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Master Thesis

Deploying ICT Services in South African Townships

an ICT4D approach

Author: Pieter Hoppenbrouwers (2599629)

1st supervisor: Anna Bon
daily supervisor: Melissa Densmore (University of Cape Town)
2nd reader: Hans Akkermans

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“What counts in life is not the mere fact that we have lived. It is what difference we have made to the lives of others that will determine the significance of the life we lead.”

by Nelson Mandela

Abstract

Context. South Africa in the post-apartheid era has found itself on the less fortunate side of the digital divide. This is especially evident in the South African townships, where affordable internet accessibility is a challenge, further disadvantaging its inhabitants and enlarging the digital divide. Ocean View is one of these townships, and is the pilot location for iNethi, a grassroots project serving low-resource environments by building community wireless networks aiming to provide affordable internet access to these disadvantaged communities.

Goal. With the installation of this network being technologically challenging, there is an assessed need to improve this process by means of designing and building an intuitive installer, and deploy this as an ICT service. In this thesis our aim is two-fold: to learn how to approach deploying an ICT service in a low-resource environment, and secondarily put this into practice by building, deploying and validating an ICT service: the iNethi installer.

Method. In order to approach the development process with structure, we conducted design science action research, during which we adopted the comprehensive ICT4D 3.0 framework in combination with user-centered design principles. These comprehensive frameworks have guided the development in various stages and are thoroughly applied and documented throughout this thesis.

Results. This has resulted in a software artifact: a cross-platform compatible and lightweight installer that delivers an intuitive experience and is more robust, efficient and effective than its bash-script based predecessor. Moreover and notably, the result has been successfully validated through the collection of feedback during multiple workshops.

Conclusion. In addition to successfully applying the ICT4D 3.0 framework, we have shown through successful validation that the produced artifact takes into account the contextual challenges and adequately addresses the needs and requirements. Notably this has resulted in not only the development, but also the successful validation and deployment of an ICT service.

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I hope to see iNethi flourish in Ocean View and other communities and make a difference.

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Introduction

The rise of the internet has dramatically reshaped our societies, providing individuals with unparalleled access to knowledge, information exchange, and digital services. However, the benefit and the potential of the internet isn't shared equally, resulting in what is known as the 'digital divide' (3). The digital divide represents the differences in access to, use of, or benefit from information and communication technologies (ICT) among various groups. This divide can exist between those living in rural areas and those in cities, between the educated and the uneducated, between socioeconomic groups, and between the developed and developing countries. The digital divide isn't just about access, but also includes the unequal ability to use and apply ICT and the internet for multiple positive outcomes (4). It includes disparities in physical access to technology as well as the resources and skills necessary to participate effectively as a digital citizen (5). Essentially, the digital divide covers a broad range of disparities that go beyond simple physical access, including factors like digital literacy, affordability, and societal attitudes towards technology adoption.

One of the countries that struggles with the digital divide is South Africa. In their context, the problems linked to the digital divide are severe and complex. Aside from global aspects of the digital divide, South Africa encounters unique issues that exacerbate the situation. One could argue that South Africa as a country is suffering from this digital divide, but within the country itself, there is a digital divide as well: a considerable part of the South African population lives in rural or underserved urban areas, where inadequate ICT infrastructure poses a significant barrier to internet access (6). These underserved urban areas house about half the population and are commonly referred to as townships (7). During the apartheid era, cities were made exclusive for white people, and nonwhite citizens were forcibly removed from their urban houses and assigned to live in residential areas outside of the city; townships. In contrast to cities, the townships had and still

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don't have a good infrastructure. Roads, electricity and sewage are improvised, and cable internet and TV is virtually non-existent. Now that we are in the post-apartheid era, one would expect that the black population has reintegrated into the urban culture. However, in practice, the city still remains the home for the white South African. Although cities have seen black people move back into the city, the opposite is sadly not true: townships remain a place for the black community.

Moreover, the high cost of internet services compared to income makes it unaffordable for a large segment of the population living in township. Less directly related but of certain substantial influence are the contextual challenges South Africa is facing, which include high rates of crime, poverty and unemployment, educational inequalities, and limited resources for ICT training and skill development. More socio-economically related and deeply embedded challenges include the quality of infrastructure and the political situation, which in recent years has seen a trend towards decline, troubling not only the deployment of ICT solutions, but also causing a potential shift in development priorities. These elements collectively impede the possibility for digital inclusion, signifying an urgent need for innovative solutions to bridge this divide.

Community Wireless Networks (CWNs) have emerged as a promising solution to address this digital divide, aiming to democratize access to the digital world by providing affordable, community-managed internet access (8). CWNs are essentially grassroots initiatives wherein communities deploy and manage their own locally-owned infrastructure for communication and internet access (9). These networks aggregate demand at the community level, allowing residents to purchase internet services at bulk rates. CWNs effectively bypass the traditional internet service providers (ISPs), who may lack the incentive to improve infrastructure in economically less viable regions (10). Particularly in the context of the Global South and more specifically South Africa, CWNs hold substantial promise. The principles of local and communal ownership and control, a key aspect in CWNs, align well with the socio-cultural background of many communities in these regions. By leveraging local resources and fostering local innovation, CWNs can effectively bypass the infrastructural and economic barriers that hinder internet access in these regions (9).

The iNethi project is a pioneering initiative in South Africa, embodying the principles of CWNs to bridge the digital divide (11). The flagship deployment in Ocean View, a township in Cape Town, serves as a testament to the transformative potential of community-managed internet access. iNethi provides the community with tools and platforms to manage their own internet infrastructure, enhancing local communication, and fostering digital content creation. By doing so, it empowers residents to leverage the internet's vast

potential. Furthermore, iNethi is not just about providing internet access but also about nurturing a digital ecosystem within the community. It facilitates the sharing and authoring of local digital resources and services, encouraging community members to create local content and build locally hosted apps and services. This aspect of iNethi is particularly significant, as it enables the community to maximise the potential of their internet access, further narrowing the digital divide. In this thesis we will contribute to the existing iNethi project and use it as a case study to perform Design Science and Action Research, on which we will elaborate in section 1.3.

1.1 Motivation

The deployment and management of a CWN such as iNethi is a nontrivial task, especially considering the technical complexities and user literacy level. Traditionally, the installation and configuration of iNethi involved the use of a bash installation script with command-line prompts. This non-intuitive approach to deploying the system was rather error-prone, and difficult to recover from or debug when gone wrong. This is complicated by iNethi architecture, consisting of various open-source services, each running in its own secure Docker container¹. These services include both network management services, such as a reverse proxy² for service-routing or currency voucher management services, as well as content providing services. Together they create the iNethi system. iNethi leverages the benefits of service containerization for their system: isolation, portability and scalability of services contribute to enhancing the overall security, robustness and flexibility. Nevertheless, the deployment and orchestration of these multiple containerized services require a high degree of technical knowledge. This is further complicated by the counter-intuitive command-line interface of the bash installation script, which requires users to understand and execute specific commands and prompts in a terminal environment.

Although this method is efficient and suitable for an audience with substantial ICT skills, it presents a significant challenge in communities with lower levels of digital literacy (12). This issue of digital literacy exacerbates these deployment challenges. Digital literacy extends beyond the capability to use digital devices and access the internet; it encompasses the skills required to find, evaluate, create, and communicate using digital information (5). Consequently, the existing deployment mechanism, relying heavily on command-line interfaces and bash scripts, places an undue burden on users with limited digital literacy

¹<https://docs.docker.com/>

²<https://www.nginx.com/resources/glossary/reverse-proxy-server/>

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who are looking for an entry-level solution. Together, these limitations make the adoption of iNethi a significant challenge for such communities. Therefore, addressing this troubled deployment procedure forms the core motivation for this thesis.

The solution to the stated problem lies in moving away from the bash script to a more intuitive, less error-prone, better accessible and easier to maintain solution. Adopting a GUI on the front-end provides a more intuitive, interactive, and user-friendly installation process. It streamlines the user experience by abstracting complexities and providing error detection through user prompts and feedback messages. GUIs are richer than bash scripts, in that they can provide visual feedback, help, tips, and more context than a simple terminal. The user experience becomes interactive, intuitive, and less error-prone as validation checks can be incorporated at each step, reducing user-induced errors. Users don't need to have specialized knowledge in command-line interfaces, lowering the technical barrier and required digital literacy level.

1.2 Research Questions

This thesis aims to answer the following main research question:

How to deploy ICT services in low-resource environments, specifically in South African Townships?

To approach the main research question comprehensively, we break it down into the following sub-questions:

1. *What are the specific challenges and constraints encountered when deploying ICT services in low-resource environments?*
2. *What is the best approach to design and deploy an ICT service in a low-resource environment in a sustainable way?*
3. *What ICT solution uses this approach and satisfies the encountered constraints, and how do we design this solution?*

The answers to these sub-questions will together provide the basis for the solution proposed in this thesis.

1.3 Method

The approach towards the design of the GUI installer is rooted in the principles of user-centered design (UCD) and context-aware development using the ICT for Development Service Design 3.0 framework, both of which are particularly relevant when designing applications for low-resource environments. Combined, we will categorize and refer to them as Design Science and Action Research. As will be explained in this section, these frameworks have been influenced by the constraints posed by the fact that the artifact is produced within a pre-defined system context. It should be noted that the key contribution and the learning of this thesis does not come from the development of the GUI installer itself, but from the Action Research in combination with the Design Science Research, that has provided a unique experience and was instrumental in guiding this research.

UCD is an iterative design process in which designers focus on the users and their needs in each phase of the design process (13, 14). UCD involves multiple stages of design and evaluation, incorporating user feedback at each step to refine the design until it effectively meets the end-users' needs. It could be argued that the ICT for Development Service Design 3.0 framework proposed by A. Bon et al. (12) essentially drills down on UCD, and tailors it to a low-resource context. The framework provides extremely detailed guidelines on how to approach the development of a variety of aspects present in the cycle of designing an ICT solution in such environment. The framework is comprised of five 'components', rather than 'phases', the writers argue, as they heavily interact and rely on one another, and is depicted in Figure 1.1. The components are: context analysis, needs assessment, use case and requirement analysis, sustainability assessment and development, testing and deployment strategies. This context-aware development approach ensures that the GUI installer is tailored to the constraints and realities of low-resource environments, such as unreliable power and internet access, and the reality of a high degree of digital illiteracy (5). This involves making conscious design and technology choices, such as using lightweight yet highly-compatible frameworks and offline-first strategies, to ensure the application remains functional and accessible despite these constraints, as we will see in Chapter 5.

