to the number of processor cores available; a load of 4.0 means utilization is at full capacity [11].

The Monitoring System uses *cat /proc/loadavg* to read the load averages over the last minute, the last five minutes, the last 15 minutes. An average of these was taken by hourly measurements over the 20 day period. We recorded an average utilization of 0.41, 0.40, 0.41, 0.39 and 0.38 respectively for each community with a maximum utilization of 1.54, 2.03, 2.03, 1.46 and 1.89. (see Table 6)

The average and maximum CPU and IO utilization are well below the capacity of 4.0. This indicates the various components of Tibaŋsim require little processing power and are efficiently utilizing resources even with continuously looped broadcasts over FM and call-ins to the system.

UPTIME The availability of a system is largely dependent on its uptime. The formula given for the calculation of availability is

$$\frac{\text{uptime}}{\text{uptime} + \text{downtime}} \qquad \text{(Stearley, 2005)}$$

For a system hosted in a resource-constrained community, this could be a major issue due to unreliable electricity.

The Monitoring System uses *uptime* to read the uptime of each device over the 20 day period. A calculation yielded the maximum uptimes registered for each day. The average of this was calculated to give values of 16.83 hours, 17.16 hours, 16.59 hours, 16.39 hours and 17.01 hours respectively for each community with a calculated availability of 70.10%, 71.51%, 69.11%, 68.28% and 70.89%. (see Table 6)

Upon further investigation, the average downtimes of 7.18 hours, 6.84 hours, 7.41 hours, 7.61 hours and 6.99 hours respectively, turned out to be during the night (between 10pm and 7am), where the local hosts powered-down the devices.

4.4.4 *Content Evaluation*

The Context Analysis and Needs Assessment (see Section 4.1) of the methodology used necessitated the solicitation of required content from the end-users. In fact, this was one of the starting points of the project. Being involved in the development process and being gradually becoming aware of the possibilities, end-users, as well as stakeholders (who work close in-hand in the rural communities) were able to clearly specify the type of information that would be relevant to them. Furthermore, post-deployment, empirical data was gathered on the type of content end-users would find relevant (see Appendix A). Notable among information considered relevant in the research area are; Crop Farming Practices, Market Prices, Information on seed, Climate Information and Placing ads for sales of produce (see Section 4.2). With regards to quality, stakeholders (like CSIR-SARI) are already mandated officially to solicit, create and disseminate content, in areas such as agriculture. Of note is information from the World Wide Web, and example being climate information; this requires more technical work to enable automated updates to the system (see Chapter 3).

11 https://scoutapm.com/blog/understanding-load-averages (accessed 17-07-2024)

4.4.5 *Cost-Effectiveness and Affordability*

Based on our context analysis, Cost-effectiveness was of utmost importance and therefore considered a Non-Functional Requirement (see Section 4.2.4). As such, design choices were made for low-cost hardware (see Section 4.2.4.2) and open-source software (see Section 4.2.4.3). The system is also designed to enable rapid and little to no cost setup (see Section 4.2.4.4). For purposes of sustainability, it is imperative that running costs and affordability are catered for and as such, design choices are made to facilitate low-cost maintenance and affordability to end-users. Furthermore, a business model was designed (see Section 4.2.4.6) to facilitate the project's financial sustainability. The Internet Society is in the process of funding the next iteration of the project, which will establish a financially-sustainable project with a business entity and which will expand the system to over 100 communities.

4.5 CHALLENGES

4.5.1 *Remote Communities*

Development of systems for resource-constrained environments with the methodology used requires physical visits (possibly several) to communities. Some communities are remote, with bad road access, making the required multiple visits tedious. This, on the contrary, is the very reason why information access for such communities is vital.

In this project, all communities were remote, with bad road access, but visits were necessary for information elicitation and deployment. However subsequently, it will be possible to deploy with the help of Agricultural Extension Agents who, as part of their existing jobs, visit these communities from time to time.

4.5.2 *Poor 3G/GSM Reception*

Information dissemination through ICTs rely on telecommunications networks, but unfortunately, many rural communities lack sufficient access. As previously mentioned, in some rural communities in Ghana, there is little to no 4G, sparse 3G and patchy GSM reception.

This needs to be taken into account to build systems that do not require constant internet access, high bandwidth, constant uptime, etc. The details will depend largely on the particular community.

Some communities visited for Tibaŋsim's deployment had very bad GSM reception; this led to the change of a few communities for the pilot. There were some locations within those communities with good GSM coverage, but were not ideal for placement of the hardware. The next iteration of development will consider the use of an outdoor, waterproof enclosure coupled with solar-power supply andGSM boosters to enhance reception to the device.

4.5.3 *Unavailability of hardware*

In many developing countries, hardware needed to build ICT systems may not be readily available. This was not a major issue during the pilot process of this project, but considering the sustainability of such projects, it is important to ensure that local developers are able to obtain the hardware required. As such, hardware requirements are not trivial.

For Tibaŋsim, the required hardware (Raspberry Pi 3B+ and Huawei 3G Modems) had to be imported into the country due to its unavailability in Ghana. This caused some delays with the initial pilot. However, the above hardware is readily available in many places around the world and local developers with prior planning should be able to obtain the hardware. Future plans include working with the Internet of Things (IoT) Network Hub Africa[12] to build custom boards tailored specifically for Tibaŋsim.

4.5.4 *FM Broadcast Range*

A project specific issue worth mentioning is the FM broadcast range of the Raspberry Pi 3B+ which is about a 120 Meter radius. As much as this covers enough of each of the communities to be available to community members, the ideal would be a wider range to cover the entire community and to cater for larger communities. The next iteration will consider boosting the range of the FM transmission. This however would require liaising with the National Communications Authority (NCA)[13] in Ghana or obtaining a broadcast license once transmissions begin to exceed official community ranges and/or becomes a commercial product.

It should be noted that innovative ICT solutions such as this one can have legal implications which have to be addressed, especially due to the need for financial sustainability which makes the innovation a commercial product.

4.5.5 *Manual Recordings of all Broadcasts*

One of the advantages of digital media is the ability to automate and easily duplicate (Truscello, 2003). A written article can be sent to millions of people with little to no extra effort. In the case of voice technologies for small languages, automation becomes a problem due to the lack of Text-to-Speech (TTS). In addition, in the case of Tibaŋsim the design prevents duplication of audio content since all broadcasts must be recorded over GSM. This is a challenge in the area of scalability. In future iterations, and with the advent of advanced AI capabilities, research into innovative ways of building of Text-to-Speech and Automatic Speech Recognition for small languages will be considered. A subsystem that automates call-ins to the deployed systems will also be designed.

12 https://iotnetworkhub.org/ (accessed 17-07-2024)
13 https://www.nca.org.gh/ (accessed 17-07-2024)

4.6 CONCLUSION

Information access remains a problem in many parts of the world[14]. Developing countries, such as Ghana, have numerous rural communities that have little access to up-to-date and relevant information (Schmida et al., 2017). The telecommunication infrastructure is lacking in these communities and is mainly limited to GSM reception. Rectifying the issue of infrastructure alone unfortunately does not solve the problem due to other major issues such as the unaffordability of Internet-capable devices, Internet access and voice services, low levels of literacy, and the unavailability of relevant content further compounding the issue (Estache et al., 2007).

Available literature points us towards the use of 'technology-in-use' (Heeks, 2009); in the case of Ghana, mobile telephony and FM radio, concentrating on voice technologies and local languages (Boyera, 2007).

This use-case applied an ICT4D methodology (Bon et al., 2016) in the development of an ICT4D system which is hosted and used in a low-resource environment. Empirical data obtained from rural communities and other stakeholders, was used iteratively to design a low-cost, voice-based information system for rural communities meeting the contextual requirements and operational goals of the various stakeholders. A proposed business model was also presented from brainstorming with stakeholders. The business model uses the e3value ontology (Fosu, 2011) to present an appropriate financial interaction pertaining to the system that would aid its sustainability.

Furthermore, a System Usability Scale (SUS) (Brooke, 1996) test was administered to 106 community members from five (5) communities where the system was deployed, and we presented an analysis of the SUS, Usability, and Learnability scores which indicate that the requirements of the end-users were met and the system is easily used and learned. System data, which was gathered through an innovative remote monitoring system, was also analysed. The data showed that the deployed devices had no thermal issues and are well below the high of 85°C. CPU and IO utilization are well below the capacity of 4.0, indicating good use of processing power and resources even with continuously looped broadcasts over FM and call-ins to the system. Analysis of the availability of the system also showed that local hosts powered down the devices during the night (between 10 pm and 7 am), but broadcasts were available during the day.

Information is a very important commodity for development (Allen, 1990). As such, bridging the digital divide is vital, not only for developing countries, but for the world, as the successes of attaining the SDGs will benefit the planet as a whole. The process of systems development for low-resource regions is therefore critical to successfully attaining SDGs. This process is however not trivial and requires appropriate methodologies that are collaborative, user-centered, and iterative. This aids in fixing issues that exist for the stakeholders and end-users as opposed to fixing perceived problems.

The Tibaŋsim project shows this development process for low-resource areas practically and hopes to serve as a guide for future projects.

14 https://www.statista.com/statistics/278414/number-of-worldwide-social-network-users/

4.7 CHAPTER SUMMARY

This chapter introduces Tibaŋsim (RadioNet), an innovative means of providing information access in resource-constrained environments. The study was conducted in five rural communities in the Savannah Region of Ghana, where traditional internet-based solutions are impractical because of poor infrastructure, low literacy rates, and a lack of locally relevant content.

In these communities, Tibaŋsim exploits FM radio and GSM technologies as reliable channels for delivering voice-based information services in local languages. It utilizes affordable components and open-source software to promote sustainability.

This chapter centrally addresses the question of how to "find practical and sustainable ways to improve digital information provisioning and communication access for rural and peri-urban communities in the Global South". The answers demonstrate that the channels of existing technology—in this case, GSM and FM radio, are far more effective than trying to establish entirely new digital infrastructures. Thus, Tibaŋsim uses broadcasts short-range FM to directly overcome the obstacles of insufficient literacy and poor Internet access.

A key project component was its user-centric evaluation. The System Usability Scale (SUS) test returned an overall score of 80.50 from 106 end users, indicating a high level of usability and acceptance. This score lines up nicely with our feasibility question and says that we are deploying something that is truly user-centric.

Beyond the technical aspects, the chapter also looks at the economic sustainability of the system. The proposed subscription-based model, designed with stakeholders, demonstrates a potential pathway for maintaining the system beyond the pilot phase. While the model presents a feasible framework, long-term sustainability remains a challenge, particularly to ensure continued participation of stakeholders and affordability for end users.

This chapter concludes with a transition to Chapter 5, which shifts focus from rural to urban digital inclusion challenges. While Tibaŋsim explores how technology can be adapted to low-literacy and low-connectivity environments, the next chapter examines how similar principles can be applied to urban settings where affordability and accessibility remain critical barriers. This transition expands the scope of the research, reinforcing the overarching argument that ICT solutions for the Global South must be context-aware, participatory, and adaptable to different socio-economic contexts.

5 SEFARIM AND WOOM: APPLICATIONS FOR URBAN GLOBAL SOUTH

This Chapter provides a case-study for urban communities in the Global South. We start with a juxtaposed view of the digital divide in rural/peri-urban Global South against that in urban Global South; lack of infrastructure versus unreliable infrastructure, low literacy versus low digital literacy, and lack of relevant content versus lack of local content. We then take a look at two ICT solutions (Sefarim and Woom) which employ the same community-based, user-centric, inter-disciplinary methodology for development of ICT solutions. We take a look at the resulting functional and non-functional requirements obtained from using this methodology and their relevance in mitigating the barriers of the digital divide. This Chapter is based on the practical response to the issue of decolonisation of the Internet, as discussed in Saa-Dittoh, Francis, 2023. "Connecting the Unconnected: Decolonising ICTs for the Developing World." Connected World: Insights from 100 Academics on How to Build Better Connections. *URL:* `https://vuuniversitypress.com/product/connected-world/`.

5.1 CONTEXT ANALYSIS & NEEDS ASSESSMENT

The digital divide, as we may have seen by now, although more prevalent in rural and peri-urban communities, as evidenced by the preceding use cases, exists in the urban areas and populace of the Global South. It is therefore imperative that a scientific contribution to closing the digital divide, such as this, flesh out all relevant aspects, in this case rural and urban. ICT solutions for the urban populace of the Global South require a high level of innovation and could form a driving force for development (United Nations Development Programme, 2021). However, ICT innovation is hard in the Global South, especially in light of the colonization of the Internet and dominance of BigTech (Kwet, 2020)(Saa-Dittoh, 2023). This has resulted in a majority of ICT Startups in the Global South failing (Maher et al., 2021) and the market is saturated by foreign companies or Western-funded Startups who know little nor care about the local context (Global Change, 2021).

In light of this, employing the right methodology becomes very necessary for local developers to mitigate the issues of the digital divide. The major barriers faced in overcoming the Digital Divide, which are highlighted in Section 2.1 also exist in the urban areas of the Global South, they are simply in a slightly different context.

5.1.1 *Infrastructure*

Urban areas in the Global South range from very developed metropolis to developing cities. Most of these have similar infrastructure to those that would be found in any developed city in the world with one big difference; reliability (Chambers et al., 2020). ICT services like 4G and Broadband are available but not always reliable. Internet speeds may also be often be slow in some locations and latency (the time delay between the initiation of a request and the completion of the response) is most often high due to the constant reliance and connections to servers and cloud services hosted outside the continent. One reason for the lack of cloud servers within the continent is related to stable electricity (Murenzi et al., 2025), which is required for running server equipment with some reliability, but also for cooling purposes for the immense heat produced by such equipment in an already high-temperature environment.

5.1.2 *Literacy*

As at 2022, Ghana had a literacy rate of about 70%, with Greater Accra Region, the most developed political Region in the country having a literacy rate of 88%[1], however studies have found that there are very low levels of digital literacy where, teachers perceive themselves as digitally literate, whiles a significant portion did not actively use digital tools in their professional practice (Quaicoe et al., 2020), socioeconomic inequalities resulting in limited or late access to digital devices (Gadjanova et al., 2022), or where it was found that university students, during the COVID-19 pandemic, due to low levels of digital literacy had increased technostress, which adversely affected their academic performance and productivity (Essel et al., 2021). These, and many more are evidences of the low levels of digital literacy even within the literate urban populace.

5.1.3 *Content*

ICTs are beneficial because they provide us with content that is relevant to us, for livelihood, education, entertainment, etc. They therefore become less of us when the content users would rather have cannot be found. This is the plight of many urban smartphone users in the Global South. Due to the reliance on ICT solutions from the Global North, coupled with a lack of content being generated from most countries in the Global South, it is often difficult to find localized content online. This leads to the eventual disuse of such solutions.

5.1.4 *Sefarim - Ebook Reader*

Sefarim is an ebook reader that hosts books of Ghanaian Authors on Android and iOS. The very concept may sound useless to some of our foreign readers, but I can imagine a Ghanaian reader right now nodding her head at the idea. There are tens of thousands of Ghanaian Authors, some renown and quite popular (especially in the Christian circles), some with little popularity and a few followers, and majority being up and coming young authors. The similar problem these authors all have is the cost of publishing books.

In recent years, the introduction of eBooks has somewhat alleviated the challenges associated with book access and distribution in Ghana. However, we observed a persistent lack of patronage from both readers and local authors towards foreign platforms such as Amazon and Google Books. To explore the root causes of this phenomenon, we employed a multi-modal research approach, combining both quantitative (questionnaires) and

1 https://census2021.statsghana.gov.gh/ (accessed 17-07-2024)

qualitative (Focus Group Discussions) methods. The survey (see Appendix B), was carefully designed to capture demographic, behavioral, and attitudinal data regarding digital reading habits, eBook awareness, pricing preferences, and perceptions of foreign platforms.

We conducted the study with a sample of 125 respondents, 75 through an online survey and 50 through face-to-face interactions in various public locations such as university campuses in Tamale and Accra. The online survey was shared on social media platforms such as Facebook. The questionnaire was administered in English since we were targeting book readers.

Complementing the surveys were two FGDs, conducted with (i) university students and young tech-savvy readers, and (ii) a mixed group of local authors and publishers. These sessions were held at the University for Development Studies, Nyankpala Campus and online, respectively, and each session lasted approximately 90 minutes. The discussions probed into the barriers identified in the survey: platform trust issues, lack of localized content, difficulties in payment due to international credit card requirements, perceptions of cultural relevance, and the desire for offline access. Notably, authors expressed hesitation in uploading works to Amazon due to unfamiliarity with Digital Rights Management (DRM) and perceived exploitation through low royalty percentages.

The combination of structured questionnaires and open-ended FGDs provided data that showed the nuanced, contextual realities behind the poor uptake of foreign eBook platforms. This in turn guided the design and prioritization of features in our locally relevant Sefarim application, such as mobile money integration, offline access, DRM support tailored to local author concerns, and a curated marketplace for Ghanaian and African literature.

From our survey, we found that 83% of Ghanaian smart device users had never bought an eBook published by a Ghanaian. It was further found that half of these (47%) had never bought an eBook published by a Ghanaian because of the unavailability of the content online. Furthermore, it was found that Ghanaians do not buy eBooks in general because they are *able to pirate* (35%), they *do not find the mode of payment (Credit Cards) favorable* (22%) or they find the books to be *too costly* (14%). We also found that 80% of Ghanaian readers have never bought an eBook from Amazon. Reasons were that *they do not find the mode of payment (Credit Cards) favorable* (39%), they find the *process too complicated* (15%) or they are *able to pirate Amazon eBooks* (14%).