The guidelines combined that entails Design Science and Action Research are useful tools when approaching the core problem of this thesis, as they align with the environment and cover all the steps involved into designing an ICT solution. It should however be noted that in the case of the iNethi project, we are not designing a solution from the ground up in an unconstrained setting. We are rather iterating on a component (the deployment, or installer) of an pre-defined system. This ties us to the environment and architecture

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Low-resource aware framework for development of ICT4D services		
Components	Possible methods	Techniques & tools
Context analysis	Action research Roadshow Literature review	Field visits Focus groups Demos Interviews
Needs assessment	Field research Collaborative workshops Participatory rural appraisal (PRA model suite)	Field visits Focus groups Demos Interviews
Use case & requirements analysis	Use case modeling Requirements elicitation Agile Development Methods	Demos & focus groups Rapid prototyping Conceptual modeling
Sustainability assessment	Functional evaluation Business case evaluation Technology assessment Scenarios	Interview, focus groups E3 Value modeling Dynamic systems conceptual modeling
Developing testing, deploying	Living Labs Agile Development Methods User-centered evaluation	Demos & focus groups Prototypes

Figure 1.1: Framework for ICT4D Service Development with five components, with related methods and tools (12)

of the existing iNethi system, and poses limitations on the approach towards redesigning this component. The negative connotation often experienced when mentioning limitations could however also be approached from a different perspective: dealing with a partially-predefined set of practices and technologies scopes the available selection of tools and approaches, making the selection procedure less difficult. The development of the GUI artifact produced in this thesis is a result of a cumulative endeavour where developers who have contributed to the iNethi project in the past have been consulted on a regular basis, in order for the artifact to adhere to the practices and fundamental architecture they set out, consequentially performing optimally.

The main guideline when structuring this thesis however have been the five components of the ICT for Development Service Design framework, which have been applied throughout the design process of the artifact proposed in this thesis, and will come forward in the following sections in various ways and to varying degrees. Chapter 2 will provide the context analysis. Chapters 4-6 will discuss the needs assessment and use case and requirement analysis. The sustainability assessment and the application of the development, testing and deployment strategies will come forward in chapters 6-8.

1.4 Contribution

In the upcoming chapters we extensively discuss details of the developed GUI installer for iNethi. The choice of the technologies used are thoroughly justified and their role within the installation process is explored. Also the integration of these technologies within, and their relation to the iNethi system is explained, providing insights into the decisions that have guided the development process. We contribute by expanding on the design and implementation of the GUI installer, showcasing the strategies employed to create an intuitive and accessible interface. This includes the application structure, the mechanisms used for configuration input collection, and the transfer of this data to Ansible playbooks. The subsequent chapters comprehensively evaluate the developed GUI installer by reflecting on the methods used and measure the system's performance. During the validation process we delve into the workshops having enabled this process, and discuss the insights they yielded. More specifically, we will demonstrate the iNethiRadio service as a proof of concept during one of these workshops to validate the installers effectiveness and usability, concluding the development cycle. Towards the end we present the result in the form of an artifact, and discuss the overall implications for the iNethi project.

The main contributions of this thesis include:

1. A user-friendly, intuitive GUI installer for iNethi that drastically lowers the barrier to entry for users with varying levels of digital literacy and is validated by the intended user group. This is our primary general contribution, as this artifact should be considered the main deliverable of this thesis project.
2. A successful validation of the performance and effectiveness of the developed installer, providing valuable insights for further development and implementation.
3. An evaluation of the methods used in the process of designing and implementing the developed installer, providing valuable insights for future research.
4. An examination of how technology choices and design decisions can significantly impact the usability and accessibility of a tool within a community wireless network context. This is our primary research contribution and enables us to answer the main research question.

Collectively these contributions offer the solution to the problem stated in the motivation section of this Chapter. The next chapter discusses the methods used in the process

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of designing and implementing the developed installer. After that, we move on to the background chapter, where we provide a comprehensive overview of the various contexts related to this thesis. This is also where we discuss the first component of our service design framework: the context analysis. Further, we dive into the birth and the core concept of community wireless networks, and provide a background of the existing iNethi deployment state; all key aspects to this thesis, contextualizing the core problem and the subsequent design and implementation of the GUI installer.

In chapter 2 we will further discuss the background of the iNethi network. In Chapter 3 we will dive into a literature study on CWNs and present the findings and discuss how we can leverage them for our research. Then, in chapter 4 we will provide an expansive overview of the inner workings of iNethi, gearing up for the solution proposed solution in chapters 5 and 6. Chapters 7 and 8 reflect on the method used in the design and implementation process and validate the effectiveness of the artifact by discussing workshops.

2

The Complex Context of South Africa and its Digital Divide

2.1 Context

This section sheds light on the general, deployment and development related context in which this thesis took place. These three contexts contribute to the general context analysis and individually hold significance in setting the stage for Chapter 5 where we discuss the design. The context will relate to constraints encountered during design and development and account for certain design choices made based on these constraints.

2.1.1 General Context: South Africa

South Africa has a complex socio-economic landscape, with a history that has profoundly shaped the country's present. Although the country has made substantial progress since the end of apartheid, numerous challenges still remain, greatly affecting the livelihoods of its citizens and inhibiting social and economic development.

Ranging to the highest levels of South Africa's bureaucracy, the nation is troubled by pervasive corruption in their political system, impeding the country's development in numerous ways (15). Systemic corruption in both public and private sectors not only diminishes trust in government and institutions but also hinders economic growth, and drains resources from essential public services, and exacerbates inequality. This has resulted in numerous challenges, with a heavily disturbed and troubled economy as a result. Consequently, this has led to a alarming high unemployment rate, especially among the youth, represents another pressing challenge. Official numbers remain questionable, but go up to an unemployment rate of 32,9% (16). This widespread unemployment fuels social tension,

2. THE COMPLEX CONTEXT OF SOUTH AFRICA AND ITS DIGITAL DIVIDE

exacerbates poverty, and contributes to the ongoing socio-economic disparities. For these unemployed individuals, the inability to afford and access digital resources further deepens their social and economic marginalization. This, in turn, has had a strong impact on crime, of which the numbers have also gone through the roof. The effects of this are widely spread and everyday noticeable throughout the country, and include theft, robberies and violence, requiring extensive security measures for those who can afford it.

Townships in South Africa bear the brunt of the discussed negative aspects, facing the most severe impact of the country's complex socio-economic challenges. Pervasive corruption in the political system not only undermines trust in institutions but also exacerbates inequality and hinders economic growth, disproportionately affecting the already marginalized communities living in townships. The alarmingly high unemployment rate, particularly among the youth, intensifies social tensions and deepens poverty, with townships being hit hardest by the resulting socio-economic disparities. Moreover, the inability of many township residents to afford and access digital resources further isolates and marginalizes them in an increasingly digital world. The reliance on cellular connectivity for internet access amplifies the challenges, with expensive data costs rendering internet services unaffordable for many township inhabitants. As a result, the digital divide in South Africa is not merely a technological issue but also a socio-economic one, reflecting the wider context of the country's ongoing struggles.

2.1.2 Deployment Context: Ocean View, Cape Town

Ocean View, located in the Southern Peninsula of Cape Town, is an example of one of the many townships across South Africa grappling with the effects of these socio-economic challenges. Established in 1968 during the apartheid era, Ocean View was originally conceived as a community for individuals classified as "Coloured" under apartheid laws. They were forcibly removed from their homes in Simon's Town, Noordhoek, Red Hill, and other areas around the Southern Peninsula, and relocated to Ocean View (17). Ocean View is now home to an estimated population of 20,000 people, living primarily in low-income households. The township is marked by high unemployment rates, crime, and limited access to resources. (2).

The only publicly accessible internet service, not being Wi-Fi, is available at the local library. Usage is limited to 45 minutes per day per user, and users need to procure vouchers before they can access the library's computer facilities. Not surprisingly therefore, most community members access the internet via cellular connectivity. Both GSM and UMTS networks cover Ocean View fairly well, but there is very limited LTE coverage, as it is

currently in the early stages of deployment. The majority of users use prepaid mobile plans and purchase airtime or data bundles from local shops or shopping malls (2). And these are expensive: according to the World Bank, townships and informal settlements are home to half of South Africa’s urban population, representing 38% of its working-age citizens, and nearly 60% of the unemployed reside there (18). In Khayelitsha for instance, one of Cape Town’s poorest townships, the median monthly income for a family of five is around ZAR 1600, or USD 110 / EUR 100¹. This same research has shown that the average monthly spending on mobile data can range from ZAR 100-200 per user. Given their limited income and these high costs, many users may find mobile data unaffordable.

Relevant to our research context, this underdeveloped infrastructure and high data costs have resulted in the lack of reliable and affordable internet access in Ocean View. Naturally, this has made the community’s access to digital resources more difficult, such as educational materials, employment opportunities and social networks. It is in this context that the need of a Community Wireless Network (CWN) like iNethi emerges. As we will further expand on in the next section and aim to demonstrate throughout this thesis, CWNs can be a lifeline for communities like Ocean View. Once connected to the network, users can buy a gigabyte at a very competitive price: R20 a gigabyte. This makes them at least five times cheaper than the cheapest one-gigabyte data bundle offered by South African mobile service providers (2, 19). This is an example of how community wireless networks offer an affordable means of access to the internet and digital resources, which without doubt is vital for socio-economic empowerment in townships low-resource environments like Ocean View, contributing to narrowing the digital divide.

2.1.3 Development Context: University of Cape Town

Providing background on the environment where the research for and the development of the artifact produced took place is highly relevant to this thesis as a whole, as it hold value for future research, dealing with contextual problems and adopting appropriate solutions to them. Also, this is where the context analysis starts.

The iNethi project is primarily lead by Keegan White, the recently assigned director of iNethi Technologies, as the company is officially called. White is a University of Cape Town Computer Science alumnus, who’s dissertation project context was iNethi. After graduating, he decided to take part-time responsibility for the iNethi project. At the time, and still, the project is supervised and co-coordinated by Melissa Densmore, a HCI

¹Note: Research data and therefore exchange rates from November 2016.

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and ICT4D professor at the University of Cape Town (UCT). Today, the UCT Computer Science department is still heavily involved in the project. Prof. Densmore assigns students to various tasks related to the iNethi project, who report back to her. During bi-monthly meetings with White and other stakeholders, progress is discussed and students initiatives are presented. This is an ongoing endeavour. It should be noted however that none of this is strict: the number of students working on the project varies and the meetings are loosely planned.

The students work in and around the Human-Computer Interactions Laboratory at the Hasso Plattner Institute, a building located on middle campus on the University of Cape Town grounds. Here, students are assigned a desk and come in daily to work on the project in a collaborative manner. Moreover, they meet on Thursdays for a weekly progress update. This fosters collaboration and creativity, both important aspects when designing a community owned artifact.