Extrapolating from the above analysis, since we know that quite a number of eBooks by Ghanaian authors *are* available online, "unavailability of content online" was actually more of their inability to find said content, which is a problem of digital literacy combined with the lack of a Ghanaian eBook store or a section of an international eBook platform for Ghanaian content (or any other specific country for that matter). This suggested that the Ghanaian user needs even more ease of use in apps that are thought to be sufficiently user-friendly. It also suggested that Ghanaians, and by extension Africans, needed a one-stop shop to make finding local content easier.

In addition to this, the method of payment was unexpectedly a rather profound issue. The use (and trust) of mobile money banking in African and especially Ghana, coupled with the occasional debit or credit card issues (pin problems, lost cards, stolen cards, credit card-related online fraud) has made the typical Ghanaian wary of using credit or debit cards online, which leads to the refusal to buy digital content online. This also suggested that Ghanaians need an app with local payment options.

Moving further, it was found that some Ghanaian authors will not host their content on Amazon. Reasons being *piracy* and *cost*; both the price ranges required by Amazon and the royalties paid to authors; the price range (minimum of 30 Ghana Cedis ($2.99)[2]), although seemingly normal to the typical Westerner is quite substantial for a Ghanaian and Amazon's 70% royalty option applies only to certain so-called "70% territories"[3] and therefore does not apply to buyers from Ghana (royalties for the author from Ghanaian buyers is defaulted to 35%). This suggested a review of pricing for the Ghanaian market and higher royalties for authors. Unfortunately most of the Ghanaian authors who do have their content on Amazon were found to be unaware of this dubious royalty scheme.

The issue of piracy was also a big concern (if not the biggest) to authors. They had found on their own that by doing a little search online or joining a few Telegram groups, one can eventually get a free copy of their books, and it can easily be identified as having originated from Amazon. Basically, Amazon turns a blind eye towards book piracy[4]. This suggested a critical look at anti-piracy solutions.

5.1.5 *Woom - Music Player*

Woom is music player on Android and iOS, that hosts music of Ghanaian musicians. Again, the concept will sound unnecessary to a someone from a developed country, since there are so many similar, and well established Apps, but once again the African situation is different.

At the moment, musicians in Ghana hardly make revenue from released songs; interestingly, the advancement of the technologies for music has been the cause of this. A few decades ago, musicians would release songs (albums) on Compact Disc (CD)s, which would then be sold by distributors in shops and even on the streets. However, as smartphones and MPEG-1 Audio Layer 3 (MP3) resulted in music being released digitally, coupled with the lack of enforcement of Cyber laws and digital rights by authorities, musicians quickly lost this form of revenue and can only rely on stage performances.

In conversations with Ghanaians on music, there are a lot of people who would rather not pirate music, but even that is sometimes difficult for them, because access through the right sources is often riddled with the same problems as pertaining to Sefarim; *method of payment*, *cost* on foreign platforms, *complicated processes* and the *lack of protection of digital music* making it very easy to pirate. Also, music producers have noted that it is very difficult to keep track of sales as a determinant of the ranking of musicians; this would be possible, and also would be a motivator for fans of these musicians to purchase their content.

2 https://kdp.amazon.com/en_US/help/topic/G200634560 (accessed 17-07-2024)
3 https://kdp.amazon.com/en_US/help/topic/G200644210 (accessed 17-07-2024)
4 https://hairysun.com/amazons-book-piracy-problem.html (accessed 17-07-2024)

Woom therefore would need to factor all these contextual issues, just like Sefarim to produce a mobile App that uses local payment systems, is very easy to use, has music at affordable cost and enforces digital protection of the content.

5.2 THE APPLICATIONS

From the above analysis of the context and needs assessment, we came up with some Must-Have functional requirements and some non-functional requirements that pertain to both ebook reader and music player to be viable in the Ghanaian Market.

Requirement	Type	Description
Mobile App	Functional	App should run on Android and iOS
Ease of use	Functional	App should be very simple to use with no overly complicated processes
Local One-Stop Shop	Functional	App should be limited to Ghanaian content
Local Payment Options	Functional	App should allow use of Mobile Money for payment
Anti-Piracy Solution	Functional	App should prevent illegal copying and redistribution of content
Affordable Ebook Pricing	Non-Functional	Prices should be affordable for the typical Ghanaian

Table 7: Must-Have Requirement for Sefarim and Woom

5.2.1 *Mobile App*

The adoption of mobile phones in Africa has been staggering. As we discussed in Chapter 1, the early 90s was the era of telephone lines and dial-up Internet with modems in more developed countries. At the time, in Ghana only a few places had telephone lines and it was not cost effective for telecommunication companies to create lines for a populace that would not be able to afford the cost; we can expect this to be similar in many African countries. As such, when mobile phone technology emerged, Ghanaians, having hardly any telephone lines, were immediately hooked; first to GSM and the sudden ability to reach people over vast distances through voice and later with internet (for the more urban and educated population). Due to this, most urban Ghanaians started using smart phones before they used computers (laptops or desktops)(see Chapter 1). Almost every educated Ghanaian adult owns a smart phone, but this is not the same for laptops and desktops (Dabalen et al., 2022). As such, mobile Apps are perhaps the only way to reach the Ghanaian market.

5.2.2 *Ease of use*

As mentioned, although literacy may be high enough in urban Ghana, digital literacy is still an issue. Digital Literacy is defined as the ability to use digital technology, communication tools or networks to locate, evaluate, use and create information . According to the Household Survey on ICT in Ghana Report by the NCA and the Ghana Statistical Service (GSS) in March 2020 (Statistical Service (GSS) et al., 2015), 99% of Ghanaian mobile phone users use them to make calls, 61.2% use them to send SMSes and 60.1% of them use them for financial transactions. This is in large contrast to use of mobile phones for Entertainment (37.9%), Internet (35.1%), Social Media (26.3%) and taking pictures and videos (5.2%).

One of the reasons for the above disparity in usage is of course the fact that only 46.1% of the phones referred to in this survey are smartphones, but another reason is the low levels of digital literacy in Ghana. This tells us that the ease of use in applications is ever more vital in the Ghanaian market, since most smartphone users will be unable to, or less motivated to, navigate numerous menus, enter excessive information, and/or initiate complex processes in the attempt to use any software. It is worth noting that even well-known procedures, like setting up 2-Factor Authentication (2FA) and inputting OTP without automatic detection by the app, may be considered too complicated for most; as evidenced by the number of hacked Facebook and WhatsApp accounts[5].

5.2.3 *Local One-Stop Shop*

The current web services and apps, including those for ebooks (e.g. Amazon/Kindle) and music (e.g. Spotify) are in truth tailored for the Western world. As such, it is often difficult to filter out local Ghanaian (or African) content from the rest, unless you know the exact book or song you are looking for. Searches on these platforms are tailored more to titles than locales, and moreover, the foreign content far outweigh any African content much less to talk of a single African nation.

Some Social Media Apps on the other hand were successful in the African market because they facilitated a local space within the international platform; Facebook *Friends*, Whatsapp and Telegram *Groups*, Instagram *Followers*, etc are naturally from one's locality and so the content naturally becomes local; of course, including any non-local content the individual has allowed themselves, e.g. by joining groups with topics that are of interest to them.

All this points to the fact that creating yet another platform with local content lost in a sea of international content will not be favorable for the Ghanaian Market. It is therefore important; at least in the context of these particular media-related apps, to focus on local content available at the push of a button.

5 https://www.myjoyonline.com/cyber-security-authority-warns-of-rising-social-engineering-attacks-as-whatsapp-scams-surge/ (accessed 17-07-2024)

5.2.4 *Local Payment Options*

As mentioned, due to a number of reasons, Ghanaians prefer Mobile Money transactions to Credit Card transactions. This, interestingly is the number one reason for most not using online platforms that require payments. This is as a result of the fact that Ghanaians generally don't use Credit Cards, but use Debit Cards. The concept of credit schemes and mortgage have never really taken a hold in the Ghanaian populace. As a people, Ghanaians would rather not owe, and if they will, not to a corporation and not large amounts. As such, micro-credit schemes seem to work far better (Amankwa et al., 2020). Now, using a Debit Card for online transactions would mean actual money is deducted at the time of the transaction. This becomes even worse with subscription-based platforms which automatically charge user's cards. In addition to this, since these Debit cards are tied directly to the individuals bank account, any illegal access to the card information will result in loss of money directly from said account.

Mobile Money on the other hand leaves most of the control in the hands of the user. It is impossible to automatically charge the account, and it does not use any cards that can be exploited online. Every transaction, regardless of where it is initiated from requires the end-users input from their mobile device (specifically their SIM card) and a pin. These layered protections, coupled with years of seeing the system work without any major exploitation, has made it the preferred method of payment. Any App targeting the Ghanaian Market must therefore have Mobile Money payment options. In addition, any subscription-based service developed will have to be tailored to work very differently from the "normal" method.

5.2.5 *Affordable Pricing*

The minimum allowed cost for an ebook of 10 megabytes or greater on Amazon is $2.99 (30 Ghana Cedis) and the cost of one month of subscription for a Spotify account is $9.99 (100 Ghana Cedis). In comparison, the monthly minimum wage is about $40 (405 Ghana Cedis). This would mean spending a quarter of the month's earnings on Spotify or 3 ebooks. Granted, the average earning for a high skilled worker may be higher, but would be around $220 (2200 Ghana Cedis) a month. This disparity is not stable since the Dollar rate (10 Ghana Cedis as I type this) changes quite frequently and often upward. These costs are naturally not feasible in the long term for a typical salaried earner in Ghana, having to deal with a myriad of other finances which are much more pertinent. To make the purchase of these digital assets feasible, Authors and Musicians would therefore need to reduce the cost for the Ghanaian market and instead rely on the increased number of purchases resulting from low cost and availability.

5.2.6 *Anti-Piracy Solution*

One of the major issues, the world over, with digital content is the issue of piracy. This is more so in a country like Ghana where cyber laws are in their infancy (the Cybersecurity Act (Act 1038) was passed in 2020[6]) and hardly enforced unless in major cases; the major

6 https://www.csa.gov.gh/ (accessed 17-07-2024)

cases being Cyber fraud, Blackmail and Hacking. Moreover, there is hardly any digital protection on digital content current sold by local platforms, and foreign platforms, having other methods of enforcing cyber laws, are not overly worried about implementing and updating protection (see Section 5.1.4 on the case of Amazon).
An example of platforms currently running locally which most musicians use, enables buying by shortcodes (Unstructured Supplementary Service Data (USSD)), provides unprotected download links upon purchase, and delivers unprotected digital content directly to the user. Of course, this means that content can thereafter be distributed freely. These reasons contribute to creators of media content not being too keen on selling their content digitally. An App for media content would therefore have to revisit the now largely defunct (by Western standards) DRM systems to protect digital content.

5.2.7 *Offline Access*

One of the major issues with Internet access in Ghana, even in places with regular access is speed, reliability and availability. In some places in the world, 4G or 5G is 99.99% available and reliable with high speeds, and one can stream content or access them online at any given time. Let's take the case of music; most Western digital music services are streaming services. In Ghana however, this is may not be practical. Apart from the unreliability of the internet to stream content, one has to take into account the cost of data to repeatedly stream songs when one wishes to listen. Note that almost all Ghanaians use prepaid internet services and not subscription-based internet as in the West. This necessitates Apps that allow downloading of content for offline access. Both Sefarim and Woom take this into account and as such have downloadable (encrypted) books and music which are decrypted directly to memory (making copying impossible) and streamed from memory to the App for display/playback.

Sefarim was built following these requirements and furthermore, in adherence with the methodology is currently in an iterative cycle with authors and readers to fine-tune its functions. Woom is in its first phase of development based on the requirements from music producers, musicians and the general public and will go through the same iterative cycle.

5.3 CONCLUSION

The digital divide in the Global South may be erroneously regarded as a rural problem; an issue of lack of infrastructure, poor or no connectivity, and low literacy. But as shown in this chapter, the divide also manifests, albeit differently, in urban settings. Here, the barriers may not be of absolute unavailability, but of unreliability, inaccessibility, and irrelevance. In this sense, the digital divide is not so much about absence as it is about exclusion from systems that are either not designed for, or not accessible to, the people in these contexts.

In Chapter 1, we established that three core barriers, Infrastructure, Literacy, and Content, underpin the digital divide. In Section 2.1, we saw how these manifest sharply in rural and peri-urban communities. This chapter revisits these barriers, but now in the urban context, and shows that although the form may differ, the substance remains the same. The infrastructure exists but is unreliable; literacy levels are higher, but digital literacy remains a gap; content exists online, but local content remains largely invisible or inaccessible.

What this chapter also illustrates is the strength and applicability of the research methodology detailed in Section 1.6. The participatory, community-based, user-centric, interdisciplinary methodology that was used to address the needs of rural communities (as seen in Chapters 3 and 4) has proven equally valuable in designing ICT solutions for urban populations. Sefarim and Woom are not merely software applications, they are responses to context; the infrastructural, socio-economic and cultural realities that BigTech continues to ignore.

By employing the same methodology, we not only surface real user needs through surveys, interviews and Focus Group Discussions, but we are also able to derive functional and non-functional requirements that are contextually relevant. These requirements, as seen in Table 7, include aspects such as mobile-first design, simplicity, local content, mobile money integration, anti-piracy mechanisms, and affordable pricing. These are not optional features. They are essential components of a meaningful ICT experience in the Global South.

5.4 CHAPTER SUMMARY

Chapter 5 presents a case study for urban communities in the Global South, specifically using two ICT solutions, Sefarim and Woom, to address aspects of the digital divide. The methodological approach here is similar to the approaches taken in the previous chapters, with the exception of field evaluations.

The projects employ in-depth needs assessments that include the use of questionnaires, interviews, and Focus Group Discussions to outline the intricate user requirements of the applications. These activities aid in delineating the functional specifications of the applications: Mobile accessibility, Ease of use, Localized content, Integration of mobile money for payments, and Robust anti-piracy solutions.

The solutions directly respond to the research questions by addressing barriers of infrastructure reliability, digital literacy, and relevance of local content, albeit in an urban context. For infrastructure, the applications are designed to operate effectively even with unreliable connectivity through offline access features. For literacy, the ease-of-use requirement ensures that digital literacy barriers are mitigated, acknowledging the specific needs of users with limited technical skills. And for content, the solutions provide locally tailored content that appeals to end users.

Chapter 5 shifted focus from rural to urban, and Chapter 6 further shifts focus from urban to emerging technologies but tied back to rural Global South. In Chapter 6 we look at how Artificial Intelligence (AI) can be leveraged for ICT solutions in resource-constrained environments.

6 TIBALLI: CAN AI BE OF USE IN THE GLOBAL SOUTH?

In recent years, the use of AI has aided the development of many solutions around the world in numerous fields. However, hitherto we have looked at the contextual use of already existing, and mostly older technologies such as GSM, SMS and radio, which can easily (relatively) be utilized in resource-constrained areas because these older technologies are more prevalent in such areas. This might give the impression that more modern and emerging technologies, such as AI, Distributed Systems, IoT, Virtual Reality (VR), Blockchain, etc., are not worth investigating with regards to resource-constrained environments; this is not the case. As much as we cannot delve into all these fields in this thesis, we will step a bit into the future to see how AI can make an impact on development in resource-constrained environments. In Chapter 6, we therefore look at an innovative and practical example of how AI can be leveraged for ICT solutions in resource-constrained environments. This Chapter is based on research in the area of AI in low-resource environments as seen in Stan, George Vlad et al., 2022. "A Lightweight Downscaled Approach to Automatic Speech Recognition for Small Indigenous Languages." 14th ACM Web Science Conference 2022. *Pp. 451–458.* DOI: `10.1145/3501247.3539017`.*, Panayiotou, Antria et al., 2023. "Resourcing Small Indigenous Languages in the Field - Designing a user-centered data collection method for automatic speech recognition."* ICT Infrastructure and Computing: Proceedings of ICT4SD 2023, Volume 3. URL: `https://books.google.nl/books?id=oDfZEAAAQBAJ`*. and Saa-Dittoh, Francis et al. "Artificial Intelligence for Web Inclusion in the Global South."*

6.1 PROJECT TIBALLI

At this point in my research, I had come back full circle to my childhood days; remember the DOS tutorial which I assumed was an intelligent system (see Section 1.2). Just a few years ago Artificial Intelligence was not considered by some Computer Scientists as a major part of Computer Science; this was due to what is called the "AI Effect", which describes how tasks initially considered to require intelligence are no longer seen as AI once machines perform them successfully (McCorduck, 2004), which in turn led to what is known as the "AI Winter" in the 1990s and early 2000s, when AI's reputation suffered due to unmet expectations and reduced funding. For example, in 2005, The New York Times reported that some computer scientists and software engineers avoided the term artificial intelligence for fear of being viewed as wild-eyed dreamers (Markoff, 2005). Fast forward a couple of decades and Computer Science now almost revolves around AI (Gao et al., 2023). In my research as well, this brought new questions; *can these advanced and novel methods aid resource-constrained environments? How will the Global South as a whole, but especially our resource-constrained communities, benefit from these amazing advancements? Will the barriers in implementing solutions built on these technologies be the same or will there be more to deal with?* Combining these thoughts together with the previous research, which we have seen in detail resulted in an additional research question;

"Can cutting-edge technologies such as Artificial Intelligence be (made) useful in the resource-constrained environments of the Global South, and if so, how?"

In particular, the research looked at if AI methods (ML, NLP) can be constructed so as to make the Internet more inclusive for communities in resource-constrained environments in the Global South — such that information, like local weather data combined with Internet-based global climate information (Mr. Meteo) could become shareable beyond the Internet's current boundaries and in people's own language (Tibaŋsim)?

United Nations' SDG 9.c[1] seems to suggest that the main issue concerning the Digital Divide is having universal and affordable access to the Internet. While this is indeed an important factor in the Global South, the starting point and hypothesis underlying the TIBaLLi project is that more variables/factors are involved, in particular: (i) the local content, relevance and salience of offered Internet information (e.g., that Beyoncé just issued her latest album sitting on a horse on the cover photo might not be the top priority news right now for farming families in the Sahel); (ii) the local language(s) and their modality (speech; given high levels of illiteracy) in which Internet information is provided. This is empirical information obtained from context analysis and needs assessments.

Decolonizing the Internet (see Section 2.1.1), in my view, does not just reside in having affordable Internet access everywhere. It is also in the ability (i) to provision locally important information and (ii) in the languages and modalities people are familiar with. This is the central hypothesis for project TIBaLLi. The TIBaLLi project, which is, at the time of this writing, running, undertakes to address both factors (i) and (ii). We do so by participatory field experimentations in collaboration with rural communities in northern Ghana (methodology as outlined in Section 1.6). The project's focus is: (i) communications to and from people on highly relevant local domains such as weather/climate information as pertaining to farming in the Sahel; (ii) delivering such information via automatically generated voice messages in a domain-focused speech vocabulary that is crowd-sourced from rural communities themselves.

Technically speaking, TIBaLLi aims to deliver a novel and, more importantly, participatory AI solution that is able to deal with many "small" local languages in spoken form. Crowd sourcing and field experimentation substantiate this in the project. Participatory AI is very new, and certainly so regarding the Global South (Birhane et al., 2022). At a higher level, TIBaLLi aims to electronically deliver solid information in speech and local language to communities beyond the current boundaries of the internet; the project points to how to achieve that: *Internet information beyond the current Internet.*

TIBaLLi is sponsored by the Internet Society Foundation as part of their research program[2] that supports global research collaborations that advance understanding of the

1 https://sdgs.un.org/goals/goal9 (accessed 17-07-2024)
2 https://www.isocfoundation.org/2023/02/announcing-our-2022-research-grantee-cohort/ (accessed 17-07-2024)

Figure 14: TIBaLLi Launching and Stakeholders Workshop

Internet and its value for all, and in the case of TIBaLLi, promotes novel methodologies that generate solutions to Internet-related challenges.

6.2 CONTEXT ANALYSIS & NEEDS ASSESSMENT

The TIBaLLi project was launched on the 16th February 2023 at Nim Avenue Hotel Conference Hall in Tamale, Ghana and was attended by researchers from UDS, several members of the Internet Society Ghana Chapter[3], GhanaNLP[4], Dagbani Wikimedians User Group[5], staff of CSIR-SARI, staff from the Ghana Institute of Linguistics, Literacy and Bible Translation (GILLBT)[6], staff of the Ministry of Agriculture and, most importantly, farmers from Tingoli[7] and Nyankpala[8] (two selected communities in the Tolon District of Ghana for this pilot). Wilhelm Kutah, communication officer from CSIR-SARI moderated the meetings. In all, about 52 people attended the workshop.

The first day started off with a presentation of the TIBaLLi project to all stakeholders to provide an in-depth explanation of the intended project, the technological possibilities and the possible constraints. The participants were then formed into break-out sessions consisting of a combination of expertise. A typical group contained about 9 members including 2 farmers (one male, one female), a moderator and scribe (mostly a core team member), and about 5 others ranging from ICT4D Researchers, AI Experts, Linguists, etc.

3 https://isoc.gh (accessed 17-07-2024)
4 https://ghananlp.org/ (accessed 17-07-2024)
5 https://meta.wikimedia.org/wiki/Dagbani_Wikimedians_User_Group (accessed 17-07-2024)
6 https://www.gillbt.org/ (accessed 17-07-2024)
7 9XGR+354, Tolon, Ghana
8 92W8+938 Nyankpala, Ghana

Some of the questions raised and discussed centered on things like how we can increase equality in technology access; in terms of digital access, but also social areas like gender, the capabilities to build the software required; not just as a pilot project, but moving forward, is there sufficient local capacity?, do the community members have internet; or generally, what is the available media for digital information access in these communities and what is the impact of this on the solutions proposed?

These thought-provoking issues were not the only concerns; a lot of languages are not resourced; how do we build systems for these, how do we obtain the required language resources; one reason for the above is that policymakers are not doing enough to promote local languages; how can our research influence this?

Teams however identified opportunities such as *Faith comes by hearing*; an American initiative and software that provides the Bible in Dagbanli, as an example of work already being done that can be leveraged for use in TIBaLLi. They noted that almost every adult community member has a GSM phone and furthermore a few have smartphones that are sometimes used to snap pictures of crops, record audio, etc. and sent to the agricultural extension officers with a questions which are answered through audio messages (WhatsApp voice notes) in their languages.

One very important area of the discussion was climate information needs. Teams suggested that the most salient information regarding climate would be; the onset of the rains (that is, the rainy season), predictions of the intensity of rains (heavy, light, drizzle) and storm predictions (extreme weather).

For the second day of the workshop, some presentations were made on similar/related projects by select participants on *Translation API for Ghanaian Local Languages*, *ICT4D Projects in Ghana, Burkina Faso, Mali and Malaysia*, *Internet of Things*, *Artificial Intelligence for Development (AI4D) Solutions in Sub-Saharan Africa*, *Crowd-Sourced Rainfall Data System in Burkina Faso* and *Tibaŋsim (RadioNet); Information Access for Resource-Constrained Environments*.

These presentations, along with a Q&A session after each, helped participants to further have a good understanding of the possibilities of ICTs, AI and NLP by seeing real-world examples of such projects.

Groups were formed again for discussions. This time the groups were structured based on expertise;

- 2 AI Groups (AI Experts, AI Enthusiasts, Programmers,. . . .)
- 1 Language Group (Linguistic Experts, Media Experts, Native Dagbanli Speakers,. . .)
- 2 Climate and Farmer Group (Meteo Experts, Agriculture Experts, Farmers,. . . .)

The Artificial Intelligence groups were tasked to consider a theoretical speech system in Dagbanli[9] that aids the work of our Agricultural Extension Agents in information dissemination to various communities and discuss, amongst other things, how we would

9 https://en.wikipedia.org/wiki/Dagbani_language (accessed 17-07-2024)

build a solution that connects the last mile, how we would handle the lack of training data, how our design would cater for the fact that there are almost no smart-phones, bad GSM and very bad 4G, how our design could leverage the use of smart-phones if we can circumvent the aforementioned challenges (one smart-phone can possibly serve multiple people?), if we could consider Plug Computers like Raspberry Pi, the tech stacks we would need to achieve this system build and finally, the series of steps we would need to achieve our solution.

The Farmer groups were tasked to assume we have a system that can answer questions and asked to act out what three (3) questions they would you ask? They were also tasked to discuss the presence (if any) of community members who are considered experts in general information, climate information, information on when to plant, etc. and also how accurate this information normally is. This is an important step in identifying Indigenous Knowledge related to the proposed system (see Section 7.4.1.5). They also discussed the question of predictions versus historical climate data and if the latter would be useful.

The Linguistics Group was tasked to imagine a Dagbani speaking AI, discuss how we would make it sound as natural as possible to native speakers and they considered scenarios of people asking an AI for help in Dagbani and wrote out the conversations. In addition, they discussed what basic words would, by all means, be used in a speech system and also if there are any nuances in these words we should be aware of?

These discussions helped to tease out detailed information of the three aspects of this research. Each group made presentations of their discussions and opened the way for questions, suggestions and some debate. See Appendix C for a summary of answers from these group sessions.

Saturday 18th February 2023 was Day 3 of the project launch and a field visit was made to Tingoli. The field trip took off from Tamale with the core team and members of the Internet Society Ghana Chapter taking a 19KM bus drive to Tingoli.

At Tingoli, the team presented itself to the Chief of the village and gave a brief overview of the project. The Chief and his elders were enthused about the possibilities of such a project and were more than happy to give access to their community and lend a helping hand when needed. After the formalities, the team held FGD with almost 100 community members in three separate groups; Men, Women and Youth.

These FGDs centred on the same concepts from the workshop; ICTs, Farming, Climate and Language, but broken down for the understanding of a wider audience for discussion. For the most part, these discussions reiterated the accuracy of the information that was teased out during the first two days. In addition to the knowledge gleaned for the continuation of the project, the FGDs were recorded and kept for future use.

Overall, this context analysis and requirements elicitaion provided certain salient points:

1. Generally there is great interest by all stakeholders.

2. The technical people had high expectations.

Figure 15: TIBaLLi Focus Group Discussions by Women at Tingoli

3. The expected content is really about farming practices, weather/climate, market prices and also animal health.
4. Rain information is very important.
5. Seasonal predictions are important for the farmers but difficult to provide.
6. Radio is still a very important information provider.
7. It goes without saying that, language is a major issue

6.3 USE-CASE AND REQUIREMENT ANALYSIS

The project identified two primary use cases:

1. Voice-based information dissemination: Addressing language barriers through AI-driven speech systems for resource-constrained languages such as Dagbani, which required the collection of voice data.
2. Rainfall data collection: Using AI to automate the collection and processing of rainfall data from DIY rain gauges.

6.3.1 *TIBaLLi Speak*

In this section, we describe the design of TIBaLLi Speak, an application built to provide data for the use case identified in Section 6.3

6.3.1.1 *Key Idea*

A crowdsourcing App that permits users to record people pronouncing local words. These recordings will serve as valuable training data for the Machine Learning model that will accurately convert Dagbani speech to text and facilitate ASR.

6.3.1.2 *Actors and Goals*

The table below lists the actors and their goals as identified in the context analysis phase as described in Section 6.2.

ID	Actor	Description
1	Enumerators	Use App to collect Voice Recordings
2	Community Leader(s)	Authorize Data Collection
3	Researchers	Obtain, validate, process and utilize Voice Data for AI models
4	Support	Monitoring/Maintenance of App

Table 8: Actors and Goals for TIBaLLi Speak

6.3.1.3 *Key Requirements*

Following an understanding of the context and the need analysis, as well as considering the available technologies, the following are the key requirements of TIBaLLi Speak;

Must Have	An intuitive interface
	Support for online mode
	Temporary storage of recordings on devices
	Automatic sorting of uploaded data
Should Have	Automatic uploads of stored recordings
Could Have	Telegram Bot Integration
	Playback of audio fragments

Table 9: MoSCoW List of Requirements for TIBaLLi Speak

6.3.1.4 *Non-Functional Requirements*

- Maintainability - Local Stakeholders should have the ability to maintain the system and facilitate data collection with ease
- Scalability - The App must be easily duplicatable and scaled for different languages and for any number of users (data collection)
- Reliability - The system must ensure that data collected is stored locally, and uploaded to its server

- Usability - The targeted user group creates a requirement of simplicity in the user interface

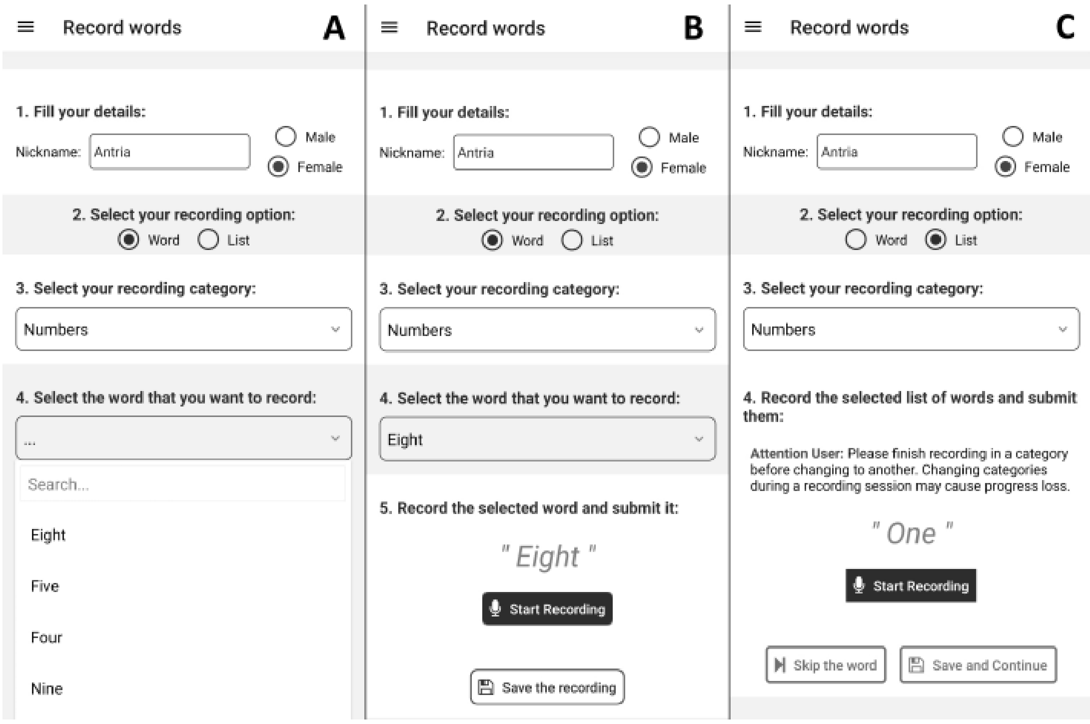

Figure 16: Screenshots of TIBaLLi Speak during the recording process. [A: Selecting the recording word, B: Available "word" options, C: Available "list" options]

6.3.2 *Crowd-Sourcing Rainfall with AI*

In this section, we describe the design of a system that addresses the second use case identified in Section 6.3

6.3.2.1 *Key Idea*

The use of AI to automatically detect the amount of rainfall through images of DIY rain gauges sent from farmers to a WhatsApp group.

Figure 17: DIY Rain Gauge

Figure 18: Rain Gauge with Bounding Box

6.3.2.2 *Actors and Goals*

The table below lists the actors and their goals as identified in the Context Analysis phase as described in Section 6.2.

ID	Actor	Description
1	Farmers	Send rain gauge images via WhatsApp
2	Researchers	Obtain and process images
3	Agric Institutes	Utilize processed rain fall data
4	Support	Monitoring

Table 10: Actors and Goals for Rainfall Crowd-Sourcing App

6.3.2.3 *Key Requirements*

Following an understanding of the context and the need analysis, as well as considering the available technologies, the following are the key requirements of the system;

Must Have	Processing of DIY rain guage images to obtain rainfall data
	Easy to use platform for sending images
	Support for offline mode
	Sorting of uploaded images
Should Have	Automatic uploads of stored recordings
Could Have	WhatsApp Bot Integration
	Telegram Bot Integration

Table 11: MoSCoW List of Requirements for Rainfall Crowd-Sourcing App

6.3.2.4 *Non-Functional Requirements*

- Maintainability - Local experts should have the ability to maintain the system
- Availability - Local experts should have the ability to reach the system at all times to upload gathered images
- Scalability - The system must have the ability to scale to different locations and for any number of farmers and the system should be easily replicable
- Reliability - The system must ensure that rainfall information is as accurate as possible
- Usability - Farmers should be able to simply take a picture of the rain gauge in very simple steps
- Cost-Effectiveness - The whole system must work together to be financially sustainable

6.4 ENGINEERING AND DEPLOYMENT

6.4.1 *TIBaLLi Speak*

The mobile application is developed with React Native and Expo. It offers an intuitive interface for capturing and submitting audio samples of local words. Utilizing the capabilities of mobile devices, the application ensures high-quality recording of voice fragments. A list of words are provided (currently; “yes”, “no” and the numbers 1 to 10) which the user can select and then prompt a willing participant to record said word in a local language. The recorded fragments are stored (temporarily) on the device and can be later uploaded to our server (Firebase). The source code can be found at https://github.com/franditt/TIBaLLi-project-voice-services.

This simple but effective tool was used by enumerators to take recordings from members of the communities and has been used to record almost 4000 voice fragments in roughly 4 months with only a beta team of about 8 users. This data has been published, with permission from the communities, as open-source (Saa-Dittoh et al., 2024)

The process of building this app was not trivial, especially in terms of Participatory Action Research; ensuring that end-users and stakeholders are involved in the process so as to iteratively build a solution that really works both technically and contextually in the local setting. The concept of a *localized* (designed by the people, for the people) app for crowd-sourcing in itself is quite novel in the context of resource-constrained communities and came about due to the user-centric, community-based, participatory mindset resulting from the methodologies learnt and used over the years. Panayiotou et al. (2023), details our process.

6.4.2 *Crowd-Sourcing Rainfall with AI*

Water bottles were used to build rain gauges that were placed in various locations within the communities (see Figure 17). After each rainfall, a few community members who have smartphones and are on a farmer WhatsApp group, take pictures of the level of water and send to the group. This hitherto was manually read and taken down for later reference; this is used to provide data needed to build an accurate cropping calendar (Yulianti et al., 2016).

This initially existing solution however posed a problem of scalability; the virtually no-cost rain gauge makes this replicable anywhere, but it would be impossible, with the above data collection method, to keep track of incoming data with 100s or 1000s of rain gauges. This is in addition to not being totally reliable or efficient. Therefore, the proposed solution sought to automate the collection, processing, and identification of patterns as much as possible using AI.

Due to the challenge of detecting water levels in user images that may have low qualities, YOLOv8[10], a high performance and efficient ML model that enables rapid prediction generation, was opted for.