On a more social note, it should be mentioned that there are certain noteworthy 'tensions' when it comes to the interactions between the University of Cape Town and the Ocean View community members. As the inequalities between the member of the iNethi team and the Ocean View residents are substantial and given the fact that the research is situated in South Africa in the post apartheid era, there are still some social tendencies that remain. The intentions from the University of Cape Town are nothing but to help and assist, and the members involved in the iNethi project are aware of the social tendencies and history, and are strictly instructed to tread socially careful when it comes to interacting with the community members as the relation they have with them are a result of years of effort. This includes and is formalized by the ethics clearance that is required when hosting workshops, and ensures that the community members are protected of social undesired behaviour.

As the process of developing and co-creating on the iNethi project in a deployment stage is a rather unique experience, we dedicated a full section to this where we further dive into a more personal experience, which details lessons learned and holds significant value for future researchers as it includes non-trivial experiences with non-trivial workarounds. This can be found in Chapter 9.



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2.2 Community Wireless Networks

The birth of Community Wireless Networks (CWNs) can be traced back to the late 1990s and early 2000s when communities began to experiment with the early stage Wi-Fi technology to provide local, affordable, and accessible internet connectivity (20). Since, communities in both the Global North and South have been developing CWNs in a variety of ways, using numerous combination of hardware and software to unlock their potential. CWNs are decentralized, community-based initiatives that provide internet connectivity at a local level. These networks are typically created, maintained, and governed by the communities that they serve, utilizing low-cost, commercial off-the-shelf (COTS) hardware and open-source software (21). In many cases they employ a mesh network topology, where each node in the network connects to multiple other nodes, creating a flexible, robust and resilient infrastructure. In the Global South, CWNs have emerged as a response to the lack of infrastructure and affordable internet access, and they have played a critical role in bridging the digital divide.

CWNs provide numerous benefits. First and foremost, they democratize internet access, making it available to communities that are often overlooked by commercial ISPs due to their low economic potential or challenging geographical locations (21). As we have just seen, by leveraging shared resources and collective buying power, CWNs can provide access to internet services at lower costs than conventional ISPs. The fostering of local content creation and community engagement is another benefit (22), as CWNs allow for hosting local servers to provide community-oriented services and promote the exchange of local knowledge, bringing down the commercial data consumption, hereby reducing costs. This encourages residents to become active creators and contributors rather than passive consumers of content, thus enriching the local digital ecosystem. Another aspect harnessing community empowerment are the education, healthcare, and government related services. These can create an environment enabled for local entrepreneurship and foster community development.

As stated before, CWNs are reliant on the technical skills and commitment of community members for their operation and maintenance. This can be a significant barrier in communities where digital literacy levels are low (5). Nonetheless, with the appropriate support, adaption and training, CWNs have the potential to transform digital access in marginalized communities. In the next Chapter we will take a closer look into the inner workings of a CWN and delve deeper into the Community Wireless Network of our research context: the iNethi project.

Related Works: A Literature Study on Community Wireless Networks in the Global South

This section presents an overview of the existing literature on CWNs as found in our literature study (21), which focuses on the state of software deployment, the tools and technologies used in these deployments, and the challenges encountered. Additionally, we discuss the key takeaways from the literature study, which can guide the approach and contribute to our software design. Note that the study primarily targets CWNs in the Global South, as these are most relevant to our research.

3.1 Software Tools and Technologies Used

The literature study revealed that CWNs predominantly rely on open-source software due to its cost-effectiveness and flexibility in deployment. The study moreover identified several software tools and technologies used in CWN deployments. Containerization and orchestration tools like Docker and Kubernetes are commonly employed to ensure efficient deployment and management of applications. These technologies enhance scalability and reliability, making them highly recommended in the deployment process. The use of open-source software ensures community support and flexibility, but compatibility and interoperability challenges need to be addressed to ensure successful deployment.

3. RELATED WORKS: A LITERATURE STUDY ON COMMUNITY WIRELESS NETWORKS IN THE GLOBAL SOUTH

3.2 Challenges in Deploying Software in CWNs

Challenges encountered in CWN deployments encompass technical, socio-economic, and regulatory aspects. Technical challenges include hardware limitations and software interoperability, while socio-economic challenges are characterized by digital literacy and economic constraints in the communities. Regulatory hurdles, such as licensing and data privacy, also impact software deployment. A noteworthy finding from the study is that economic constraints significantly influence the nature of challenges encountered in CWN deployments.

3.3 Guiding Principles for Designing Software for CWNs

Based on the findings of the literature study, the following guiding principles are suggested for designing the software architecture of CWNs:

1. **Embrace Open-Source:** The use of open-source software offers several advantages, such as cost-effectiveness, flexibility, and community support. However, addressing potential challenges related to compatibility and interoperability is essential to ensure successful CWN deployments.
2. **Consider Local Contexts:** Technical, socio-economic, and regulatory considerations should guide software deployment decisions. Understanding the local digital literacy levels, economic constraints, and regulatory environment is crucial in tailoring software solutions to the specific needs of the community.
3. **Prioritize User Needs** User-facing applications and the overall CWN should be designed with the specific needs and contexts of the local community in mind. By adopting and adapting these applications correctly, CWNs can empower the community and bridge the digital divide effectively.
4. **Employ Modern Deployment Technologies:** The use of containerization and orchestration tools in the deployment process ensures efficient management of applications, leading to improved scalability and reliability.
5. **Documentation and Sharing:** Comprehensive documentation and sharing of software design, including updates to the infrastructure, play a vital role in learning from

3.3 Guiding Principles for Designing Software for CWNs

successful and failed approaches in CWN deployments. This documentation facilitates the development of future CWNs, enabling continuous research and innovation in the field.

The literature study revealed both immense opportunities and significant challenges. Open-source software and modern deployment technologies offer flexible and scalable solutions, while considerations of local contexts and user needs are critical for the successful adoption and usability of CWNs. It was concluded that by addressing challenges related to technical, socio-economic, and regulatory aspects, CWNs have the potential to empower local communities and democratize internet access.

This study is extremely helpful in our case as it aims at setting a standard with respect to deploying CWNs and provides guiding principles for approaching the deployment of software within CWNs. In Chapter 4 we will see that the current iNethi system has many similarities to the recommended software and deployment tools recommended in this literature study. The guiding principles furthermore stress that considering local contexts and prioritizing user needs are instrumental in developing sustainable software, which is extensively taken care of throughout our research. Last, they argue that there is a lack of documentation and sharing, both in terms of specific documentation and in general approaches: this thesis is a first step in the right direction as it aims at documenting both the technical aspect of this research, as well as the lessons learned throughout, providing valuable information for future practitioners designing software for Community Wireless Networks.

3. RELATED WORKS: A LITERATURE STUDY ON COMMUNITY WIRELESS NETWORKS IN THE GLOBAL SOUTH

4

iNethi: A Background of the Case Study of a Community Wireless Network Deployment

4.1 A Project Overview

iNethi, meaning "in the network" in Xhosa, one of South Africa's twelve official languages, is a community-driven open-source project¹ founded by the University of Cape Town in collaboration with the Ocean View community. Its primary goal is to deliver internet to the underprivileged. iNethi allows communities to quickly bootstrap a community-built ISP in underserved areas. So far there have been multiple deployments, although to date, none of them are as significant as their flagship deployment in Ocean View.

The deployment of iNethi in Ocean View in was initiated by a group of researchers, developers, entrepreneurs, and community activists from Ocean View in a careful four-step process. Firstly, the iNethi team, in collaboration with the University of Cape Town, conducted extensive community surveys and meetings to identify the connectivity needs and internet usage patterns of the community. The second phase entailed conducting workshops to understand the community's vision and outline the requirement. A common requirement was a platform for affordable content sharing, a crucial aspect for educators, musicians, and businesses. With these inputs, the team moved to the third stage: building services on the iNethi platform and co-creating content. Initial offerings included decentralised social networking, file-sharing applications, and an instant messaging service, among others. The

¹<https://github.com/iNethi>

4. INETHI: A BACKGROUND OF THE CASE STUDY OF A COMMUNITY WIRELESS NETWORK DEPLOYMENT

fourth step focused on making tools available to run publicly as a network. A cooperative called OVCOMM (now Black Equations) was formed in Ocean View to manage these resources, eventually evolving into a community-owned commercial ISP.

The general motivation behind iNethi is to empower communities to take control of their infrastructure and data and provide affordable internet. It serves as a starting point for digital self-sufficiency, encouraging communities to provide their own internet connectivity, host their own digital platforms, and create and share locally relevant content. This model not only mitigates the high costs of mobile network internet access but also avoids the need for services from large tech companies. Through iNethi, communities are enabled to harness their talent and capacity for local digital growth and economic development.

All this is supported by its open-source nature: iNethi allows anyone to contribute to the project, and have communities tailor the system to their context's needs. This is a rather unique property in the CWN landscape, and was in part motivated by the results from a research by Moreno et al. (23). This research has shown that among the 30 CWNs researched across Africa, the majority of the contributors of these networks was not aware of the development of similar projects. The research consequentially concludes that there is a need for a more collaborative environment in which CWNs are able to empower one another. This has been key in the motivation behind creating the iNethi CWN. Since its birth, students from the University of Cape Town, for instance, have actively participated in the expansion of iNethi, leading numerous postgraduate projects focused on iNethi, with the university's so called Developers' Society recruiting members to participate actively in iNethi's development.

Today the iNethi project provides various services to the Ocean View community, such as e-learning platforms, streaming services for locally produced content, chat applications, and a community currency system. The latter is a particularly innovative feature, as it allows residents to earn digital credits for participating in network maintenance and local content production, which can be used for purchasing internet access or traded for goods and services within the community. In chapter 6 we will have a brief glance at each of these services.

Although the project has encountered several challenges, iNethi has made significant strides in its mission to bridge the digital divide in the Ocean View township, and is set to play a leading global role in open-source Community Wireless Network development thanks to its unique open-source approach. The next section will delve into the technical details concerning the iNethi network.

Computer Science Lab
Ocean View Secondary School
Ocean View, Cape Town



4. INETHI: A BACKGROUND OF THE CASE STUDY OF A COMMUNITY WIRELESS NETWORK DEPLOYMENT

4.2 The iNethi Platform

In this section we will discuss the iNethi platform as a network, and delve into the key components of a iNethi server. For the network we will examine the topology and hardware and software used in their flagship deployment in Ocean View. Next, we will be taking a closer look at the iNethi server and examine the fundamental software architecture and network software and configuration. Together, this will lay the foundation, and define the contextual limitations and software constraints, which we will use when designing our installer in Chapter 5.

4.2.1 Network

This subsection will provide an overview of the Ocean View’s network topology, the hardware and software used, and explain how the iNethi platform powers it. Then, we will give a brief explanation of how the network is managed.