A notable obstacle was the lack of available images of community-used rain gauges, since this was at the earlier stages of the project and not many images had been taken as yet. A diverse dataset is needed to ensure the detection of factors such as water content, angles, lighting conditions, identified objects, bottle types, colors, and reflections (Wang et al., 2024). The dataset was therefore expanded using images of homemade rain gauges from online sources and synthetically generated images from image generators, introducing images with varied attributes. This data augmentation process was essential to enhance the model's generalization capability and is unfortunately required in conditions such as this when the datasets are simply insufficient (Silfverberg et al., 2017).

After formulating the training data set, manual annotation was performed by marking the boundaries around the relevant image objects; the rain gauge and the water surface near the measurement point (see Figure 18). This step allows the model to generate bounding box coordinates, enabling the cropping of images at the water level so that subsequently a digit classification model can interpret the cropped images to estimate

10 https://yolov8.com/ (accessed 17-07-2024)

the water measurement.

The renowned Modified National Institute of Standards and Technology (MNIST) dataset[11], which is a classic set of 70,000 28x28 pixel images of handwritten digits from 0 to 9, often used in ML and image processing, was tailored for the digit classification model

Subsequently, a Convolutional Neural Network (CNN), a type of neural network especially effective in processing grid-like data such as images, was trained on the dataset. The model resulted in an accuracy of around 84% on the validation set, but tests with real data from local communities tended to have poor performance and accuracy. This is most likely due to the lack of sufficient data (images) from the communities in the dataset, and therefore the accuracy is expected to increase as the local data increases.

Lastly was the integration of the AI-based system into a Telegram Bot. This enables pictures taken and sent to a Telegram group or channel to be automatically uploaded to the system, which will process the image against the developed ML model, extract the required data (amount of rainfall, user, location, date) and store in a database. The system would also return the validity of the uploaded picture (based on the accuracy of the model's detection) to the user in the form of a voice note in their own language.

6.5 EVALUATION

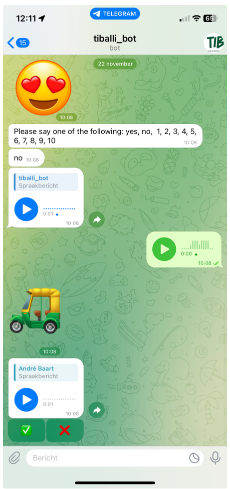

Figure 19: Screenshot of Telegram Bot Prototype

In order to evaluate the data collection App and the efficacy of building an ASR system with the training data gathered of approximately 4000 utterances of Dagbani words, an AI model was trained. The base model used was Wav2Vec Massively Multilingual Speech, by Meta (Pratap et al., 2023). This is a model based on the well-known wav2vec2 architecture that is pre-trained on 1100 languages. This model was fine-tuned using the training data of the limited initial vocabulary (yes, no, 0 through 10). This resulted in a model that is tuned to these specific words and will only give back results that fall

11 https://www.kaggle.com/datasets/hojjatk/mnist-dataset

Figure 20: Prototype under testing in the community

in this vocabulary. To test the model, a Telegram bot was built that 'parrots back' the user. Telegram was chosen because it is well suited for rapid development of prototypes. The prototype bot expects a voice message from the user, containing one of the words in the vocabulary. This message is then processed by the ASR model, which results in a written version of what the user said. This text is then converted back to speech (using the slot-and-filler method (Baart et al., 2019) and sent as a voice message back to the user. The user can then listen to the response of the bot, and confirm whether the result was correct or not. A two button rapid-response system was included, with a green check-mark (correct) and a red cross (incorrect), which the user can use to indicate the quality of the result. The result is stored and can be used (together with the user input) as additional training data to improve the accuracy of the model at a later stage. The Telegram bot can be accessed at https://t.me/tiballi_bot

The prototype was tested in the Tingoli community, resulting in near-perfect accuracy through the diverse population (young, old, male, female, etc.).

6.6 CHALLENGES

These case studies met substantial challenges as would be expected in the use of emerging technologies such as AI in low-resource communities.

6.6.1 *Limited availability of local data for training AIAIodels.*

One of the most significant challenges faced in the project was the limited availability of local data required to train the AI models effectively. AI systems, particularly those involving natural language processing (NLP) and automatic speech recognition (ASR), rely very heavily on the types and amounts of data that allow them to achieve the kinds of accuracies and generalizations for which they are famous. However, in the context of resource-constrained projects like these, the kinds of datasets needed to achieve the required performance do not (yet) exist or, where it is supposedly available, it is often found in a state that is too poor to be actually useful.

Notwithstanding this obstacle, the initiative resulted in the creation of a fundamental dataset for Dagbani, which hopefully will aid any future AI endeavors in the region. Still, the experience shows the necessity of constant effort in data collection and emphasized the imperative of constructing methods that are both high-scale and high-sustainability for the procurement and upkeep of resources in local languages. The endeavor thus also revealed data inequality's many facets, particularly the way low-resource languages and communities tend to be left out of the worldwide AI revolution.

6.6.2 *Low quality of pictures*

In AI applications based on image data, the performance of the models is significantly dependent on the quality of the input images. Community members participating in the initiative to crowdfund rainfall measurements took and sent pictures of their homemade rain gauges. Unfortunately, due to lighting, angle, and other variations, not to mention blurriness and background issues (see Figure 17), many of the pictures were poor quality and consequently not very good training (or testing) data for our models. In AI, bad data in equals bad data out.

To address these challenges, the project educated the participants to ensure that they knew how to take clear and consistent images, the kind that best serve AI models. Also, to best train the AI, the project used diverse datasets, which included not only the clearest images but also images of lesser quality (which the AI, needing to work in the real world, must be able to handle).

6.6.3 *Integrating the ASR Model into an Application for Low-Resource Communities*

Deploying an ASR model in low-resource communities involves navigating several challenges, particularly concerning infrastructure limitations and user accessibility. Integrating the ASR system into TIBaLLi required real attention to the technological landscape of the community, where there is limited internet connectivity that is just barely good enough for the most basic of web browsing.

These limitations point to the need for AI models capable of offline function and being able to run on low-end hardware.

6.7 CONCLUSION

From the two use-cases shown in Sections 6.3.1 and 6.3.2, we can see, in the former, an example of the process by which the data required for AI (Machine Learning for Natural Language Processing in this case) can be obtained even in resource-constrained environments where such data is almost non-existent, and in the latter, a direct use of AI (Machine Learning through Computer Vision) to aid the collection of digital information from resource-constrained environments.

In the TIBaLLi project, I worked very closely with Antria Panayiotou, a master's student at the Vrije Universiteit Amsterdam (VU). She played a key role in the iterative co-design and prototyping of TIBaLLi Speak. The collaboration helped address one of the core challenges in designing voice technologies for low-resource environments: bridging the gap between the technical and user domains. Antria' work introduced used methodology grounded in agile development and participatory design. With each short, iterative cycle, the team relied on direct user input to inform the design. Antria's work in this regard was vital, of course, to providing a path toward creating a functional prototype. Tools used in the early prototype phase included proto.io, where field-based testing with native Dagbani speakers in northern Ghana was enabled. Such testing gave the team real-time interaction and feedback directly from local speakers to refine both interface and workflow in a way that met local requirements for usability, clarity, and purpose. Our understanding of the intricacies that arise when software engineers and users hail from diverse cultural, linguistic, and technological backgrounds was advanced by this work. Successful design of voice technologies for indigenous languages was found to require not just technical know-how but also a deep, empathetic engagement with the users' lived realities and methods of communication.

For the rainfall crowd-sourcing app, I worked with six master's students—Parissa Akefi, Laurens Beck, Alexander Edin, Ruthu Rooparaghunath, Krasen Todorov, and Kairui Wang—on. Their work tackled the problem of the inaccessibility, inaccuracy, and lack of localization of current meteorological data. They approached this problem by developing the AI-based system which automates rainfall measurement using community-made rain gauges and image recognition technologies. The students co-designed and field-tested an end-to-end solution that let farmers send images of their gauges to the system via WhatsApp. From these images, the system automatically extracted key variables such as water level, date, and location (Akefi et al., 2023). This collaboration resulted in an improved understanding of how to make AI systems resilient to environmental variability and usable in resource-constrained, low-literacy communities. Their design choices, such as using alphabetic ID markers to mitigate confusion between digits and tuning YOLO models to their local images, show how local context must be considered and actively shapes the design of the system. Their work validates that with adequate co-design and attention to contextual robustness, AI can support sustainable agricultural practices by enabling community-owned data collection and empowering local decision-making.

This is already a clear indication that, even with the special challenges that must be met in the context of the Global South, AI can indeed be of immense use, but it is however important that the lessons learnt from the work done so far be 1) incorporated into the future work and 2) be disseminated to other researchers.

Some relevant lessons learnt as outlined in Panayiotou et al. (2023) include;

- Context-awareness of the conditions and limitations are key success factors in designing or using AI systems for resource-constrained environments.
- Context analysis and stakeholder analysis are essential and need to be done at the start of an AI project (or any project for that matter).
- User requirements must be prioritized against costs/ease of implementation (MoSCoW). This is especially important because emerging technologies like AI are very expensive to use.
- To bridge the communication and knowledge gap between developer and user(s), field visits, test sessions and frequent meetings are required; local communities are deficient in AI knowledge and AI researchers are deficient in their indigenous knowledge and context.
- Resourcing local data for AI systems (e.g. indigenous language, local images) must be done in close collaboration with members of the targeted communities.
- Real-life demonstrations followed by rapid prototyping and frequent user-tests are appropriate for elicitation of requirements and reiterative design as local users will be unable to understand the design process in AI without using a real system.

6.8 CHAPTER SUMMARY

Chapter 6 examines the use of Artificial Intelligence (AI) in resource-constrained environments, especially in the Global South. In order to increase information accessibility in rural communities, the chapter presents Project TIBaLLi, an initiative that uses AI, specifically Machine Learning (ML) and Natural Language Processing (NLP). TIBaLLi's main goal is to increase the accessibility of Internet-based information by mitigating obstacles like digital illiteracy, infrastructure limitations, and language barriers. The project supports the SDG 9.c of the UN, which calls for universal and affordable access to the Internet in addition to recognizing that Internet access alone is inadequate without pertinent and locally understandable content.

Two primary use cases emerge from the research: TIBaLLi Speak, a crowd-sourcing application for indigenous language voice data collection, and AI-assisted rainfall data gathering using DIY rain gauges and computer vision. TIBaLLi Speak collects Dagbani speech recordings to train Automatic Speech Recognition (ASR) models, enabling AI to process and understand local words. The rain gauge project utilizes image recognition via YOLOv8 to estimate rainfall levels from images submitted to WhatsApp, offering a scalable, low-cost alternative to conventional weather monitoring systems. These AI-driven approaches aim to extend digital services to underserved communities beyond the traditional Internet boundaries, making information available via speech in local languages.

Insights from TIBaLLi Speak and from the AI-powered rainfall monitoring affirm that AI can play a transformative role in resource-constrained environments, but only when it is designed with a deep contextual understanding of the local environment and with the participation of the local community. What these two projects have taught us about the feasible use of AI in low-resource environments shines a light on the (often) hidden difficulties of scaling and sustaining such initiatives. They have exposed the critical necessity of local data collection, the need to involve a wide variety of local stakeholders in the project, and the importance of an iterative design process that values the real-world context.

Chapter 7 directly follows from this and talks about the "Plug-in Principle" a framework for ensuring that ICT4D projects are not only technically functional, but also have a socio-cultural fit and are sustainable. The next chapter examines a set of projects that serve as case studies to explain why some succeed and others fail. These serve as a basis for the proposal of scalable and adaptable approaches to ICT Solutions, AI and other emerging technologies to ensure they empower communities in the Global South.

7 THE PLUG-IN PRINCIPLE FOR ICT4D

In this Chapter, we take a look at the factors that influenced adoption in a number of ICT4D projects/innovations over the years. We then contrast them to see the main differences that ensured the successes of some, and although we will see that in some cases, it was coincidental, there are underlying reasons, the very reasons outlined in this thesis and researched by several fielded experiments in the Global South, which I have coined "The Plug-in Principle for ICT4D", a Conceptual Framework, which is imperative to follow deliberately to ensure that our ICT projects are truly 4D. This chapter is based on Saa-Dittoh, Francis, 2024. "Information and Communication Technologies: The Plug-in Principle for ICT for Development." The Plug-In Principle: Integrating Indigenous and Scientific Knowledge for Sustainable Food Systems in Africa.

7.1 FACTORS THAT NEGATIVELY AFFECT ADOPTION

7.1.1 *Chaotic Disruption*

I have mentioned in passing the issue of disruption in the bid to introduce technologies to communities. Disruptions can cause ripples through society; disrupt social interactions and relationships, organizational structures, institutions and public policies. Because innovation ecosystems are complex, dynamic, adaptive systems, technological design and development will by all means interact with social trends (Schuelke-Leech, 2018). Disruptions are not inherently negative, however chaotic disruptions can stem from a number of factors including attempting huge, complex, and very expensive undertaking and poor requirement capture (Othman et al., 2009).

An example of possible disruption came from my own research in voice-based marketing for agricultural products: a case study in rural Northern Ghana which led to the development of a voice-based prototype that allows medium to large-scale farmers in rural areas to place advertisements on the WWW (Dittoh et al., 2013). At the time, this seemed like a great idea, until further research (Dittoh et al., 2021; Purnawan et al., 2021) showed that this solution would cut out "middlemen". These "middlemen" are community members who traditionally would liaise between farmers and markets and/or market to market. They may buy from farmers directly and sell at community markets, thereby incurring the cost and logistics of transportation, or they may also buy from one market and resell at another (Purnawan et al., 2021). The agricultural value chain will therefore have a number of these "middlemen" along the way from farmer to end-consumer. Along value chains, transportation naturally increases the prices, but also the multiple wholesaler and retail profits as well as several intermediaries with unclear functions further increase the final costs (Tracey-White, 2005).

The prototype that was developed allows farmers to call directly into the system with a normal GSM mobile phone, get prompts in their own language which guide them to leave information on what produce they are selling (typically grains; maize, millet, rice, soybeans, etc), in what quantities (normally, in bags) and how much. This information is automatically formatted and placed visually on a website for prospective buyers. Technically, this system works well to this point until it was discovered that there could be a problem; prospective buyers would be unsure of the quality of the produce and would not fully trust that information from the seller. This scenario showed that although cutting out these middlemen with our digital ICT solution would possibly increase revenue for the farmer or lower the cost to the buyer, it was indeed a disruption of an already existing system; the quality of the produce, which hitherto we had brainstormed on how to handle, is determined and communicated by these very people we wished to cut out of the system.

7.1.2 *Non-acceptance*

Apart from disruption, is also the issue of non-acceptance of technologies. This is often expressed in a number of ways ranging from out-right dismissal to accepting the technology and then gradually discarding it. An example from the early days of ICT interventions for developing countries were ICT kiosks; the creation of a set of touch-screen kiosks for remote rural communities in South Africa's North-West Province were initially well received by the communities. However, the kiosks' lack of updated or local content and lack of interactivity led to disuse, and the kiosks were removed less than one year later (Benjamin, 1999). Similar setups were attempted in numerous places around the world, and similarly, except in a few cases, they were gradually neglected. In India, by 2005, over 26000 ICT Kiosks were setup in rural areas which was expected to serve 5.85 Million rural farmers. Interestingly, the majority (almost 60%) of these kiosks were by private corporate sector. Each kiosk costs roughly 66,000 Indian Rupees (over $800). Now, it was found that 92% of farmers were aware of the kiosks in their villages, but only 34% actually used them and all of these users were highly educated; tertiary (Sharma et al., 2009). These two examples give the indication that something (or *somethings*) was missing in these setups; the latter case points to a problem of literacy.

Other examples from Ghana; the Accounts and Personnel Computerisation Project of Ghana's Volta River Authority (VRA) saw managerial staff pleased with the changes brought by the new system but apparently the system had '*bred a feeling of resentment, bitterness and alienation*' amongst lower-level staff which led to resistance and non-use, particularly amongst older workers (Tettey, 2000).

And finally, another personal example; sometime in 2008/2009, during the early days of the School of Medicine and Health Sciences of the University for Development Studies in Tamale, Ghana, an institute in the Netherlands (name withheld) took it upon themselves to provide the University with an ICT Kiosk. With great cost, the kiosk, which was quite large and equipped with state-of-the-art computers and accessories (but built to function only within the kiosk), was shipped from the Netherlands to our sea port in Tema, then transported over 500KMs by road to Tamale. A platform was built at the Tamale Campus of the University where the device was placed.

It would interest you to know that after the initial opening and testing of the equipment, the kiosk stood unused and the internal equipment (now defunct and outdated) were dismantled and removed in 2021 (twelve years later!!). Having been privy to the entire arrangement, I can at least give an explanation for this case of ICT project failure due to non-acceptance. It began with the lack of proper context, and the result of making assumptions not founded on specific context. A representative of the institute in the Netherlands had been to Ghana and had in fact setup a similar kiosk somewhere in the north of Ghana; in a rural community. Upon hearing of a University that existed also in the north, and perhaps hearing of the Community-based work the University students undertook, it was assumed that the campus was located in a rural area and this kiosk would be providing internet access, transmitted to it via point-to-point radio satellite dishes (which were provided); the representative had not (and never did) visited the University. There were some suggestions from the ICT staff at the University to consider alternative equipment, but the project was fixed and would only provide what they offered as is. The result; the University *did* have internet access already (using Very Small Aperture Terminal (VSAT) at the time, and a few years later upgrading to Broadband via fibre); the students *did* go to communities, but to numerous communities and therefore one could not be selected for this purpose to the detriment of the others, and the equipment within the kiosk was setup in such a way that it was difficult to reuse for any other purpose. This led to the kiosk being abandoned for over a decade right in the middle of campus.

7.2 Projects that achieved community uptake

We have looked at some factors that resulted in certain ICT4D projects not being adopted by the intended users, now let us look at some successes in adoption, among which is perhaps the biggest ICT4D success so far in history.

7.2.1 *Tibaŋsim*

Once again, I will start off with a personal project. Tibaŋsim (see Chapter 4) is a major part of the culmination of my PhD work and is being listed here as a success because it is currently in use and it is currently sought after by all stakeholders that were involved in it (e.g. CSIR-SARI) and other projects which have found it a viable solution to their rural information dissemination needs (e.g. AICCRA Ghana[1]). The rural communities in which it was piloted scored it an 80.50 on the System Usability Scale (Brooke, 1996). Tibaŋsim was 3rd place worldwide in Internet Society's Chapterthon 2019[2] competition and is currently an integral part of a $100,000 project funded by the Internet Society Foundation[3] and is considered by the Internet Society to be the most innovative method thus far for information dissemination in resource-constrained environments. Chapter 4 sheds more light on this project.

1 https://aiccra.cgiar.org/regions/ghana (accessed 17-07-2024)
2 https://www.internetsociety.org/grants/chapterthon/2019/ (accessed 17-07-2024)
3 https://www.isocfoundation.org/ (accessed 17-07-2024)

7.2.2 *Foroba Blon*

Foroba Blon[4], developed by the W4RA is another good example of a solution that was successfully adopted. Foroba Blon, which was deployed in Mali in collaboration with the Web Foundation (Geneva, Switzerland), the VU (Amsterdam, Netherlands), and Sahel Eco (Bamako, Mali), allows community members to call radio stations and leave audio messages from basic mobile phones to a web interface about weddings and lost cattle without being connected to the internet. Foroba Blon quickly became a local journalism tool and was winner of the Press Innovation Contest in 2011, issued by the International Press Institute[5], where it was selected out of 376 submitted projects to support citizen journalism. It was also featured in the Los Angeles Times[6].

7.2.3 *Kasadaka*

Both Tibaŋsim and Foroba Blon are built on a platform called the Kasadaka (see Section 3.3.1. The Kasadaka represents another example of a successful ICT4D project in terms of adoption. Not necessarily directly by end-users but because it provides a cost-effective platform that can be used to build a myriad of solutions. Kasadaka is a platform that supports easy creation of local-content and voice-based information services, targeted at currently 'unconnected'. Kasadaka means "talking box" in several Ghanaian languages (Baart et al., 2019). The platform consists of a combination of software and hardware, that allows for the hosting and development of innovative voice-based information services in the conditions of the developing world. The platform tackles many of the challenges found in the developing world context, including: infrastructural problems (no internet), low literacy rates, support for under-resourced languages and a lack of (financial) resources. The Kasadaka platform supports the formation of an ecosystem of decentralized voice-based information services that serve local populations and communities, built by local innovators and entrepreneurs. This is very much analogous to the services and functionalities offered by the Web, but in regions where Internet and Web are absent and will continue to be for the foreseeable future. The Kasadaka, as seen from the aforementioned projects has been the technical backbone of several successful ICT4D implementations and is also actively used for teaching students in a joint ICT4D in the field course by the Vrije Universiteit Amsterdam (VU), University of Malaysia, Sarawak (UNIMAS) and the University for Development Studies, Ghana (UDS).

7.2.4 *The Mobile Phone*

Finally, I cannot end this list without mentioning perhaps the biggest ICT4D success in history to date; the mobile phone. Where other technologies, like fixed phone lines, dial-up internet, ICT kiosks, Personal Digital Assistant (PDA)s, broadband Internet and the like never took root in Africa, the mobile phone tells a different story. This unexpected phenomenon has made waves everywhere in Africa and from shantytowns to remote

4 https://w4ra.org/citizen-journalism-in-rural-areas-in-mali/ (accessed 17-07-2024)
5 https://ipi.media/ipi-news-innovation-contest-2011-delivers-3-winners/ (accessed 17-07-2024)
6 https://www.latimes.com/world/africa/la-fg-mali-social-network-for-illiterates-20190617-story.html (accessed 17-07-2024)

villages, mobile phones are being used to transfer money, monitor elections, and deliver public health messages. A large informal economy has also emerged to support the mobile sector (Etzo et al., 2010). Perhaps every successful African ICT implementation is built either directly or indirectly around the mobile phone. Tibaŋsim, Foroba Blon and the Kasadaka are built around the successes of the mobile phone.

7.3 SUCCESS VS FAILURE

So, why did so many Information and Communication Technologies for Development projects experience partial or total failures? Why did some simply fail to be adopted by end users. And what led to the successful adoption of some? At this point, you most likely have an informed idea following the detailed explanations of the concepts of developing digital tools for resource-constrained environments. In this section, we see a systematic comparison of factors that caused failure or successes of some ICT4D Projects and further elaboration of two very important dimensions.

7.3.1 *Systematic Comparison of Failure and Success Factors*

Below is a systematic comparison of the various dimensions seen in the analysis above.

Table 12: Systematic Comparison of Failure and Success Factors

Factors	**Failure**	**Success**
Stakeholder Involvement	Often missing or superficial. Example: the 2009/2010 kiosk at UDS was based on a misinformed assumption of a rural context.	Deep and iterative engagement. Example: *Tibaŋsim* involved CSIR-SARI, farmers, and developers from the start.
Communication Method	Text-based systems unsuitable for low-literacy users. Example: SMS-based Agric information systems for rural areas.	Voice-based and localized. Example: *Tibaŋsim* and *Foroba Blon* used local languages and IVR.
Context Understanding	Poor contextual grounding. Example: ICT kiosks in South Africa and Ghana failed due to incorrect assumptions.	Grounded in extensive fieldwork. Example: *Mr. Meteo* was based on direct community requests during focus group discussions.
Technological Fit	Over-complex or rigid systems. Example: the UDS kiosk was fixed and difficult to repurpose.	Appropriate and flexible tech. Example: *Kasadaka* supports offline voice services and is locally configurable.

Factors	Failure	Success
Sustainability and Scalability	Lacked maintenance and funding planning. Kiosks were abandoned or dismantled.	Technically and financially sustainable. Example: *Tibaŋsim* is part of ongoing projects (e.g., Agroecological Solutions for Resilient Farming in West Africa (CIRAWA)[7]).
Perceived Disruption	Negative disruption. Example: voice-based marketplace app displaced trusted middlemen, reducing buyer confidence.	Constructive disruption. Example: mobile phones replaced fixed lines and became widely embraced.
User Acceptance	Initial interest faded quickly. Kiosks were disused after a few months.	High ongoing acceptance. Example: *Tibaŋsim* received a SUS score of 80.5.
Institutional Alignment	Poor alignment with local institutions. Example: Dutch Non-Governmental Organization (NGO) did not consult technical people at UDS before deploying a kiosk.	Integrated partnerships. Example: CSIR-SARI, Internet Society (ISOC) Ghana and community leaders co-developed and adopted *Tibaŋsim*.
Design Methodology	Top-down, donor-led with limited feedback.	Participatory Action Research with iterative, community-involved design cycles.

7.3.2 *Stakeholder Involvement*

The lack of proper stakeholder involvement will most likely lead to failure; ICT projects are meant to solve problems, but in the case of developing countries and especially resource-constrained communities, one question we must ask ourselves is; who defines these problems? There is the tendency to perceive a problem that is not relevant within the local context. For example, the lack of access to the latest music album might be a relevant problem in certain places and totally irrelevant in others. Stakeholder involvement will give us an indication of what the real problems are and may even go as far as to provide the solution (in a non-technical form). This is however the foundational step, but requires other building blocks to ensure successful adaptation of technologies. The main stakeholder of any ICT system is the end-user, in most of our projects this would be members of a rural community. Apart from the community members, we also would normally have local industry or providers; e.g. farmer groups, food processing groups, local radio stations, etc, external organizations (governmental or otherwise) who work with and/or within these communities; e.g. Ministry of Agriculture, research institutes, universities (research groups and experts), and local and/or external

7 https://cirawa.eu/

companies; e.g. traders, bulk buyers, transporters, Telcos, etc. A combination of the aforementioned form the shareholders of any ICT system in resource-constrained communities.

Together with the communities, these shareholders form an ecosystem that functions in its own way. As such, shareholder engagement is necessary to even begin to truly identify what the problems are in the specific context and what possible solutions could exist. In the case of Mr. Meteo, the best the group of experts could propose (see Chapter 3) was the fact that information would be useful to communities and the empirically backed fact that mobile telephony and radio were the best technologies to consider. It then took a visit to the communities to ascertain the fact that climate information was a problem. In the case of Tibaŋsim, a platform was built for information dissemination to rural communities (see Chapter 4), but the manner of information was proposed by the community members; giving an indication of what is relevant to them, and the research institute; simply using the platform to improve the information they hitherto disseminated manually.

7.3.3 *Indigenous Communication*

Information and Communication Technologies, as the name clearly states, are meant to facilitate the transfer of information from person to person and place to place. Other African researchers have delved into the importance of indigenous knowledge (Millar et al., 2005; Owusu-Ansah et al., 2013; Briggs et al., 2004), but also indigenous communication is imperative for the dissemination of these indigenous knowledge as well as exogenous knowledge. In a BBC article[8] by Padraig Belton, a Technology of Business reporter, in which Mr. Meteo was featured, the writer asks an intriguing question; "*Will talking ever top typing?*". And here we realize that in most places typing never existed, how much more to top talking. He goes further to mention how even in the most advanced countries, and in urban Africa, talking seems to be making its way back into the digital space; Amazon's Alexa, Apple's Siri, Microsoft's Cortana, Google's Assistant, young people sending voice-notes on chat apps, WhatsApp voice calls, Twitter Spaces, Zoom, Google Meets, etc. Why is this the case?; because the indigenous communication method of all humans is voice, not text (Lieberman, 2007). This however becomes more relevant in the context of bringing exogenous knowledge to resource-constrained communities. The developers of the mobile telephone did not necessarily engage in stakeholder involvement in Africa, as suggested above, but the mobile phone coincidentally met the requirement of utilizing the right indigenous communication method.

We must come to the realization that in local communities, there is a local ecosystem, made up of stakeholders (see Section 7.3.2), who have their indigenous knowledge which is shared with their indigenous communication methods. Any ICT innovation or solution therefore must be "plugged-in" to the most appropriate place within this ecosystem.

8 https://www.bbc.com/news/business-43409952 (accessed 17-07-2024)

7.4 THE PLUG-IN PRINCIPLE

We do not wish to be coincidentally successful, and as such, to determine how to meet all the above mentioned requirements, I present the ICT4D Plug-in Principle. The concept of the principle is akin to the ICT4D 2.0 Manifesto which postulates centering ICT4D innovation on 'technology-in-use' as opposed to 'technology-as-invention' (Heeks, 2009), but goes beyond that.

The Plug-in Principle, is originally derived from lessons learnt from experiences in the area of Agriculture from Community-Oriented Education of the University for Development Studies, Ghana; the University was established specifically for this reason and is mandated by law to "blend the academic world with the community in order to provide constructive interaction between the two for the total development of northern Ghana, in particular, and the country as a whole" (PNDC Law 279).

Formal education in African countries is traditionally elitist and as we have seen from this thesis, in Ghana, this has resulted in an urban-rural divide (see Section 1.3), a male-female divide and a north-south divide. All these have further increased the digital divide as well, naturally (see Chapter 1).

Lessons from rural engagement showed the same type of failures of implementation of agricultural (and other fields) projects due to the lack of knowledge by researchers on how rural communities perceive development and how the problems of underdevelopment should be tackled in these communities.

The Plug-In Principle therefore is based on the following points[9];

1. Scientific knowledge cannot replace existing knowledge or situations, it only "betters" it. Therefore scientists, researchers and interventionists are at best "bettering" agents, not change agents.

2. The plug-in (intervention) should be narrower as compared to existing knowledge (in any society or community).

3. To successfully plug-in, there is the need to thoroughly understand the existing situation. Thus researchers and interventionists need to spend time in the communities and with community members

4. Community members will accept a message if they accept the messenger. The people bringing the intervention are as important as the intervention.

5. The amalgam of Indigenous Knowledge (IK) and Scientific Knowledge (SK) is very much dependent on the degree to which interventionists understand and appreciate the existing situation.

6. The understanding and appreciation of the existing situations help to modify intervention strategies to suit particular situations.

These points that are hitherto proposed in terms of the introduction of Exogenous Knowledge to communities, are applicable to ICTs;

9 Prof. Saa Dittoh; Keynote speech at the Third International Symposium Perspectives on ICT4D, 6 April 2016, at VU Amsterdam

7.4.1 *Plug In Principle Points adapted for ICT4D*

7.4.1.1 *Point 1*

Modern methods of communication (namely ICTs) should not replace indigenous communication methods, but should only better them. As seen in Section 7.2.4, in the case of the mobile phone, technology has made such a impact because it did not change the situation, it only bettered it.

This relates to the contextual and user-centric approach of the methodology of this research (see Section 1.6) as evidenced in fielded experiments (see Chapters 3 and 4) which investigated communication technologies.

7.4.1.2 *Point 2*

The ICT intervention should be narrower (smaller) compared to the existing system. Any intervention that is not narrower stands the risk of being too disruptive (see Section 7.1.1).

This also relates to the contextual and user-centric approach of the methodology of this research (see Section 1.6) as well as fielded experiments (see Chapters 3 and 4) that took on the "being narrower" approach.

7.4.1.3 *Point 3*

To successfully plug-in a new ICT system into the above-mentioned existing system, ICT4D researchers and developers must thoroughly understand the existing situation (see Section 7.3)

7.4.1.4 *Point 4*

ICT4D researchers, and perhaps even programmers need to be known, and accepted by stakeholders and community members as far possible. African communities are largely people-centered (Riesman, 1992)

Points 3 and 4 strongly relate to the PAR methodology employed in this research (see Section 1.6) as evidenced by the context analyses and needs assessments in fielded experiments (see Chapters 3, 4, 5 and 6)

7.4.1.5 *Point 5*

Our interventions must produce an amalgamation of a system that is mostly indigenous but merged with our developed ICTs; this requires that we understand and appreciate the existing system.

Chapters 3, 4 and 6 outline projects that had their design and content from local needs and actors

7.4.1.6 *Point 6*

This understanding will aid to build systems that suit specific situations

7.4.1.7 *Point 7*

One extra facet that ICT interventions may face is the replicability and scalability of our systems, since this is a major advantage of ICTs we would not want to lose. This requires an extra step in design and development where, as we develop systems in one use-case or for one community, we must consider that these systems, or at least versions of them, will be replicated and/or reused in other places or within other systems. This not only requires open-source, open-access development, but requires developers and researchers to actively brainstorm and consider the reuse and scaling of developed systems.

Section 1.6.2 emphasizes fieldwork and iterative experimentation. This links to modifying strategies to suit situations (Point 6) of which an important strategy is the design for scalability and replicability even as you localize interventions (Point 7).

Chapter 5 showed urban-focused interventions that paid attention to local market conditions and usability, and Chapters 3, 4 and 6 showed ICT solutions in low-resource contexts, which were co-designed with students, researchers and local actors, built for reuse with open data and tech stacks.

Figure 21: AI Concept Art - The Plugin Principle

7.5 HOW TO PLUG IN

7.5.1 *What is Plugged into What?*

First things first; what exactly are we plugging? And into what? This question is vital and should be asked for every developmental intervention. In the case of ICT4D, it may be a bit easier than most fields to spell out exactly what we are plugging in; *Technologies* that will aid *Information* access (from the internet, any other data source, stakeholders, etc) and *Communication* (amongst community members and/or between community members and externals (other individuals, institutions, organizations, stakeholders, etc)).

Perhaps the more interesting and difficult part of the question for ICT Experts is; plugging into what?; we have our grand idea, our well crafted IT solution, our carefully designed project; where exactly do we place it technically, and what role will it play socially?