4.2.1.1 Hardware

The iNethi network is typically built with the use of the following components: a modem connected to the internet, a pfSense/OPNsense firewall and router and a managed switch which connects both to the iNethi server and the network access points. This setup is depicted in Figure 4.1.

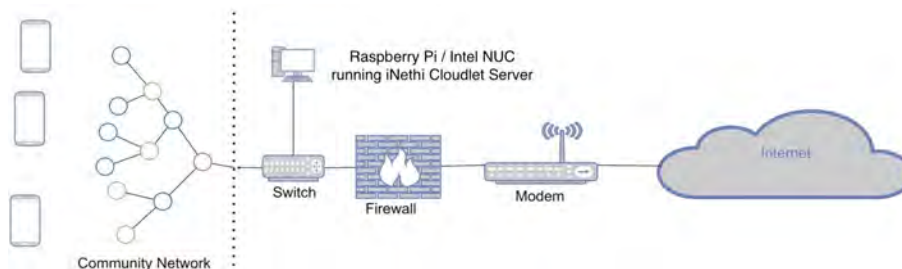


Figure 4.1: Network architecture of a typical iNethi deployment (1)

4.2.1.2 Software

At the heart of the iNethi network infrastructure lie Libremesh-based WiFi access points, deployed throughout the community. Libremesh, the open-source firmware that drives these access points, is built upon OpenWRT, a versatile firmware designed for embedded

systems like residential gateways and routers. Within Libremesh, two mesh protocols operate: B.A.T.M.A.N. (or BATMAN-ADV), a layer-two protocol, and BMX6, a layer-three protocol. B.A.T.M.A.N. is particularly well-suited for smaller mesh clusters, facilitating user roaming between access points without loss of connectivity. In the case of iNethi, given the relatively small scale of the network, traffic is primarily routed over B.A.T.M.A.N. However, as the network is set to grow, additional layer-two cluster might form, and BMX6 will manage the routing between these clusters. This layered approach to routing supports the network's scalability, especially as more inter-cluster links are established via dedicated radio links. In terms of backhaul, the iNethi network employs a combination of television white spaces (TVWS) and WiFi mesh networking. This setup guarantees resilient and robust connections, with mesh networks being chosen for their straightforward set-up and self-healing attributes. When any radios within the network fail or lose power, these mesh networks self-adjust, ensuring uninterrupted connectivity.

4.2.1.3 The Glocal Architecture

A remarkable feature of the iNethi architecture is its so called glocal (global + local) property. As the iNethi server is connected to the internet, the iNethi services can communicate with external, other iNethi deployments. Services such as NextCloud, a open-source file sharing service we will discuss in the next section, can use this connection to synchronize files with other iNethi networks. This allows for a greater library of (community-adapted) material, enriching the contents of each deployment. Note however that since this process uses the global internet, data costs are charged. Once downloaded to the local deployment however, this data becomes accessible for free to the community members. This is one of the many ways the iNethi platforms aims to implement data saving methods and foster content sharing and creation. Besides other iNethi deployments, this data could be synchronized with the 'master' iNethi cloud instance, deployed at Amazon Web Services, which primarily serves as a publicly accessible version of the iNethi system to showcase its services. This cloud instance is publicly available and its splash page (homepage) is available [here](#). See Figure 4.2 for the AWS Cloudlet server architecture and note its direct connectivity to the internet as we will compare this to a local server architecture in the next section.

4. INETHI: A BACKGROUND OF THE CASE STUDY OF A COMMUNITY WIRELESS NETWORK DEPLOYMENT

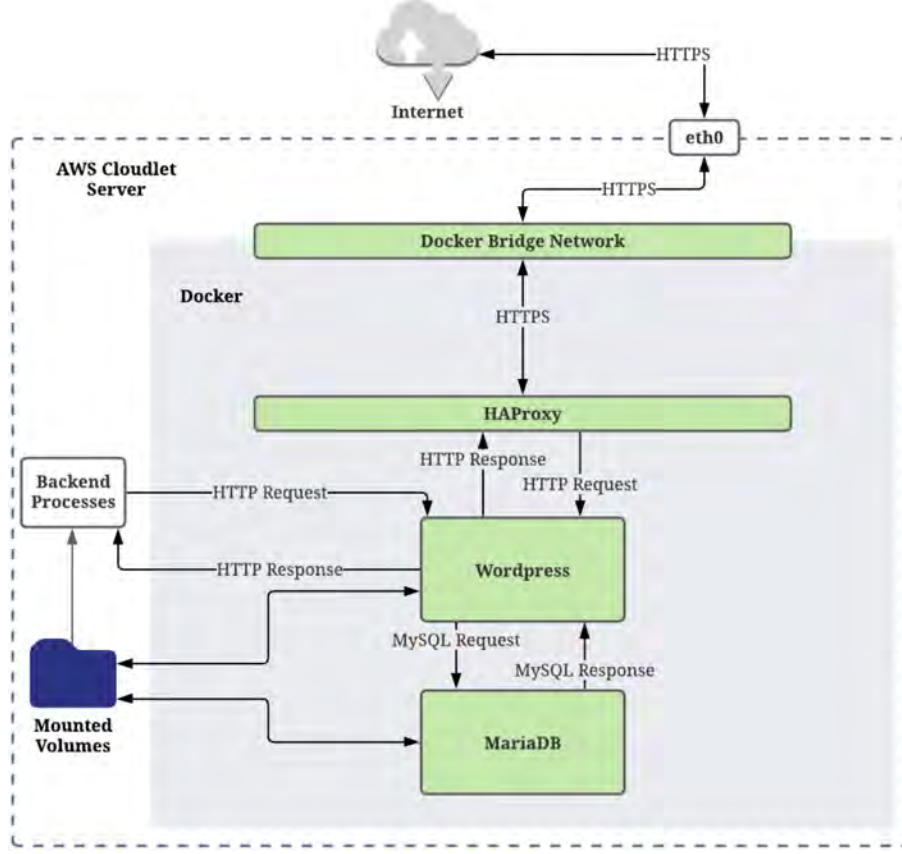


Figure 4.2: Architecture of the AWS cloudlet server (2)

4.2.1.4 Management

As the iNethi network entails a vast collection of hardware, this must be actively managed. Moreover, as the platform runs on a centralized server connected to the network infrastructure, this has to be physically located in the community, and in-line with the ICT4D co-design principles (12), and be therefore managed by a community member. For the Ocean View deployment, this is at the Computer Science Lab at the Ocean View Secondary School, and is now managed by the aforementioned company Black Equations.

4.2.2 Server

In this subsection we will briefly give the recommended minimum requirements a for system of variable size. Primarily however, we will focus on the software powering the iNethi core system. Moreover, we will discuss what services are available and how they are managed using Traefik. Finally, we will take a closer look at one service in particular, our proof-of-

concept service: iNethiRadio.

4.2.2.1 Hardware

An iNethi system can run on a variety of hardware. During development and testing we use and therefore recommend using an Intel NUC¹ with at least an i5 processor, 16 GB of RAM, and a 1TB SSD drive (for a medium system supporting up to 50-100 users) or a small Intel Atom-based minicomputer with at least 8 GB of RAM, and a 250GB SSD drive (for a small system supporting up to 10 users). Any AMD64 based system can be used however, and ARM64 is supported for most services. We will expand on this in Chapter 6.

4.2.2.2 Software

Starting of with the OS, the iNethi project prefers Unix-based operating systems, with Ubuntu Server 22.04 LTS² being the recommended choice. This is due to its open-source nature, which not only aligns well with the iNethi philosophy, but also offers a high degree of customization and transparency, both welcome attributes when designing open-source software. Additionally, Ubuntu's strong compatibility with Docker, the containerization platform central to iNethi, bolsters the efficiency of service development and deployment. Although Ubuntu Desktop is also a viable option, Ubuntu Server is preferred for its resource efficiency, a vital attribute for the iNethi ecosystem.

Now, iNethi is structured around a combination of Docker³ containerized services. Docker containers encapsulate software into standardized units for development, shipment, and deployment, simplifying the process of managing and scaling the services across the network. This approach allows the network to scale with the community's needs and empowers the local community by making the technology more accessible and manageable. Most importantly, as proposed and demonstrated by (2), this containerized approach now allows for bootstrapping services, enabling contributors to develop and deploy services onto the network with relative ease, marking a significant improvement over the original HAProxy⁴ architecture.

¹<https://www.intel.com/content/www/us/en/products/details/nuc.html>

²<https://releases.ubuntu.com/jammy/>

³<https://docs.docker.com/>

⁴<https://www.haproxy.org/>

4. INETHI: A BACKGROUND OF THE CASE STUDY OF A COMMUNITY WIRELESS NETWORK DEPLOYMENT

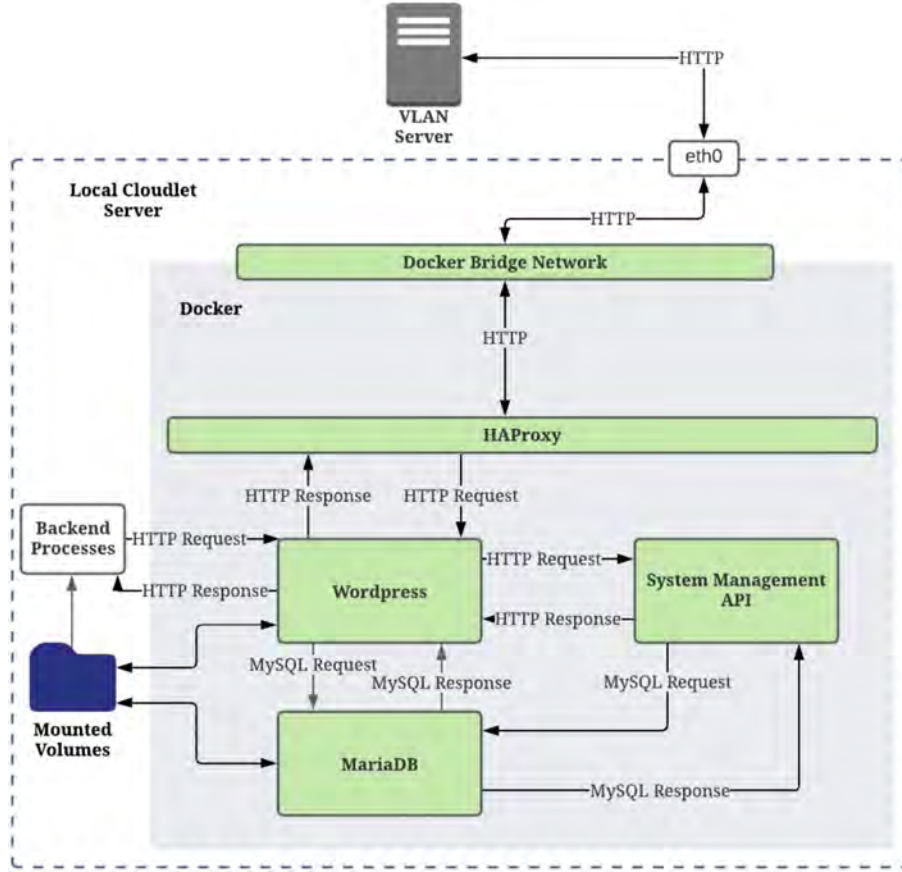


Figure 4.3: Architecture of the the iNethi cloudlet server (2)

4.2.3 Services

Once installed, user can start installing services onto the iNethi platform and seed these services with community relevant content. This is a key aspect of the iNethi platform, adding significant value to the CWN. These services are essentially a collection of pre-configured Docker containers. Before the installer was developed, a bash script would use a Docker-compose file to pull the Docker image and set it up according to the configuration specified in the Docker compose file. Many of the services offered on the iNethi platform rely on the presence of other fundamental services, and often require multiple images to be pulled and configured in a single session. This has been experienced to be a vulnerable process due to a key disadvantage of bash scripts: in case a single error occurs, the script fails, and the system is left with partially installed services. Adding that there is no or very limited user input validation to this, and the installation is extremely prone to failure.