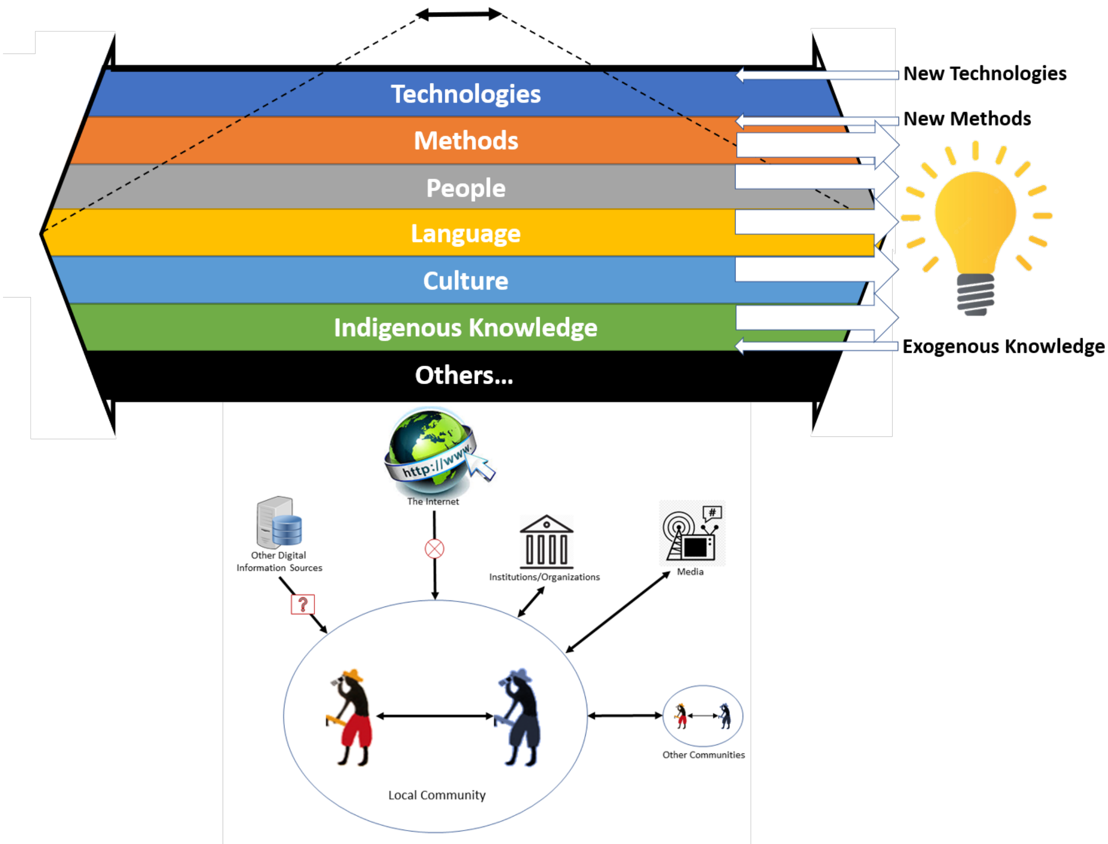

Figure 22: The Plugin Principle

Taking a critical look at exactly what is being plugged in also helps to determine where. Figure 22 shows us the various aspects of information and communication in these communities; information flow within the communities, between members of the community and others outside; family, friends, acquaintances, traders, farmers, etc that live in other places, information from, and to, media providers (TV, and especially radio), information to and from institutions and organization, both governmental and non-governmental, other digital information systems that may exists, and information to and from the internet; which of course is mostly non-existent.

In addition, information flow is a composition of various constructs including, but not limited to; the method of communication (see Section 7.3.3); the technologies being used, be it natural (hand, mouth) or man-made (phone, radio); the people (and communities, organizations) involved; the language being used and the culture, both of which can have a large influence on how the communication would take place; the indigenous knowledge, which is being shared alongside scientific knowledge in some of these flows of communication; and many other things we might not always account for.

By and large, the technology construct is where we wish to plug into, and as much as possible ensure that we do not influence these other aspects mentioned. Although that is often next to impossible, we minimize this influence by gaining a good understanding of the rest of the existing aspects; these aspects form the context (see Section 7.5.2). Taking a look at Figure 22, and considering a change or modification of only the thread labeled "Technology", we can already visualize the intent of the principle which would have an intervention that is narrower than the existing system (Plug-in Principle Point 2), avoid replacing indigenous methods (Plug-in Principle Point 1) and promote a good understanding of the rest of the system (method, people, language(s), culture, IK, etc; i.e. context)(Plug-in Principle Point 3).

7.5.2 *Understanding the Context*

Perhaps the most tedious step in the process is gaining a deep understanding of the context. Throughout this thesis, we have seen how contextual issues are immensely important to solving any developmental issue and more so using ICTs. The Plug-in Principle therefore begins at this vital point; the need to have an in-depth understanding of the local context (see Plug-in Principle Point 3). Note that this cannot be done simply by remote observation alone but by active on-the-ground investigation of the socio-cultural context. Computer Scientist of course are not traditionally social scientists, but the argument here is that we need to become that to a certain extent if we wish to understand the context in which these communities we wish to provide services for function. The first thought on reading this may be that a social scientist should handle this on our behalf, but unfortunately, no one can do this for us; the view-point we have as software developers is very important to the process and yes, we have said that our intervention should be minimal as compared to the existing system, but that minimal "plug-in" is very vital and only we, having a good grasp of what ICTs entail, can merge that context with the local context, when we have a good understanding of it.

It is important to mention here, that in order to gain an understanding of local contextual issues, our own biases, howbeit difficult, must be set aside, else they will influence our views on issues. This even becomes more vital because, without an intentional push to ignore our own bias, there is the tendency for local communities to "prefer" whatever technological artifact or scientific knowledge they believe to be developed or suggested by the "experts" as opposed to even identical alternatives (Dell et al., 2012). Dell et al., 2012 finds that when the interviewer is a foreign researcher requiring a translator, the bias towards the interviewer's opinion or solution doubles. This also brings to mind the need for an increase in indigenous researchers, who would already have a bit more contextual knowledge and less external bias, in this field because a researcher's identity may enable access to a community (or prevent it) (Jimenez et al., 2021)(see Plug-in Principle Point 4)

A good (negative) example is my own bias in the early stages of becoming an ICT4D researcher where I assumed the introduction of an ICT system that cut out intermediary traders from the agricultural value chain was a good idea (see Section 7.1.1)

7.5.3 *Understanding the Problem*

It is irrefutably that a developer and/or researcher may have an idea of the problems in a community or a target population and may even have the possible solutions. For example, one may confidently say that low literacy levels are a problem in communities in the Northern Region of Ghana and could even go further to say that building a school in one of these communities is a possible solution to this problem. However, as seen from this research, local context is of utmost importance and is possibly different in different communities. The differences may be subtle or very diverse, but either way could mean that very different approaches are needed.

I wish to posit that for a developer or a researcher, there are 1) perceived problems that do not really exist, 2) perceived problems that exist but are not considered problems in the context of community members, 3) perceived problems that exist but are not considered relevant to tackle by community members and stakeholders, and 4) perceived problems that exist, are considered problems and also relevant by community members and stakeholders.

Due to the uncertainties of the classification of perceived problems as suggested, it is best from the onset to rely on the community and stakeholders to brainstorm on problems and think of possible solutions (see Plug-in Principle Point 6). This is often neglected by researchers and developers mainly because, as we have seen from the various projects in this research, it takes a lot of effort; workshops with stakeholders, discussions with experts, community visits, etc. When done well, the problems, as well as possible solutions (even if perceived beforehand), would be issues that are of relevance to the stakeholders, especially the community members

7.5.4 *Understanding the Solution*

Some confounding questions to answer would be; *what is the solution to the problem we have identified?* and *who decides the solution?*. There is a tendency to assume that illiterates and literates without ICT knowledge, knowledge of Computer Science concepts, or programming skills will not be able to offer ideas for ICT-based solutions. This is erroneous. Granted, ICT developers must take technical lead on coming up with these solutions, however, just as contextual understanding results in an understanding of the problems, community and stakeholder engagement will result in the best possible solution.

One reason why this is helpful is the fact that we do not intend to build a solution that replaces their existing systems (see Plug-In Principle Point 1), but a system that merges with what they know and do (see Plug-In Principle Point 5) and is as minimal as possible compared to the existing system (see Plug-In Principle Point 2). Engaging with local stakeholders and community members to come up with a solution naturally makes the above aim possible since they are involved from the very start.

Of course, the solutions proposed by stakeholders and community members, although absolutely relevant, must also be technically feasible and it helps to (during workshops and focus group discussions) explain (in lay terms) what is technically possible and what is not. It should not be expected that perfect solutions will result immediately; they may even be false-starts and the total scraping of proposed solutions, but one vital facet of the methodology used in this research (see Section 1.6) is its iterative nature. After gaining the initial functional and non-functional requirements, engineering and evaluating a prototype, there is the need to iterate, based on feedback from evaluations from stakeholders and end-users, and fine-tune your understanding of the solution needed.

7.5.5 *Building the Solution*

Regardless of the methodology used, there should be constant community and stakeholder involvement; remember, we are "plugging in" our innovation into their ecosystem to solve a problem they have identified together with us. The lifecycle of the solution development must therefore include end-user and stakeholder engagement, with prototyping where they can utilize the modules of your solution to see if they fit in with what they require and are inclined to use. (see Plugin Principle Point 1 and Point 5)

One important thing to remember is the use of 'technology-in-use' (Heeks, 2009); building innovations around technology that the communities already use, or if you must introduce new technologies, focus on simple, cost-effective technologies that can be used in tandem ("plugged in") with what they already use. An example is the case of Tibaŋsim (see Chapter 4) where we introduce new hardware (Raspberry Pi) but we ensure it's low-cost technology (about $45), simple (communities only have to plug-in the device to power plug or power bank), and "plugged-in" to already 'technology-in-use' (Radio); this was the case with mobile phones as well where it was affordable technology, simple to use and "plugged-in" by way of its use of indigenous communication methods.

Also, just like there is the tendency to want to replace Indigenous Knowledge with Scientific Knowledge, which we must work against (Simonds et al., 2013; Dentzau, 2019; Kimmerer et al., 2024), knowing that whatever information our systems provide should be given as is and allowed to naturally merge into their existing knowledge (see Section 7.4), we should also work against the tendency to want to replace Indigenous Communication (see Section 7.3.3) with ICTs but work towards merging them (see Plug-in Principle Point 1) and ensuring that ICTs are as minimal as possible (see Plug-in Principle Point 2).

7.5.6 *Sustainability and Scalability*

I must admit that financial sustainabilty has not been a major focus of this thesis, mainly because this is largely based on scientific research and not corporate research for business. However, what happens to these projects and interventions when we as scientists have gone home? What happens when the funds for the project (which came from some agency in the West) has run out?

This has been a recurring theme of a lot of projects, including successful ICT implementations which did not fail for lack of following the right methodology, but simply run out of funding.

It is therefore imperative that we as researchers and developers who are concerned, not only with increasing scientific knowledge and gaining empirical evidence of the various facets of the digital divide, but more importantly, with using this knowledge to foster development, to consider what we can do, by way of design and implementation to make ICT projects financially sustainable. (see Plug-In Principle Point 7)

One area that we have previously looked at is Cost Effectiveness and Affordability (see Section 4.4.5). If I were designing the latest AAA 3D Computer Game, I would most likely not be too concerned with the cost of the hardware required, based on the assumption that avid computer gamers have very high-end gaming machines and consoles. However, in designing solutions for resource-constrained environments, I would have to consider what hardware would run my implementation in terms of cost. This leads us to consider affordable but usable hardware (see Section 4.2.4.2), open-source software and platforms (see Section 4.2.4.3), minimal setup cost stemming from simple setup methods (see Section 4.2.4.4), and low running costs (see Section 4.2.4.5), so as to make sustainability of the project more feasible.

The issue of running cost then leads us to the concept of a business model; as ironic, counter-intuitive and controversial as it may sound, our ICT4D Projects will remain pilots and inevitably degrade into disuse if they are not built around a business model that generates revenue. In his article, "*To Really Help the Global Poor, Create Technology They'll Pay For*" by Alex Deng, Chairman of Huawei's Corporate Sustainable Development Committee, in the Harvard Business Review[10], he makes the point that for many ICT4D projects to scale beyond a pilot, there needs to be some sustainability plan on how those projects will become self-sufficient in the long-term. Deng argues that we, as developers, need to produce solutions that the users will pay for and further argues that; *"supplying something that customers will pay for has another virtue: it provides feedback, which many digital inclusion projects lack. By charging even a small amount, ICT initiatives get a clear signal about how to adapt their offerings in response to changing conditions. Without this feedback, they operate in a vacuum of good intentions, insulated from the market and ultimately cut off from the very communities they are trying to serve. Nothing provides clearer evidence of a project's viability than a base of paying customers, and this proof of success makes scaling up vastly easier"* (Deng,

10 https://hbr.org/2015/08/to-really-help-the-global-poor-create-technology-theyll-pay-for (accessed 17-07-2024)

2015).

I fully agree with Deng on this; it is fundamental that people value what they pay for and pay for what they value (Fay, 1930; Szasz, 1998), as such it is imperative that our intervention must be of value (and if we have adhered to all we have learnt so far, then we know it is) and users must pay for this value.

In addition to this, at least in the case of Tibaŋsim, but applicable to many other ICT4D interventions, is the addition of other revenue sources; stakeholder funding for services of value to them; inclusion of advertisement of relevance to communities by companies and organizations (sellers of seeds, agric-input, etc) and other forms of announcements (meetings, invitations, sales of produce). One of the contributions of my thesis is the real-world experiments I bring to this area of research and based on that I can boldly say that, the assertions of communities paying for ICT4D services, were not just acceptable by the local communities, but was in many cases, first suggested by them.

7.6 MAKE IT SO

Over the years, I have seen this principle, unintentional sometimes and very intentional in some interventions, in action in various fields, especially in agriculture and food security; having been involved in a lot of developmental work in rural areas mainly in the north of Ghana. I have seen many, many interventions over the years and unfortunately have seen the many that failed. My experience has been that, all the failed interventions (ICT or otherwise) failed to adhere to the aforementioned principle. Those that succeeded for the most part followed these guidelines, mostly not as a scientific principle per say, but based on informed knowledge and experience, or simply by coincidence. We can however not rely on accidents to close the digital divide; it must be intentional!!

Years of research and experience has taught these lessons which have been organized into this conceptual framework and hopefully up and coming Computer Scientists in the Global South can utilize this to get a head start in their quest to connect the unconnected and close the digital divide.

7.7 CHAPTER SUMMARY

Chapter 7 introduces and elaborates the Plug-in Principle, a conceptual framework developed from years of practical and field research to explain the conditions under which ICT4D projects in resource-constrained environments succeed or fail. Through detailed reflection on failed interventions, including cases of disruption, nonacceptance, and poor contextual grounding, the chapter argues that these failures stem primarily from disconnects between technological solutions and the sociocultural and infrastructural realities of the communities involved. In contrast, successful projects such as Tibaŋsim, Foroba Blon, and Kasadaka demonstrate the value of deeply contextual, voice-based, stakeholder-driven approaches that align with indigenous knowledge systems and communication practices.

The chapter moves from these empirical examples to define and contrast the underlying dynamics of success and failure through a systematic comparison framework. Dimensions such as stakeholder involvement, communication method, context understanding, and sustainability are examined in parallel across successful and failed projects. This comparison sets the stage for the introduction of the Plug-in Principle: the notion that ICT interventions must "plug into" existing social, technological, and communication ecosystems in a manner that is minimal, respectful, and complementary rather than disruptive. Adapted from development approaches in agriculture (particularly community-oriented education at UDS), this principle is argued to be essential in ensuring long-term adoption and relevance of ICT4D projects.

Following this, the chapter outlines seven Plug-in Principles, adapted specifically for ICT4D. These range from respecting and enhancing rather than replacing indigenous communication (e.g., voice over text), to ensuring scalability and sustainability through open-access, community-co-created systems. The chapter emphasizes that successful plug-in requires developers themselves to understand context intimately, often requiring them to operate outside their disciplinary comfort zones. Fieldwork, participatory action research, and iterative design cycles are presented not as optional add-ons but as central to any serious ICT4D undertaking.

Chapter 7 ends with practical advice on how to plug in, going step-by-step through identifying what is being plugged into what, understanding local context and problems, designing appropriate solutions collaboratively, building them with users, and ensuring scalability through open, low-cost, business-model-aware systems. This detailed methodological contribution leads directly into Chapter 8, which synthesizes the thesis' findings. In the last chapter, the research questions are answered, the cases are summarized, and the broader implications of this research, especially the value of the Plug-in Principle in both theory and practice, are critically reflected upon.

8 CONCLUSION AND DISCUSSION

This concluding chapter summarizes the key findings from each chapter of this thesis, explains the interconnections between the chapters, and provides comprehensive answers to the research questions posed at the onset. The overarching goal of this research was to explore and develop sustainable ICT solutions for resource-constrained environments, particularly in the Global South. Specifically, the research sought to address whether we can overcome existing barriers and find practical and sustainable ways to improve digital information provisioning and communication access for rural, peri-urban and urban communities in the Global South. It also examined how we can ensure that such information and communication is locally relevant and truly fits the needs, priorities, and local context of communities. Furthermore, the research investigated the nature of the technological solutions involved, given that the methods and results of technological advancement in the Global North often fail in the Global South. Furthermore, it explored whether cutting-edge technologies such as AI can be made useful in the resource-constrained environments of the Global South and, if so, how. Finally, the research aimed to determine the extent to which it is possible to draw more general lessons and conclusions about building and deploying information and communication systems in these highly local and context-specific environments. This resulted in a conceptual framework dubbed the Plug-In Principle for ICT4D

8.1 OVERVIEW OF CHAPTERS, PROJECTS, RESEARCH QUESTIONS, AND PLUG-IN POINTS

The following section provides an overview of the practical fieldwork and systems developed across the various chapters of this thesis. It presents a tabular summary linking each chapter to the corresponding project or intervention, the specific research question(s) it addressed, and the Plug-in Principle points that were demonstrated or highlighted. This concise overview serves to show how the conceptual framework was grounded in real-world experiments and to clarify the contribution of each use-case to the overall research aims.