Name	Required	Description
Traefik ¹	Yes	An open-source Edge Router that automatically manages HTTP and TCP routes.
Nginx ²	No	A web server for displaying a splash page for iNethi service selection.
Keycloak ³	No	Provides single sign-on with identity and access management for iNethi services.
NextCloud ⁴	No	Enables local cloud-based file hosting similar to Dropbox and Google Drive.
Jellyfin ⁵	No	Acts as a media server for videos and music with account-based user access.
PeerTube ⁶	No	A federated video platform for content dissemination and user engagement.
WordPress ⁷	No	A content management system for local network webpage creation.
Payment and User Management	No	An iNethi service providing payment systems, service access, and user management.
RADIUSDesk ⁸	No	A web-based hotspot manager for network users, vouchers, devices, and mesh-setups.
AzuraCast ⁹	No	A self-hosted, all-in-one web radio management suite.

Table 4.1: Overview of available services on the iNethi platform

4.2.3.1 Traefik

As describing the functionalities of each of these services is out of scope for this thesis, we do want to note the first required service: Traefik. The iNethi platform employs Traefik as its reverse proxy¹⁰, which is an integral component of the network's service

¹<https://doc.traefik.io/traefik/>

²<http://nginx.org/en/docs/>

³<https://www.keycloak.org/documentation.html>

⁴<https://docs.nextcloud.com/>

⁵<https://jellyfin.org/docs/>

⁶<https://docs.joinpeertube.org/>

⁷<https://wordpress.org/documentation/>

⁸<https://radiusdesk.com/docuwiki/start>

⁹<https://docs.azuracast.com/en/home>

¹⁰<https://doc.traefik.io/traefik/getting-started/quick-start/>

4. INETHI: A BACKGROUND OF THE CASE STUDY OF A COMMUNITY WIRELESS NETWORK DEPLOYMENT

orchestration. A reverse proxy is a server that sits between client devices and web servers, forwarding client requests to the web servers and returning the server's responses back to the clients. This establishes an additional level of abstraction and control to ensure the smooth flow of network traffic. Traefik is an open-source Edge Router which automatically and dynamically handles HTTP and TCP routing within the iNethi ecosystem. With Traefik, the iNethi platform can efficiently direct incoming traffic to the appropriate services based on the specific request. This setup optimizes resource use, enhances security and enables load balancing to prevent any one service from becoming a bottleneck, ensuring a smooth and streamlined user experience.

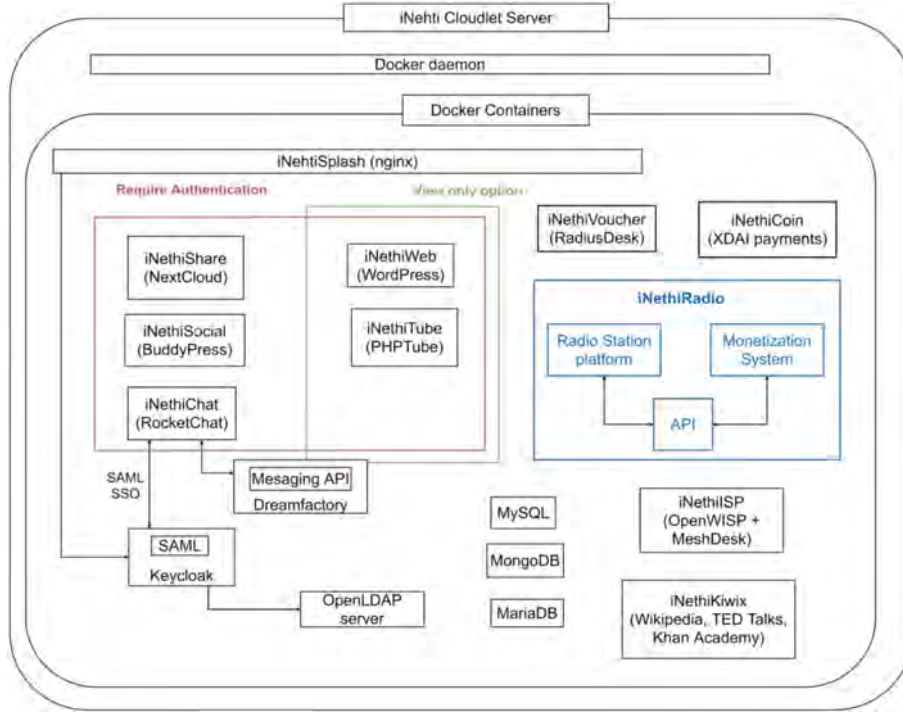


Figure 4.4: iNethi cloudlet server and its services (1)

4.2.3.2 iNethiRadio

A service we want to highlight in particular is iNethiRadio, which is powered by the AzuraCast open-source radio management suite, see Table 4.1. iNethiRadio is a novel project concept designed to address challenges and leverage opportunities within the Ocean View musical community, using a combination of community radio and digital financial systems. This initiative is motivated by the drive to offer a platform for local talents, foster community engagement, and stimulate local economic growth. The primary stakeholders

4.2 The iNethi Platform

for iNethiRadio include local musicians, artists and podcasters. Secondary stakeholders are the researchers from the University of Cape Town, Black Equations, and the broader Ocean View community. The radio station aims to provide a space for local talents to showcase their work, creating an avenue for monetization and job creation.

From a technical perspective, iNethiRadio is comprised of two core components: a radio station system (AzuraCast) and a monetization system (WordPress). The radio station system could allow for live and on-demand streaming of shows, while the monetization system facilitates the selling of music played on the station and the purchasing of advertising space. Integration with the existing iNethi Payments and User Management system enables financial transactions within the radio station environment. These systems together create a self-contained financial ecosystem, promoting local economic activity and providing job opportunities. See Figure 4.4

In an effort to validate the iNethiRadio service and use it as a proof-of-concept for the iNethi GUI installer, a workshop was hosted involving local musicians and the Black Equations iNethi system manager. This validation process proved vital in assessing the feasibility and effectiveness of the project within the target community. Detailed insights and outcomes of this workshop are covered extensively in Chapter 8.

4. INETHI: A BACKGROUND OF THE CASE STUDY OF A COMMUNITY WIRELESS NETWORK DEPLOYMENT

5

Iterative Design of the Technical Solution

This chapter outlines the process we undertook to apply the ICT4D framework methodology (12) in designing and implementing the GUI installer for the iNethi network to solve the ICT illiteracy problem among others. Moreover, throughout this application, the User-Centered Design principles (14) were taken into account. The framework, which comprises five components, guided our process from the analysis of the local context through to the sustainability analysis of our solution. Here, we provide an extensive account of each of these steps. In the next Chapter, based on the five components, we will justify our design decisions by linking them to the requirements and use cases produced in this section. By means of providing diagrams and tables we provide a detailed insight into our design process.

5.1 Context Analysis

A first and crucial step in the ICT4D framework is the analysis of the context in which the ICT solution is to be deployed. In our case, understanding both the general context of South Africa and the specific context of Ocean View was essential. South Africa's societal challenges and how they relate to the ICT landscape impose unique constraints on the deployment and management of ICT solutions. A non-exhaustive list of these constraints and their corresponding demands are laid out in Table 5.1.

These South African related constraints and demands do not have direct impact on the design choices of our GUI installer. However, in the specific context of Ocean View, the constraints are both a reflection of the larger South African context and unique to

5. ITERATIVE DESIGN OF THE TECHNICAL SOLUTION

Constraints	Demands
Load shedding	Power-aware design; backup power
Political corruption	Transparency in system design
High crime rates	Robust security measures
High unemployment rates	Training and job opportunities

Table 5.1: Constraints and demands in the general context of South Africa

the locality. They are characterized by low ICT literacy levels, economic hardship, and infrastructural challenges, among other things. These constraints, and the demands they give rise to are applicable to both the iNethi platform as a whole, but also apply to the design of the GUI Installer. They are presented in Table 5.2.

Constraints	Demands
Low ICT literacy levels	User-friendly and intuitive design
Economic hardship	Affordability of services
Infrastructural challenges	Robust and flexible system design
Lack of local digital content	Glocal content generation and sharing

Table 5.2: Constraints and demands in the context of Ocean View

By understanding these contexts and the constraints they impose, we were able to identify specific demands that our ICT solution needed to address. These demands, in turn, guided our design and development process.

5.2 Needs Assessment

The need for an improved installer was identified through discussions with the iNethi development team and from users who had struggled with the installation process due to the drawbacks of the bash script. The current installation method was not intuitive and required a certain degree of ICT knowledge and skill. This situation presented a need for an installer that could be easily used by a wider range of people, including those with lower ICT literacy levels. In order to identify the specific requirements that the GUI installer should meet, we sought input from the development team and from prospective users. We also considered the contextual demands identified in the context analysis, such as the need for power-aware design and user-friendly interfaces. The identified functional and non-functional requirements are presented in Tables 5.3 and 5.4, respectively.

5.3 Use Case and Requirements Analysis

ID	Functional Requirements
FR-01	The installer must provide a graphical user interface for users to interact with.
FR-02	The installer must automate the deployment and configuration of iNethi services.
FR-03	The installer should check and ensure minimal system requirements, ensuring compatibility with older hardware.
FR-04	The installer must allow for configuration options to be set by the user during the installation process.
FR-05	The installer must have the ability to verify the success of the installation process.
FR-06	The installer must provide clear error messages and instructions for troubleshooting.

Table 5.3: Functional requirements for the GUI installer

ID	Non-Functional Requirements
NFR-01	The installer should have a user-friendly interface that can be used by people with low ICT literacy levels.
NFR-02	The installer should be robust and able to handle interruptions (such as power outages) without failure.
NFR-03	The installer should be compatible with the major operating systems (Linux, Windows, macOS).
NFR-04	The installer should provide a satisfactory user experience, minimizing waiting times and ensuring responsiveness.

Table 5.4: Non-functional requirements for the GUI installer

By defining these requirements, we aimed to align the design and development of the GUI installer with both the needs of our users and the constraints of our context. This requirements-driven approach was crucial in ensuring a user-centered and contextually relevant design. As we will see in our evaluation and validation chapters, all requirements have been met in the proposed artifact.

5.3 Use Case and Requirements Analysis

Following the requirements, we proceeded to the next component of the ICT4D framework — use case and requirements. These use cases describes "who" can do "what" with the In-

5. ITERATIVE DESIGN OF THE TECHNICAL SOLUTION

staller. In other words, the use cases listed below function as a roadmap of the Installer's expected functionality. As the sole user in our environment typically is the network administrator, this is only user group for who we have designed use cases. Note that this is a non-exhaustive list.

1. **Administrator installs iNethi:** This use case illustrates the scenario where an administrator uses the GUI installer to install the iNethi services on a new system. The use case commences when the administrator launches the GUI installer and concludes when the installation finishes, leaving the system ready for use.
2. **Administrator checks installation status:** In this use case, the administrator triggers the GUI installer to check the status of the installation. The installer should provide concise feedback on the installation progress and any errors encountered.
3. **Administrator troubleshoots installation:** Here, the administrator utilizes the GUI installer to obtain possible feedback and troubleshoot issues that may have arisen during the installation process. This process could involve looking up error messages and implementing suggested troubleshooting steps.
4. **Administrator verifies installation:** In this scenario, the administrator checks the GUI installer to confirm the successful installation of iNethi services. The installer should provide a clear indication of successful installation, or failure, including troubleshooting steps if available.
5. **Administrator updates iNethi services:** This use case aims at an administrator using the GUI installer to update the iNethi services to the latest versions, or add services to an existing installation.

Moreover, we developed GUI installer mockups (see Figure 5.1 or Appendix A for improved readability) based on these use cases, which greatly facilitated the process of requirements elicitation and validation, and as can be seen in Implementation Chapter 6, have served as a strong guidance in the design process. These use cases and mockups were discussed with the iNethi development team and then ratified by the two directors of iNethi: Keegan White and David Lloyd Johnson.

5.3 Use Case and Requirements Analysis

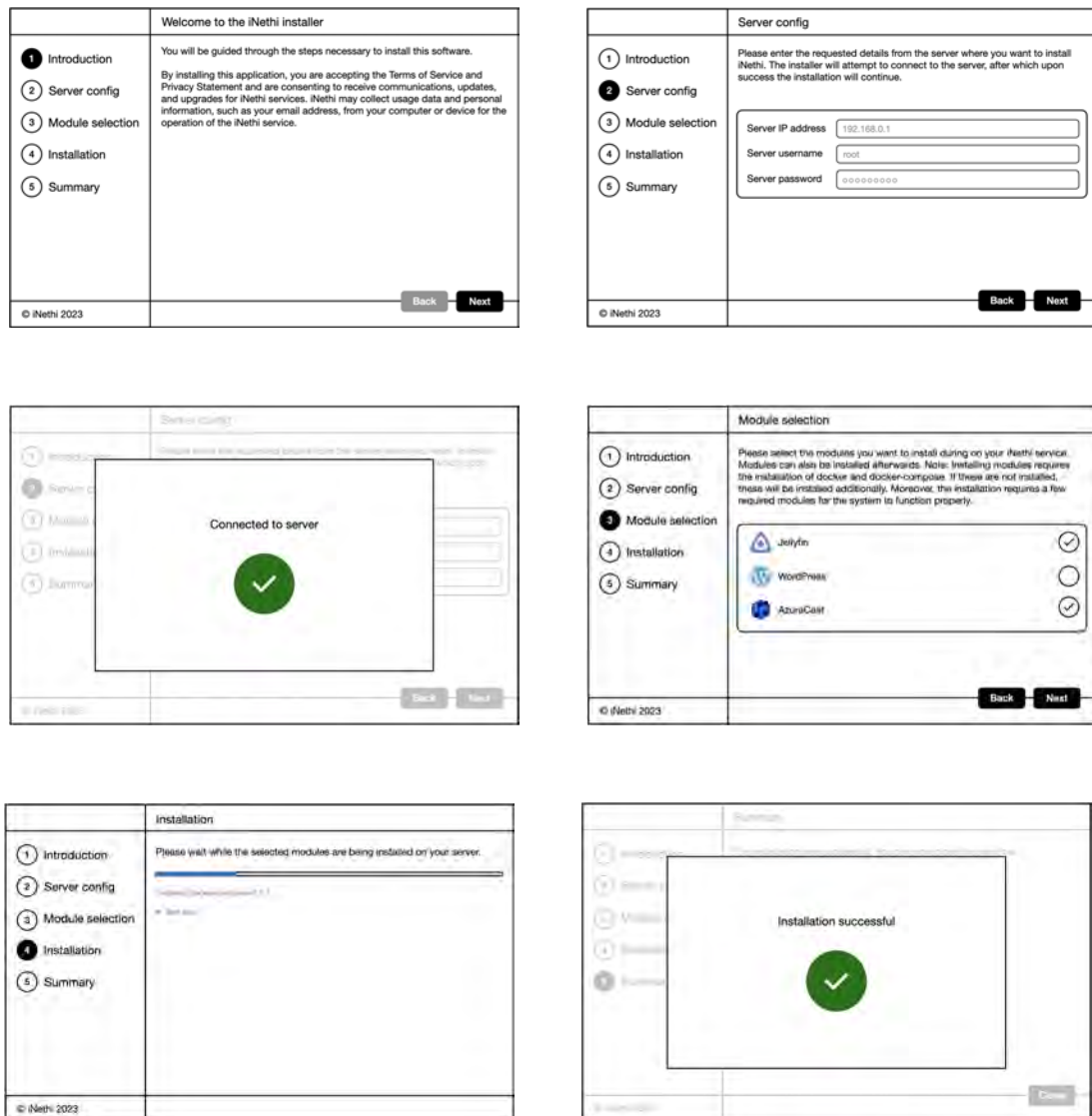


Figure 5.1: Mockups designed for the GUI Installer

5.4 Developing, Testing, Deploying

The next stage in the ICT4D framework is the actual development, testing, and deployment of the solution. A more in-depth discussion of the development process is presented in the implementation section. In brief, a working prototype of the installer was developed and subsequently tested in the field. We conducted two workshops to validate its functionality with users, and these will be covered in the validation section. As for the deployment of the new installer, it will be used in all updates and new deployments of the iNethi network. As the current deployment in Ocean View is operating well, there is no need for a fresh installation using the new installer.

5.5 Sustainability Analysis

The final component of the ICT4D framework concerns the sustainability of the developed solution. The sustainability of the GUI installer, as with all iNethi developed solutions, is assured by the partnership between the University of Cape Town and the Ocean View community. Being an open-source project, the code is available to the public, and ownership of the solution is shared among the contributors. The solution is maintained by both UCT students and post-graduates and the iNethi development team. This model of shared ownership and maintenance ensures the long-term sustainability of the GUI installer, making it a reliable tool for the deployment and management of the iNethi network.

6

Solution Engineering

6.1 Software

The design of the GUI installer was influenced by a range of considerations, from the technical constraints of the task to the needs of our user group. It employs several technologies, each chosen for specific reasons to produce a result that provides a smooth, efficient, and reliable experience for a wide user group.

6.1.1 Electron

As mentioned before, We built the GUI installer using the Electron framework. Electron is an open-source software framework developed and maintained by GitHub. It allows the development of desktop GUI applications using web technologies by combining Chromium and Node.js into a single runtime. It can package this runtime into an application's binary, resulting in a stand-alone application that's does not rely on the user's pre-existing system configuration¹ and therefore suitable for a wide range of users. Electron was chosen for several reasons:

1. **Cross-platform compatibility:** One of our main goals was to develop an installer that can be run on every operating system, expanding our reach to a broader user group. Electron is well-known for its cross-platform support, enabling the creation of applications for Windows, Linux, and macOS from a single codebase. See the results section of this chapter for more information.
2. **Ease of development and maintenance:** Electron uses web technologies like JavaScript, HTML, and CSS, which makes the development process more accessible

¹<https://www.electronjs.org/docs>

6. SOLUTION ENGINEERING

to developers with a web development background. This also means that it's easier to find developers for updates and maintenance since these technologies are easy to learn and widely used, a welcome attribute in digital literacy-challenged environments.

6.1.2 Node.js

The GUI installer is driven by a backend developed in Node.js¹, a runtime that enables JavaScript to be run outside of a web browser. Although Node.js is an integral part of the Electron framework and therefore used in Electron's main process, we nonetheless list its strengths to further substantiate the choice for this native application development framework:

1. **Single-threaded, event-driven architecture:** Node.js is designed to optimize throughput and scalability in web applications with many input/output operations. This makes it suitable for the backend of our GUI installer, which needs to handle various tasks such as sending, receiving and saving installation details and credentials, running scripts, and updating the user interface.
2. **Interoperability with Electron:** Since Electron combines Node.js and Chromium, we can use Node.js APIs such as IPC in the main process and take advantage of its asynchronous, non-blocking functionality.
3. **Package ecosystem:** Node.js comes with npm, a package manager that includes thousands of open-source libraries. This was invaluable for enhancing the functionality of our application without having to develop everything ourselves. The password prompt required to obtain root privileges for the system requirements check was for example realised with use of the 'sudo-prompt' package, taking care of securely handling the root password to authorize our scripts.

6.1.3 Electron IPC

Communication between the Electron's main process and the renderer processes happens asynchronously with the Inter-Process Communication (IPC) module². Its relation to Electron is similar to Node.js in that it is also an integral part of Electron. However, as a less popular but in our context important part of the installer, we list its key functionalities valuable to our software design:

¹<https://nodejs.org/en/docs/>

²<https://www.electronjs.org/docs/api/ipc-main>

1. **Data transfer:** IPC enables the transfer of data between the frontend and the backend. In our GUI installer, we use IPC to send data like the server's IP, username, and password from the frontend to the backend, and to send feedback and notifications from the backend back to the frontend.
2. **Handling synchronous and asynchronous messages:** Electron's IPC allows the sending of both synchronous and asynchronous messages from the renderer process to the main process and vice versa. This is useful for our installer, as we can choose the type of message to use depending on the context, resulting in a non-blocking smooth sequence of events.