Table 13: Overview of Chapters, Projects, Research Questions, and Plug-in Points

Chapter	**Project Name / Focus**	**Research Question(s) Covered**	**Plug-in Point(s) Highlighted**
Chapter 3	*Mr. Meteo*	RQ1, RQ2, RQ3	Point 1 (Better, not replace), Point 2 (Be narrower), Point 3 (Understand the context), Point 4 (Be known and accepted)

Chapter	Project Name / Focus	Research Question(s) Covered	Plug-in Point(s) Highlighted
Chapter 4	*Tibaŋsim*	RQ1, RQ2, RQ3, RQ5	Point 1–7 (Full plug-in implementation: context, voice tech, sustainability, open source, reuse)
Chapter 5	*Sefarim & Woom*	RQ3, RQ4	Point 6 (Adapt to specific situations), Point 7 (Design for scalability and reuse)
Chapter 6	*Project TIBaLLi*	RQ4, RQ5	Point 3 (Understand the context), Point 6 (Adapt to situation), Point 7 (Scalability, reuse, open tech design)
Chapter 7	*The Plug-in Principle*	RQ1–RQ5 (Comparative and synthetic insights)	Point 1–7 (Synthesized from multi-project experience and conceptualized as framework)

8.2 SUMMARIZATION OF KEY FINDINGS

Chapter 1 set the stage by discussing certain myths and realities that have a bearing on the issue of the digital divide, highlighting the fact that there is rural-urban divide by providing my personal history, and tracing the history of the internet in Ghana. It established the research problems and questions that this thesis aimed to address. Understanding these foundational issues is imperative as it sets the stage for the practical solutions explored in later chapters, especially giving readers an opening into the myriad contextual issues that exist in the Global South.

Chapter 2 looked at the major challenges of digital information access in the Global South; namely colonization, a lack of infrastructure, low literacy and the lack of relevant digital content, contrasting the original intentions of the World Wide Web with its current state. The chapter explored various technologies, such as Radio, mobile telephony, SMS, and AI, that can be leveraged to bridge the digital divide. This understanding is critical for transitioning to localized solutions like Mr. Meteo, which are addressed in the next chapter.

Chapter 3 detailed the context analysis and needs assessment leading to the development, deployment, and evaluation of Mr. Meteo, a GSM-based voice service that provides weather forecasts in local languages. The direct impact on the issues of infrastructure, literacy, and relevant information vis-à-vis the methodology adopted was significant. Insights gained from Mr. Meteo's deployment were pivotal in informing the design of more complex systems like Tibaŋsim.

Chapter 4 detailed the context analysis, needs assessment, development and deployment of a GSM and FM-based award-winning information delivery system for rural areas.

It also took a more in-depth technical look at the components of the system as well as a detailed user evaluation from five communities. We see how our iterative methodology has enabled us to further tackle the barriers, and goes further to build a more sustainable system as proof that digital information systems are possible in the rural Global South.

In Chapter 5 we take a step into the urban Global South, where we see that the issues of the digital divide exist. Using the same methodology, we outline the context analysis, needs assessment and development of two smartphone applications (Sefarim and Woom). We see in this chapter how the issues of unreliable infrastructure, low digital literacy and lack of relevant content can be tackled to ensure that applications are built in the right way for the urban Global South.

Chapter 6 takes an even further step into emerging technologies while at the same time taking a step back into the rural context. We ask if emerging technologies like AI can be leveraged in anyway to foster web inclusion for resource-constrained environments. We outline TIBaLLi, an ongoing project that looks at the effective use of Artificial Intelligence (namely Machine Learning and Natural Language Processing) for building Automatic Speech Recognition solutions for small languages. We look at the various project activities which in effect outline the methodology in use. We also take a look at two tools built to facilitate this process; one for effective data collection for NLP and the other using AI to crowd-source rainfall data to improve the accuracy of climate data provided by the system. We see how the lessons learnt align and/or overlap lessons from our previous chapters.

Chapter 7, after outlining some failed and successful ICT4D projects and looking at the reasons behind their respective end-states, adds the lessons gleaned to lessons learnt from previous literature; our personal knowledge of the digital divide in context of the Global South; the major barriers that have been identified; the possible technological solutions; the appropriate methodologies that should be employed; various context analysis, needs assessments, design and development of ICT solutions; fielded experiments carried out; evaluations and multiple reiterations, into a concise conceptual framework dubbed "The Plug-In Principle for ICT4D. This principle answers the missing SDG provision of how ICTs can be made available in resource-constrained environments.

8.3 ANSWERS TO THE RESEARCH QUESTIONS

8.3.1 *Overcoming the Barriers*

In view of the existing barriers discussed above, can we overcome them and find practical and sustainable ways to improve digital information provisioning and communication access for rural and peri-urban communities in the Global South?

Indeed, we can overcome the barriers to improving digital information provisioning and communication access in the Global South, but it requires a multifaceted approach that integrates both technological and social solutions. The thesis highlights several key strategies:

1. **Community-Based, User-Centric Approach**: Utilizing Participatory Action Research (PAR) as the main methodology, which emphasizes the involvement of local communities as co-creators of the solutions, ensures that the solutions are tailored to the specific needs and contexts of the users. This method has proven effective in projects like Mr. Meteo and Tibaŋsim, which addressed local needs through community engagement and iterative design processes. (see Sections 1.6, 3.1, 4.1, 5.1 and 6.2).

2. **Leveraging Existing Technologies**: Rather than introducing expensive and unsustainable new technologies, the focus should be on using existing, widely available technologies such as GSM, SMS, and Radio. These technologies are already prevalent and can be adapted to local contexts, as shown in Mr. Meteo and Tibaŋsim, which utilized GSM and Radio respectively for information dissemination. (see Section 2.2).

3. **Addressing Literacy and Content Relevance**: To overcome low literacy rates and the lack of relevant local content, solutions must incorporate local languages and culturally appropriate formats (e.g., oral communication, symbols). Tibaŋsim demonstrated success by broadcasting information in local languages and through formats easily understood by the community. (see Sections 2.1.3 and 4.4.4).

8.3.2 *Local Relevance*

How can we ensure that such information and communication is locally relevant and truly fit the needs, priorities, as well as local context of communities?

Ensuring local relevance requires a deep understanding of the community's needs, priorities, and context, achieved through:

1. **Context Analysis and Needs Assessment**: Conducting thorough context analysis and needs assessments through stakeholder workshops, field visits, and focus group discussions helps identify what information is relevant and how it should be delivered. For instance, the design of Mr. Meteo and Tibaŋsim was based on feedback from community members about their specific informational needs and preferred communication methods. (see Sections 1.6, 3.1, 4.1, 5.1 and 6.2).

2. **Indigenous Communication Methods**: Emphasizing the use of indigenous communication methods, such as voice rather than text, which aligns with the cultural practices of many rural communities. This approach was highlighted as critical in projects like Tibaŋsim, where information was disseminated through FM broadcasts in local languages. (see Section 7.3.3).

3. **Iterative Design and Prototyping**: Employing iterative design and prototyping allows for continuous refinement of the solutions based on user feedback. This method was effectively used in the development of Sefarim and Woom, applications tailored to urban Global South communities but adaptable to rural contexts. (see Chapter 5).

8.3.3 *Rethinking Tech for the Global South*

What is the nature of the technological solutions involved, given that methods and results of technological advancement in the Global North often fail in the Global South?

The nature of successful technological solutions for the Global South must include the following:

1. **Adaptation to Local Infrastructure**: The solutions need to be designed in a way that they can work with existing infrastructure, which is usually not sufficient. For instance, such was an applicable approach in Tibaŋsim by using GSM and Radio as opposed to relying on unreliable internet connectivity. (see Section 2.2 and Chapter 4).

2. **Cost-Effectiveness and Sustainability**: Technologies need to be affordable and sustainable within local contexts. In the Tibaŋsim project, low cost hardware such as Raspberry Pi and 3G modems helped to reduce costs while still ensuring sustainability. (see Sections 4.2.4.1 and 7.5.6).

3. **Local Data Utilization**: Successful solutions leverage on local data and context-specific information. This saw the TIBaLLi project focus on AI tools development for local languages which necessitated data collection directly from communities, by the communities, for training NLP models. (see Section 6.3.1).

8.3.4 *AI in Context*

Can cutting-edge technologies such as Artificial Intelligence be (made) useful in the resource-constrained environments of the Global South, and if so, how?

Yes, cutting-edge technologies like AI can be made useful in resource-constrained environments by:

1. **AI Development that takes context into account**: This involves the creation of Artificial Intelligence systems that can adapt to local settings where they operate. The TIBaLLi project demonstrates this by creating Automatic Speech Recognition (ASR) AI models which are specific to particular languages and backgrounds. (see Chapter 6).

2. **Data Collection Collaborations**: The involvement of locals in data collection ensures that the AI models work with relevant information sets. In TIBaLLi, for instance, voice data was gathered from and by rural communities to facilitate language model development. (see Section 6.3.1).

3. **Scalable and Low-Cost Solutions**: In making such technologies available, prioritizing low-cost and scalable AI solutions like lightweight models and local hardware is necessary. Continued work in the TIBaLLi Project is looking at rapid development of ASR models using phonetics and the possibility of running lightweight models on low-cost hardware. (see Section 6.3).

8.3.5 *From Specific to Scalable*

In view of the highly local and contextual specificity of use cases, systems and solutions, to what extent is it possible to draw more general lessons and conclusions about building and deploying information and communication systems in resource-constrained environments?

While each context is unique, several general lessons can be drawn:

1. **Participatory Approach is Crucial**: Engaging local communities in the design and implementation process ensures relevance and increases adoption. This has been consistently validated across multiple projects like Mr. Meteo, Tibaŋsim, and TIBaLLi. (see Sections 1.6, 3.1, 4.1 and 5.1).

2. **Iterative Development and Flexibility**: Adopting an iterative development approach allows for continuous improvement based on real-world feedback, which is essential in dynamic and resource-constrained environments. (see Section 1.6).

3. **Leverage Existing Infrastructure**: Utilizing available technologies and infrastructure ensures feasibility and sustainability. Projects that adapted to existing GSM and Radio infrastructures have shown significant success in overcoming access barriers. (see Section 2.2).

4. **Focus on Local Relevance**: Ensuring that information and technology solutions are culturally and contextually relevant increases their impact and sustainability. This principle is evident in the development of localized AI tools and communication methods in the TIBaLLi project. (see Sections 2.1.4 and 4.4.4).

5. **The Plugin Principle for ICT4D**: The Conceptual Framework developed in this thesis as a result of the lessons learnt in development of ICTs for resource-constrained environments, outlines perfectly a generalized framework for building and deploying information and communication systems in resource-constrained environments. (see Section 7.4).

8.3.6 *Community-Based Ethics in ICT4D*

In ICT4D research and implementation, particularly within rural and peri-urban areas of the Global South, ethics cannot just be about ticking boxes on institutional review board forms. Instead, ethical practice must be deeply grounded within local context. It comes to life through shared responsibility, cultural awareness, and constant negotiation with local and global power systems.

8.3.6.1 *Ethics as a Cultural Practice*

In many communities in the Global South, ethics is not external or bureaucratic. It is relational, lived, and rooted in everyday life. Unlike the standardized protocols often used in the Global North and urban Global South, people in places like Tingoli in the Northern Region of Ghana see ethics as something that grows out of community relationships. Acceptability, fairness, and trust are not just defined in guidelines to them, they are shaped through their daily interactions. Consent tends to be collective, and trust is built slowly, through repeated encounters, not a single form with a signature.

This perspective aligned closely with the Participatory Action Research approach used in the study. In this framework, local stakeholders were not treated as research subjects. They were involved as co-designers of the technologies and systems being developed, shaping them based on what made sense in their lives. In practice, this approach was visible in field projects like Mr. Meteo, Tibaŋsim, and TIBaLLi. Farmers, women's groups, and agricultural officers were active participants. They decided what kind of data should be collected, what privacy meant in their context, and which technologies felt appropriate to use.

8.3.6.2 *Ethical Oversight Through Participation*

The PAR methodology naturally created a framework for ethical reflection. In the Tibaŋsim and TIBaLLi projects, for example, community members and stakeholders such as the Internet Society Ghana Chapter and the Council for Scientific and Industrial Research - Savanna Agricultural Research Institute (CSIR-SARI) did not only help design the system, they raised questions about how data would be stored, what languages should be used, and how voices should be represented. These day-to-day reflections served as real-time ethical checks, often more attuned to local needs than formal ethics committees in distant universities. Rather than applying a single global standard of ethics, this research respected the diversity of local reasoning. It made space for different ways of knowing and deciding what was right, something that is often missing from how tech is built and deployed.

8.3.6.3 *Against Data Extractivism*

Too often, development work in the Global South turns into a form of data extraction. Information is gathered, packaged, and sent elsewhere; frequently to feed institutions or companies in the Global North. This project actively worked against that trend. Data stayed with the communities and/or stakeholders that shared it unless it was unanimously agreed that sharing would be beneficial.

An example is the spoken Dagbani recordings (Saa-Dittoh et al., 2024) which was published only after the unanimous agreement that its presence as open-source would aid other NLP researchers build models and tools in for Dagbani and other low-resource languages.

8.3.6.4 *Rejecting Digital Colonialism*

Digital colonialism occurs when technologies are imported wholesale from the Global North without being adapted to local contexts. These tools often do not fit and end up reinforcing old inequalities. Failed SMS systems in rural Ghana and the rejection of top-down digital platforms clearly show this. Projects like Kasadaka and Tibaŋsim took a different path. They focused on building with tools people already used, like FM radio and GSM phones, and in the languages they actually speak. This approach centered on local needs and gave people more control over the tech in their lives.

8.3.6.5 *Engaging with Global Power Structures*

Of course, community-based work like this does not occur in isolation. It exists within systems of funding, publishing, and academia that are still largely controlled from the Global North. That context matters. This project confronted those realities openly. Even though the PhD was carried out in a Dutch university, the research questions, concerns, and directions came from the ground; from farmers, elders, and youth in Northern Ghana. Doing ethics here meant practicing humility. It meant recognizing that knowledge does not just come from Amsterdam or Accra, but also from women leading cooperatives in Tingoli, or elders sharing histories in Guabuliga.

8.4 FUTURE WORK

As with most research endeavors, this thesis opens the door to several new fields of investigation that, while rooted in the Global South, present opportunities for global impact. The challenges addressed; infrastructure, literacy, and local content, are not unique to any one region, but manifest in varying forms throughout the world. As such, the approaches and lessons learned here have wider applicability, especially within ongoing conversations around digital humanism, responsible AI, and inclusive technology.

An immediate direction for future work is to deepen the exploration of language technologies, particularly Natural Language Processing (NLP) for low-resource languages. Although the TIBaLLi project has shown early promise in developing Automatic Speech Recognition (ASR) systems for small languages, more research is needed to scale these solutions across different linguistic contexts. In multilingual Africa, Asia, and Europe facing their own inclusion challenges (especially with migrant and regional languages in Europe), such research can contribute to broader goals of linguistic diversity, equity, and access.

A promising direction stems from my collaboration with Auke Schuringa, whose thesis introduced an energy-efficient phonetic matching technique for spoken words in rare languages. His work demonstrated that phonetic overlap between a low-resource language and a high-resource language (such as Dagbani and English) can be exploited to enable basic speech matching without needing full ASR pipelines or expensive training. This approach, while lightweight, offers considerable potential for integrating speech capabilities into resource-constrained environments. Further exploration of this method—including fine-tuning with local phonetic structures and deploying it within messaging platforms like Telegram—can inform how NLP tools may be deployed more broadly across rare and regional languages with minimal computational cost.

Moreover, there is the need to examine how community-driven Information and Communication Technologies for Development (ICT4D) methodologies, developed and tested in this research, may inform more human-centered approaches within global digital ecosystems. For example, many public sector digital innovations in the Global North still operate with top-down structures that lack iterative engagement with end-users. Lessons from this thesis, especially those regarding iterative co-design, stakeholder involvement, and contextual responsiveness, can offer alternative approaches.

The *Vienna Manifesto on Digital Humanism* emphasizes the centrality of human dignity, agency, and democratic values in the design and deployment of digital systems (Werthner, 2020). The work presented in this thesis aligns with this thinking, demonstrating how socio-technical systems can be grounded in the actual realities of people, whether in Tingoli, Tamale, Accra, Kuching or Amsterdam. There is thus a compelling case for future research that continues this trajectory, bringing together Global South and North perspectives to address shared digital challenges, under the umbrella of Digital Humanism.

Finally, the *Plug-In Principle* developed offers a conceptual framework that may be adapted to other domains such as civic technology, public service delivery, and education—domains where contextual sensitivity is often neglected. These applications merit closer investigation through collaborative research opportunities aimed at translating theory into cross-regional practice.

8.5 Closing the Digital Divide - A Personal Perspective and Call to Action

It is imperative that Africa capitalizes on ICTs to effect a huge jump in development; we cannot afford to develop gradually, and the advent of IT technologies like the Mobile Phone, the Internet, IoT, AI, VR, etc has shown us that it is possible for technology to cause giant leaps in development. Our development however is held back if we continuously allow a digital divide or any other divide for that matter, within our own countries. It is akin to two groups of people on either side of a boat with a hole on one side; the boat will never be able to move forward effectively unless the group on the "good" side help solve the problems of the "bad" side.

I have been to every district in the northern sector of Ghana (over 50 districts); I have seen the poverty, I have seen the underdevelopment, I have seen the lack of infrastructure, I have seen the urgent need for development and the lack of government intervention, but I have also seen the potential and the possibilities; I have seen communities that have the potential to produce so much natural resources, especially food, such that they'd be no need for importation of most of these resources, which will further strengthen the nation, and I have also seen that most of these communities are ready to work together, and with others, to develop as much as possible. I have seen very similar situations in other countries I have visited; Nigeria, Gambia, Burkina-Faso, Uganda, Rwanda, Malaysia, etc.

However, I have seen also the lack of efficient and effective information and communication. Information is one of the most valuable resources in the world and in this Information Age is arguable more valuable than anything else. The ability to get relevant information to these underdeveloped communities will automatically aid members of these communities to foster their own development. Institutions like the ISOC and research groups like the Web Alliance for Regreening in Africa (W4RA) have been pushing this agenda for years and one thing that has been fundamentally missing in the story has been the presence of local researchers and developers who would, naturally, have a greater contextual understanding of the communities targeted, and would be easily known and accepted by local communities.

This thesis is therefore, among other things, a clarion call to Computer Science Researchers, Software Developers, ICT Experts and ICT Enthusiast who hail from Africa and other nations in the Global South; we stand at a position that is vital to the development of our nations. We will be the agents of change who will usher in a new era for the developing World. We have a lot of work to do in our rural areas and eventually bring the same principles to peri-urban and urban Africa as well; we need our own platforms, which are built in context of our situations, to foster better development. We have seen the evidence that this is doable; to build solutions for rural resource-constrained communities (see Chapter 3 and Chapter 4), build modern ICT solutions for urban Global South users in the right context (see Chapter 5), and use advanced and emerging technologies to foster development (see Chapter 6), all of which can be achieved by adhereing to the right principles (see Chapter 7).

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APPENDIX A - RADIONET SURVEY

Demographic

1. Gender
2. Age
3. Marital Status
4. Highest Education
5. Ethnicity
6. Language(s) spoken
7. Occupation

Technologies and Information

1. Do you own a mobile phone?
2. If no, do you have access to one?
3. How often do you make calls?
4. How often do you receive calls?
5. How often do you send sms?
6. How often do you receive sms?
7. Do you own a radio set?
8. If no, do you have access to one?
9. How often do you listen to radio?

Tibaηsim
Post-deployment
Rate respondent's thought about the system;

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.

6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

    What kind of information will you want to receive through this system?

B

APPENDIX B - SEFARIM MARKET SURVEY

Q1. Do you consider yourself a reader?

	Frequency	Percent	Valid Percent	Cumulative Percent
Serious Reader	9	13.0	13.0	13.0
Normal Reader	35	50.7	50.7	63.8
Neutral	13	18.8	18.8	82.6
Lukewarm Reader	11	15.9	15.9	98.6
Not a Reader at all	1	1.4	1.4	100.0
Total	69	100.0	100.0	

Q2. How many books do you read in a year?

	Q2. How many books do you read in a year?
N	66
Mean	7.30
Minimum	0
Maximum	20
Std. Deviation	6.164

Q3. How many books do you buy in a year?

	Q3. How many books do you buy in a year?
N	67
Mean	4.48
Minimum	0
Maximum	20
Std. Deviation	4.803

Q4. How many books by Ghanaian Authors do you read in a year?

	Q4. How many books by Ghanaian Authors do you read in a year?
N	67
Mean	2.34
Minimum	0
Maximum	11
Std. Deviation	2.799

Q5. Do you read on electronic devices (ebooks)?

	Frequency	Percent	Valid Percent	Cumulative Percent
Yes	58	84.1	84.1	84.1
No	5	7.2	7.2	91.3
No, but would like to start	6	8.7	8.7	100.0
Total	69	100.0	100.0	

Q6. How many ebooks do you read in a year?

	Q6. How many ebooks do you read in a year?
N	69
Mean	6.68
Minimum	0
Maximum	40
Std. Deviation	8.376

Q7. Have you ever bought any ebook?

	Frequency	Percent	Valid Percent	Cumulative Percent
Yes	19	27.5	27.5	27.5
No	50	72.5	72.5	100.0
Total	69	100.0	100.0	

Q7_why. If no, why?

	Frequency	Percent	Valid Percent	Cumulative Percent
Complicated Procedure	2	2.9	5.4	5.4
Costly	5	7.2	13.5	18.9
Don't know where to get them	2	2.9	5.4	24.3
Pirated	13	18.8	35.1	59.5
Mode of payment not favorable	8	11.6	21.6	81.1
Prefer hard copies	3	4.3	8.1	89.2
I don't know	2	2.9	5.4	94.6
Free literature	2	2.9	5.4	100.0
Total	37	53.6	100.0	
Missing	System	32	46.4	
Total	69	100.0		

Q8. Have you ever bought any ebook by a Ghanaian Author?

	Frequency	Percent	Valid Percent	Cumulative Percent
Yes	12	17.4	17.4	17.4
No	57	82.6	82.6	100.0
Total	69	100.0	100.0	

Q8_why. If no, why?

	Frequency	Percent	Valid Percent	Cumulative Percent
Costly	2	2.9	6.3	6.3
Pirated	4	5.8	12.5	18.8
Mode of payment not favorable	2	2.9	6.3	25.0
Prefer hard copies	1	1.4	3.1	28.1
I don't know	3	4.3	9.4	37.5
Not interested	5	7.2	15.6	53.1
Unavailable	15	21.7	46.9	100.0
Total	32	46.4	100.0	
Missing	System	37	53.6	
Total	69	100.0		

Q9. Have you ever bought any ebook from Amazon?

	Frequency	Percent	Valid Percent	Cumulative Percent
Yes	14	20.3	20.3	20.3
No	55	79.7	79.7	100.0
Total	69	100.0	100.0	

Q9_why. If no, why?

	Frequency	Percent	Valid Percent	Cumulative Percent
Complicated Procedure	4	5.8	14.3	14.3
Costly	2	2.9	7.1	21.4
Pirated	4	5.8	14.3	35.7
Mode of payment not favorable	11	15.9	39.3	75.0
Prefer hard copies	1	1.4	3.6	78.6
Not interested	4	5.8	14.3	92.9
No knowledge	2	2.9	7.1	100.0
Total	28	40.6	100.0	
Missing	System	41	59.4	
Total	69	100.0		

Q10. What device do you read your ebooks on?

	Frequency	Percent	Valid Percent	Cumulative Percent
Android Device	42	60.9	64.6	64.6
iOS Device	10	14.5	15.4	80.0
Kindle	2	2.9	3.1	83.1
Windows Device	11	15.9	16.9	100.0
Total	65	94.2	100.0	
Missing	System	4	5.8	
Total	69	100.0		

Q11. Would you be interested in getting access to ebooks by Ghanaian Authors?

	Frequency	Percent	Valid Percent	Cumulative Percent
Yes	66	95.7	95.7	95.7
No	3	4.3	4.3	100.0
Total	69	100.0	100.0	

Q12. Would you buy affordable ebooks by Ghanaian Authors if you could use mobile money?

	Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Yes	57	82.6	82.6	82.6
No	1	1.4	1.4	84.1
Maybe	11	15.9	15.9	100.0
Total	69	100.0	100.0	

Q13. Would you buy affordable ebooks by Ghanaian Authors if you can't make copies for others?

	Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Yes	45	65.2	65.2	65.2
No	3	4.3	4.3	69.6
Maybe	21	30.4	30.4	100.0
Total	69	100.0	100.0	

Q14. Would you buy affordable Audio Books by Ghanaian Authors?

	Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Yes	22	31.9	57.9	57.9
No	5	7.2	13.2	71.1
Maybe	11	15.9	28.9	100.0
Total	38	55.1	100.0	
Missing	System	31	44.9	
Total	69	100.0		

C

APPENDIX C - TIBALLI WORKSHOP PRESENTATIONS (SUMMARY)

C.1 TIBALLI: MAKING AI WORK FOR INTERNET INCLUSIVENESS IN THE GLOBAL SOUTH

C.1.1 *Farmer group men*

C.1.1.1 *If you have the AI application, what are the likely questions you would ask it?*

Answers

- Which month would the rain start?
- Would there be enough rain fall this year?
- Can I plant crops with this first rain?
- Which month would the rains end?
- Would the rain be accompanied by a devastating wind or rain storm?
- Which crops would be sustainable based on the rain fall pattern?
- Which crop variety can I plant?
- Which period would there be dry spills ?
- Would it rain today or tomorrow?
- What is the best time to plant crops?
- Why did the previous predictions did not happen?
- How can we control striga?

C.1.1.2 *Do you have someone in the community, that you rely on for any information all that we have mentioned above?*

Answer: No

C.1.1.3 *Is the information received accurate?*

Answer: Because we do not get any information our answer is none of the above.

C.1.1.4 *Should the application give historical data i.e yesterday's weather forecast, would it be useful to the farmer?*

Answer: Yes

C.1.1.5 *Which other information should the machine give us?*

Answer: Market information, agro input information, harvesting period of crops, signs to know when it is time for harvest, live stock production information, an advisory on good agricultural practices

C.2 AI GROUP 1 PRESENTATION

We were tasked to build a speech system in Dagaani to aid the work of our Agricultural Extension Agencies. In information dissemination to the various communities.

C.2.1 *How do we build a solution that connects the last mile?*

Answer: Technology when created has to be simple, it ease of use. If it is so complex, I am pretty sure its reception would be difficult. Also our whole team talked about its inclusiveness, so it should have a natural feel, interactive, and simple to use.

C.2.2 *How would we handle the lack of train data?*

Answer: We have identified that, out of the general stakeholders, data was kept in silos, there is a lack of interconnectiveness. So we intend to collect data from other stakeholders, transfer them using small set crowdsourcing.

C.2.3 *How would your design cater for the fact that there are almost no smartphones, bad GSM and 4G?*

From the 2020 census, almost half of the population are not connected to the Internet. So any project must account for this, if people are not connected to the Internet, how do we connect them? So we intend developing a system, which would be in the middle of town, more like a physical box, there is going to be also a mobile app for those who have and are able to use smart phones.Then associations leaders may pass the information to those who can not access the Internet through the physical box.

C.2.4 *How may your design leverage the use of smartphones if we can circumvent the above mentioned challenges, One smartphone possibility serves many people?*

Answer: No it does not. So offline service with GSM users, online applications for smartphone users.

C.2.5 *What type of tech stacks are going to be used?*

Answer: Tech stacks are very important, data basis, and system interface, that is the user friendliness of the interface and text recognition system and also API connected to it. The storage systems.

C.2.6 *What are the series of steps needed to achieve your solution?*

Answer:

- Find an appropriate language model.
- Collaborate with Agricultural Extension Agencies, end users and NLP experts; it is going to be all inclusive.
- Audio and text infrastructural set up.
- Test with end users, we check for discrimination, exclusion, its robustness and safety. Most of these AI technologies are trying to widen the gap, but our model is going to be all inclusive. We want local stories to be told and not big tech stories. We want to design a model we can speak Dagbani to and it gives us feedback.

C.3 AI GROUP 2 PRESENTATION

In our model we adopted the Raspberry Pi technology with the use of a gateway called LoRA Network. The LoRA would help us establish a hotspot network over the entire area, that is a situation where there is no Internet connectivity at all. We establish our own network, the Raspberry Pi would allow us establish our web server and the AI model there.

C.3.1 *How do you build a solution that connects the last mile?*

Answer: When we are looking at the last mile, we are looking at the Internet, where we can not have access to the Internet. What kind of intervention do we have? The solution turns to address a situation where in a community, the average farmer does not own a smartphone or even a phone at all. How can we still ensure that we can deliver this solution to them? So we are looking at this structure inspired by LORA, and can travel over 700km. So once we setup this network, we can be able to cover 700km, this could also be repeated to cover more grounds. That is the reason we chose LORA. We realised that in the last mile, there is no connectivity, connectivity means that, there is no Internet, you can not even get a signal to make a phone call. We are able to broadcast information using our gateway to a speaker, we have this speaker at a place called the information center.

C.3.2 *How can we handle the lack of train data?*

Answer: During our brainstorming, we also realised that when you are looking at the rain fall, another approach to be able to get data is to measure the soil moisture content know when it rained or when it did not rain. Those sensor data would also help us to have enough data aside from the one we have to collect from organisations like MOFA and Agricultural Extension Agencies who already have such data.

C.3.3 *How can our design cater for the fact that there is almost no smartphones and bad GSM?*

Answer: In a case where there is no phone or bad GSM that means you can not use the small phone. We would build a radio frequency for our gateway, so if farmers have a radio set, they can access the information. In a situation where they have a phone but fail to have connectivity without the Internet, can also receive a call, our system can dial this number to receive the information.

C.3.4 *We also looked at how we can leverage our design for smartphone users as well.*

Answer: We went further to look at the same solution, being able to serve farmers who have access to smartphones, that is where our AI comes in. We have an interactive dashboard built that can give farmers more information, a conversational application where farmers can be able to communicate with the application, just like Siri in IOS phones. This would not also require Internet, due to the hotspot we would create. When 700km rage, the farmer can turn on their WiFi and connect straight to our server to get access to this data.

C.3.5 *How can we consider plugin computers like Raspberry Pi in our projects?*

Answer: Our entire server runs on the Raspberry Pi, the whole AI model also runs on the Raspberry Pi, this is a technology called edge computing where you do not necessarily need to push your data into the cloud before processing. It is processed at the point of collection. So we are using Raspberry Pi for this project.

C.3.6 *What tech stacks do we need to achieve this?*

Answer: We categorized our technology stacks into three, our hardware and software stacks and communication. We are looking at the Raspberry Pi, the LORA GATEWAY, the SMS, sensor technology are all hardware technology we would use. When it comes to the software, we are looking at the AI application that would be used, the Web application that would be displayed on the screen, and the software elements used. Communication, we are looking at interventions such as the LORAN, Loss Range Ai Network, we considering Bluetooth, where the farmer has small devices are able to pair them and get access to information.

C.3.7 *What are the series of steps needed to achieve your solution?*

Answer: Understanding the problem well, Identify target users

C.4 LINGUISTICS GROUP PRESENTATION

We look at how we would use language with the AI system. We have seen the demonstration of the AI Group on how they propose the system to work, this system can not work in a vacuum, hence the linguistics element is important. Tiballi has to work, but before Tiballi can work, it has to involve a lot of people speaking Dagbani, in male and female voices that can be synthesised and understood as a human voice.

The voices need to be clear and clean, which means it has to be recorded in the studio where filtration takes place. The language Dagbani has a lot of acrobatics in it. We want the AI to start with a salutation, time of the day, weather. In Dagbani, there are greetings for every situation, so the AI must consider that.

The scenario should be on rainfall patterns. The AI should tell what is happening recently and also previous years. The AI should be able to tell the farmers the type and variety of crop to plant at any point of time. The AI should have some advisory form of services on agroinputs. It must be able to inform those keeping ruminants and birds on the types of disease that would be prevalent at any point in time. What type of plant pest control should they use. Recommend harvest time and storage solutions. There are some basic key words the Ai should be able to use for proper communication.

With regards to the months in a year, there are little glitches there. Because Dagomba's use the lunar months whilst we also have the Gregorian calendar. So the first day of the Lunar month does not coincide with the first day of the month in the Gregorian calendar. But there are ways of describing certain months i.e Christmas is a particular month that is recognised, so you can say one month after Christmas, two months after Christmas and so on are bench marks that can be used by the Ai.

There are words in Dagbani that are gender related, gender neutral and the context can determine its meaning.

We also have homophones and homonyms in Dagbani that should be taken into consideration.

c.5 farmer group women presentation

c.5.1 *If you have the AI application, what are the likely questions you would as it?*

Answers: Will it rain the next couple of days? What is the pattern of rain for this evening? What is the weather condition for the day? How may times would it rain in a month? When would the rains stop?

c.5.2 *Do you have someone in the community, that you rely on for any information all that we have mentioned above?*

Answer: Yes. A trusted person (a husband, a friend or anyone that we have trust in) Based on what criteria would we ask these questions? The experience of the person

c.5.3 *Is the information received accurate?*

Answer: Some times accurate, sometimes not accurate. With respect to percentage, 50% accurate and 50% not accurate.

c.5.4 *Should the application give historical data i.e yesterday's weather forecast, would it be useful to the farmer?*

Answer: Yes

c.5.5 *Which other information should the machine give us?*

Answer: Livelihood advice, Market information, agro input information, harvesting period of crops, signs to know when it is time for harvest, live stock production information, an advisory on good agricultural practices

APPENDIX D - TIBALLI WORKSHOP GROUP QUESTIONS

Artificial Intelligence Group

1. Consider a speech system in Dagbanli that aids the work of our Agricultural Extension Agents in information dissemination to various communities
2. How do we build a solution that connects the last mile?
3. How will we handle the lack of training data?
4. How will our design cater for the fact that there are almost no smart-phones, bad GSM and very bad 4G?
5. How may our design leverage the use of smart-phones if we can circumvent the aforementioned challenges? (one smart-phone can possibly serve multiple people)
6. Can we consider Plug Computers like Raspberry Pi?
7. What tech stacks do we need to achieve this?
8. What are the series of steps needed to achieve our solution?

Farmer Group

1. Let's assume we have a system that can answer your questions; what three (3) questions would you ask? (act this out and let each farmer ask 3 questions)
2. Are there farmers in the community everyone relies on for;
   a) General Information
   b) Climate Information
   c) Information on when to plant
   d) Other information
3. If yes, is this information normally accurate?
4. If the system can only give climate information on what has already happened (e.g. yesterday there was heavy rain at Tingoli), would this still be a useful tool?

Linguistics Group

1. Imagine a Dagbanli speaking AI; how can we make it sound as natural as possible to native speakers?
2. Generate about 5 scenarios of people asking an AI for help in Dagbanli and write out the conversation

   e.g.
   Farmer: Ti Balli

AI: Hello, how may I help you today?
Farmer: Was there rain in the Ashanti Region anytime this last week?
AI: Yes. In the Ashanti Region, there was heavy rains on Monday and Wednesday, and light showers just yesterday

3. What would be a good keyword to activate it? (e.g. "Hey Google")?
4. What are the basic words that will by all means be used in a speak system?; words that are very common and appear in most conversations
5. Are there any nuances in these words we should be aware of?