6.1.4 Ansible

Ansible is an open-source software provisioning, configuration management, and application-deployment tool. In our GUI installer, Ansible plays a key role in setting up the remote server, running tests, and installing selected modules.¹ We chose Ansible for several reasons:

1. **Simplicity:** Ansible uses a simple syntax written in YAML called playbooks. This allows developers to describe automation jobs in a way that approaches plain English, making Ansible's learning curve significantly more manageable, consequentially positive impacting the code maintainability and project sustainability.
2. **Agentless:** Ansible doesn't require any agents on the remote hosts, which simplifies the setup process. It connects to remote machines over SSH, and it doesn't leave any software behind once it's finished executing its modules.
3. **Powerful and flexible:** Ansible is not just a configuration tool, but also a deployment and orchestration tool. It can manage complex multi-tier deployments and perform rolling updates. This is not relevant for a single-server deployment, but could become an interesting feature in the future, as it would allow for managing and supporting multiple deployments in Africa from one centralized point. This would significantly reduce the need for physical on-site support.

In the next sections, we will delve into the installer workflow and discuss how these tools and technologies were utilized to build the GUI installer and how they contribute to fulfilling the project's objectives.

¹https://docs.ansible.com/ansible/latest/user_guide/index.html

6.2 Installation Process Overview

The GUI installer's workflow is designed to be user-friendly and is divided into seven intuitive steps, ensuring that the user has complete control and a clear overview of the state of the installation process. See Figure 6.1 for a depiction of the application's sequence of events. For better readability, a full size image can be found in Appendix B.

6.2 Installation Process Overview

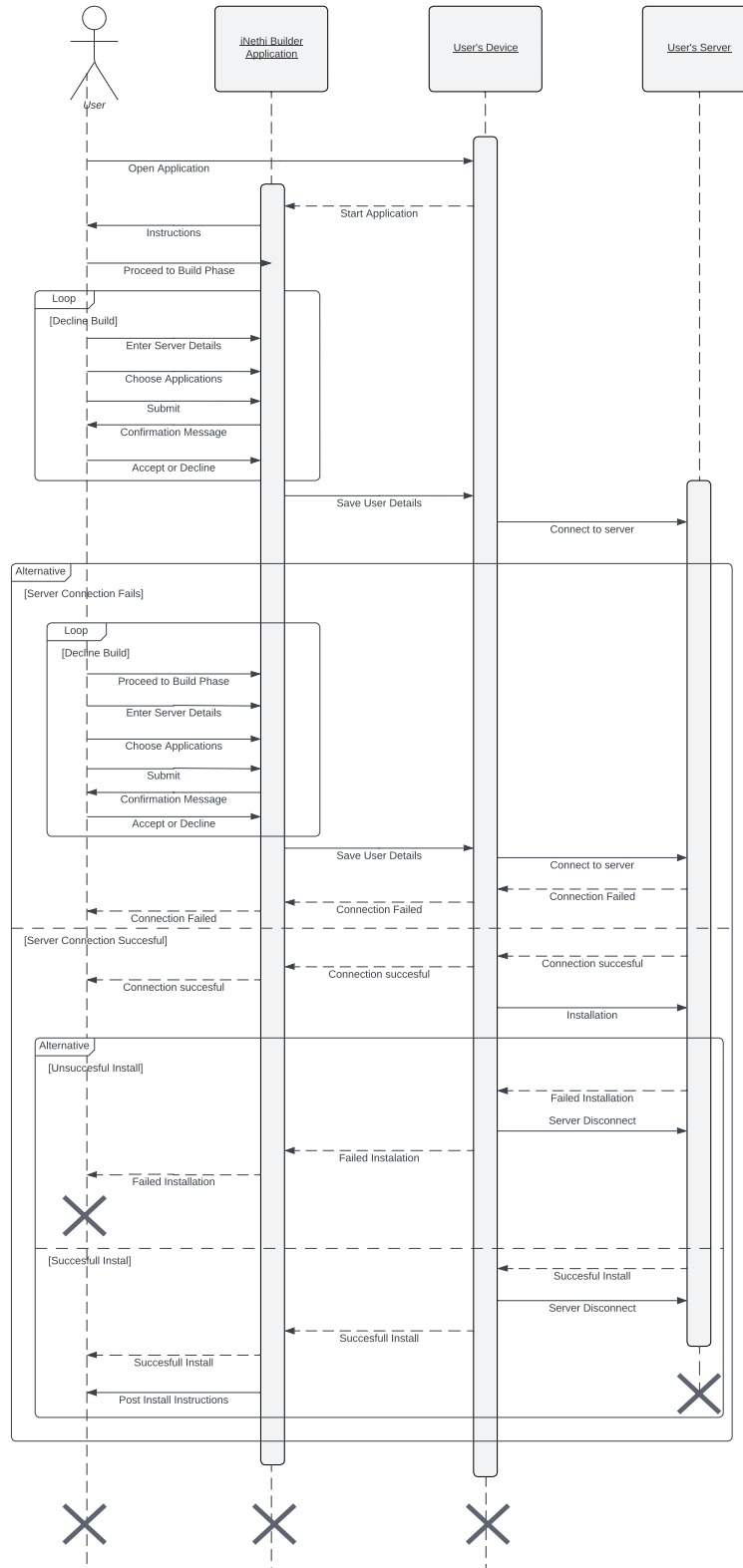


Figure 6.1: Step 1 of the GUI installer: Introduction

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6.2.1 Step 1: Introduction

The first step serves as a welcoming page to the user, outlining the intentions and contents of the installer. It provides an overview of what the user can expect in the following steps, setting a context for the user's journey and creating an understanding of the application's purpose. This step aligns specifically with NFR-01 "User-Friendly Interface" and the use case UC-01 "Start Installation".

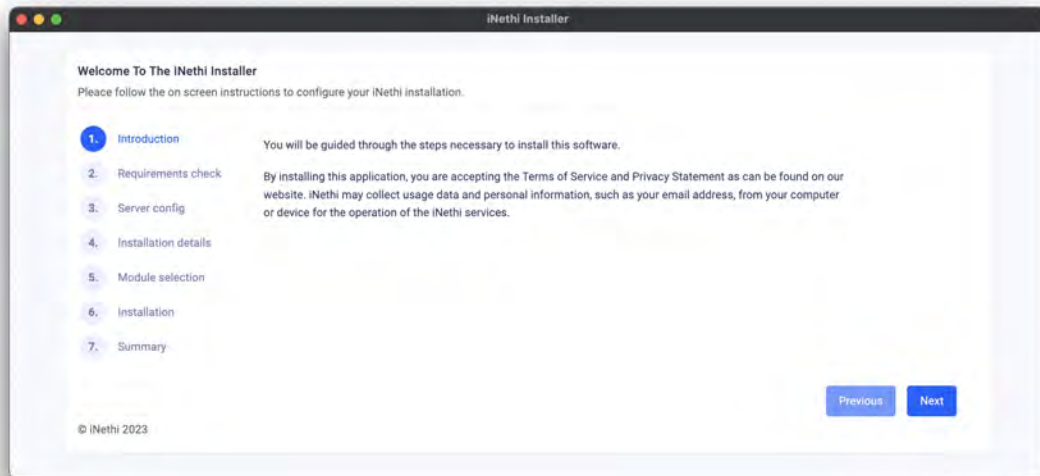


Figure 6.2: Step 1 of the GUI installer: Introduction

6.2.2 Step 2: Requirements Check

Upon proceeding, the installer presents the requirements check page. Here, the application details the need for system checks and potential installation of prerequisites, ensuring the compatibility of the user's system with the product. After the user's confirmation by clicking 'next', the installer prompts for the sudo password to perform the necessary checks and installations. This process specifically aligns with FR-03 "System Check", FR-06 "Error and Instruction Messages" and non-functional requirement NFR-03 "OS Compatibility". Moreover, it aligns with the corresponding use case UC-02 "Installation Status".

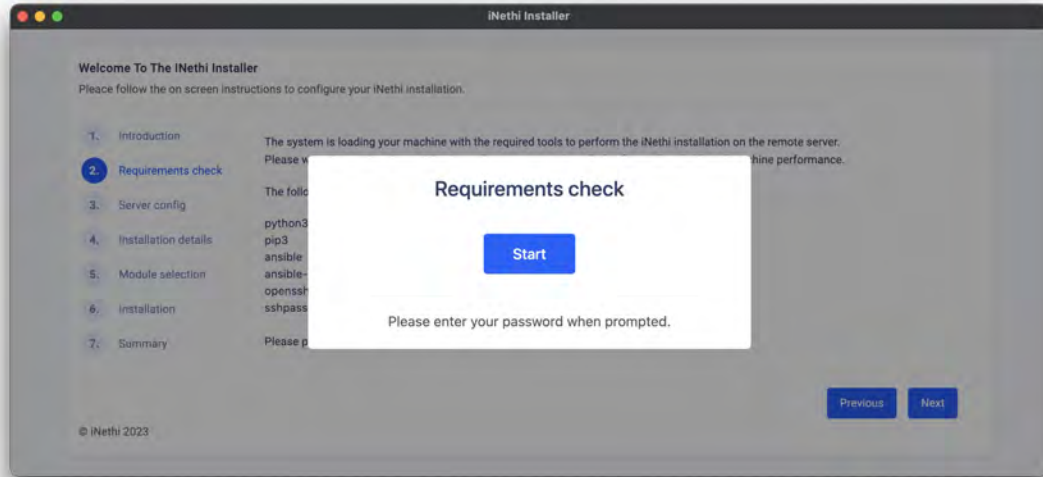


Figure 6.3: Step 2 of the GUI installer: Requirements Check

6.2.3 Step 3: Server Configuration

In the third step, the user is required to provide the IP address, username, and password of the remote machine intended for the iNethi installation. This information is crucial for establishing a connection with the remote server, which will be used for executing scripts and setting up the application. The user inputs are sent to the backend through the Electron IPC module and temporarily stored in a file. A Python-run Ansible playbook then retrieves these credentials, attempting a connection to the remote server to verify their validity. The user is promptly notified of the connection attempt's success or failure. This step specifically aligns with the functional requirement FR-04 "Configuration Options".

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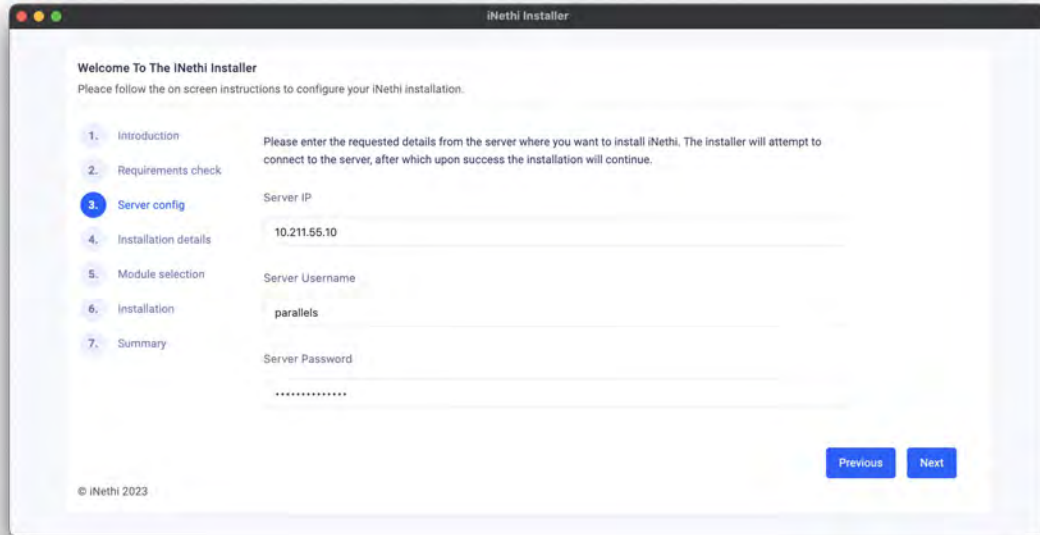


Figure 6.4: Step 3 of the GUI installer: Server Configuration

6.2.4 Step 4: Installation Details

Upon successful connection, the user proceeds to the fourth step, which involves entering installation details. The user is requested to specify the storage location for services requiring space, such as NextCloud. They are also asked to provide the domain name where the iNethi system should be accessible. For secure connections, the user can opt for HTTPS, prompting the installer to download and install the necessary SSL certificate. Lastly, a master password field is provided for setting standard passwords for services requiring administrative privileges. The data entered is again sent to the backend using IPC and stored in a file. This step also specifically aligns with the functional requirement FR-04 "Configuration Options".

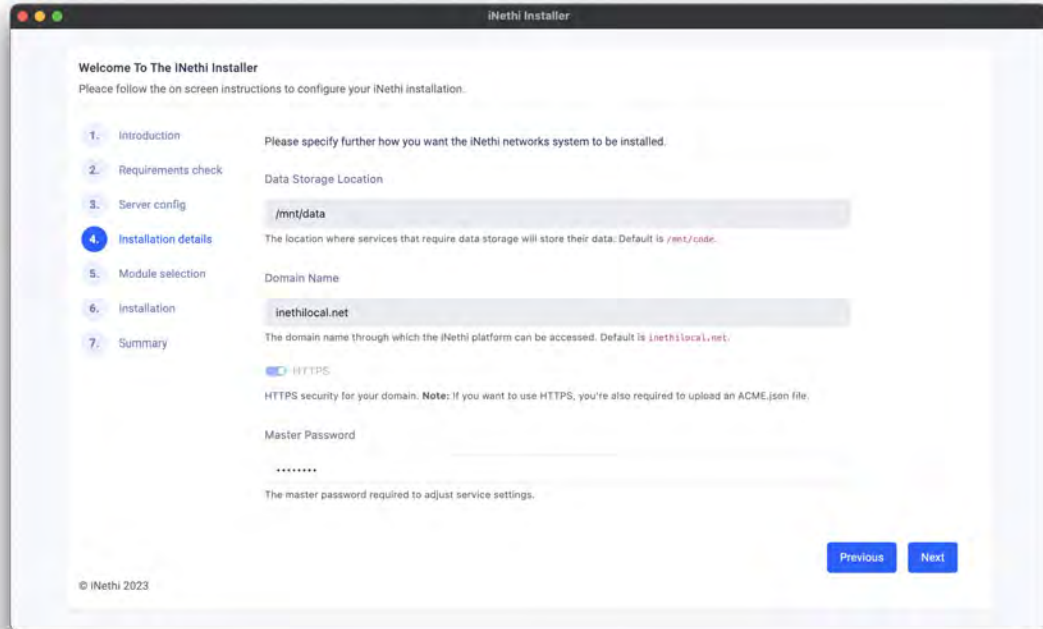


Figure 6.5: Step 4 of the GUI installer: Installation Details

6.2.5 Step 5: Module Selection

Step five is key to the customization of the iNethi platform. Here, the user is presented with a selection of available services to install. By default, Docker and the Traefik service are pre-selected and cannot be deselected as they form the foundation for the application. Once the user finalizes their selection, the data is transmitted to the backend and stored in JSON format. A confirmation modal then appears, ensuring the user is ready for installation and warning about potential interruptions due to power or internet losses. This stage satisfies non-functional requirement NFR-02 "Interruption Handling" and use case UC-05 "Service Updates".

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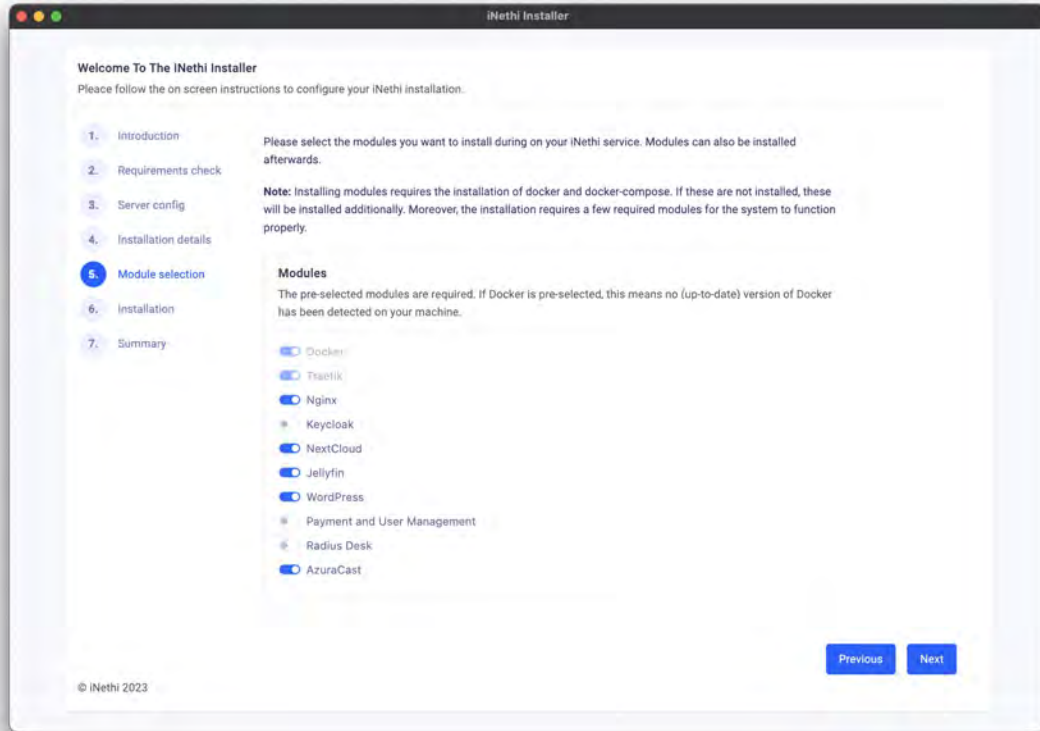


Figure 6.6: Step 5 of the GUI installer: Module Selection

6.2.6 Step 6: Installation

The sixth step commences the installation process. Using the previously stored credentials, installation details, and module selection, the Ansible playbooks corresponding to the chosen modules are run in the defined order. A progress bar and a real-time log provide feedback to the user, enhancing transparency during the installation process. The feedback mechanism aligns with the functional requirement FR-06 "Error and Installation messages" and NFR-04 "User Experience and Responsiveness". The installation phase specifically correlates with the FR-02 "Deployment of Services" and use case UC-01 "iNethi Installation" and UC-04 "Installation Verification".

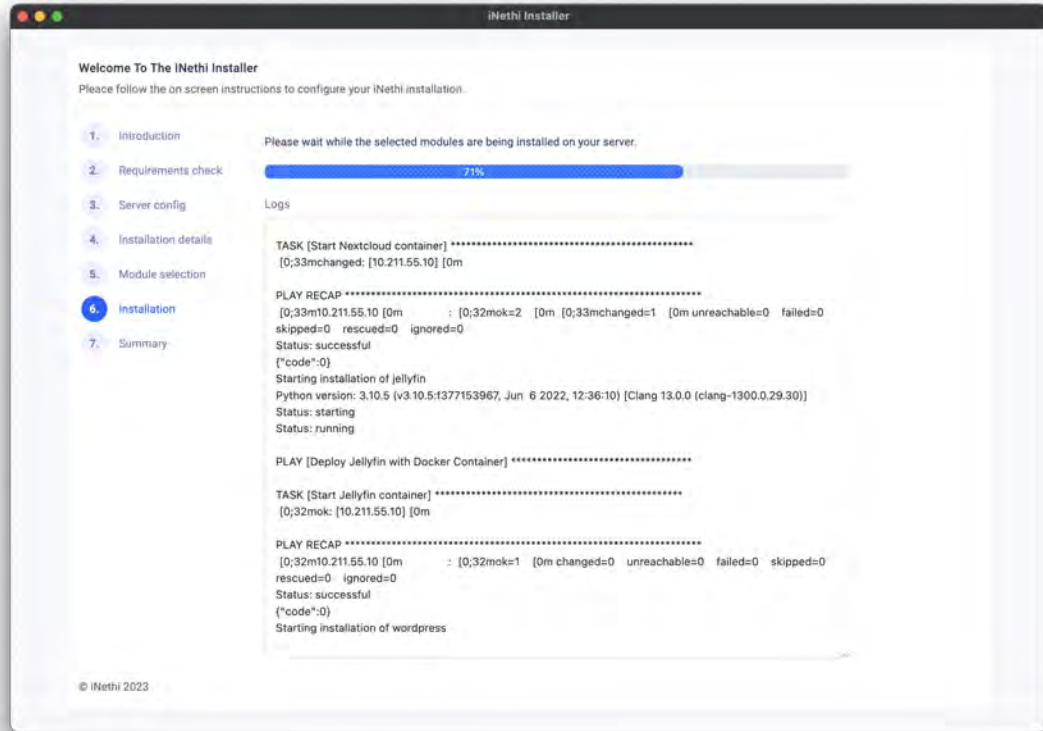


Figure 6.7: Step 6 of the GUI installer: Installation

6.2.7 Step 7: Summary

In the final step, the user is presented with a summary of the installation. If successful, the installer can be closed, and if not, the cause of the failure is detailed, and troubleshooting guidance is provided. This concluding step of the installer process satisfies the functional requirement FR-02 "Deployment of Services" and the use cases UC-03 "Installation Troubleshooting" and UC-04 "Installation Verification".

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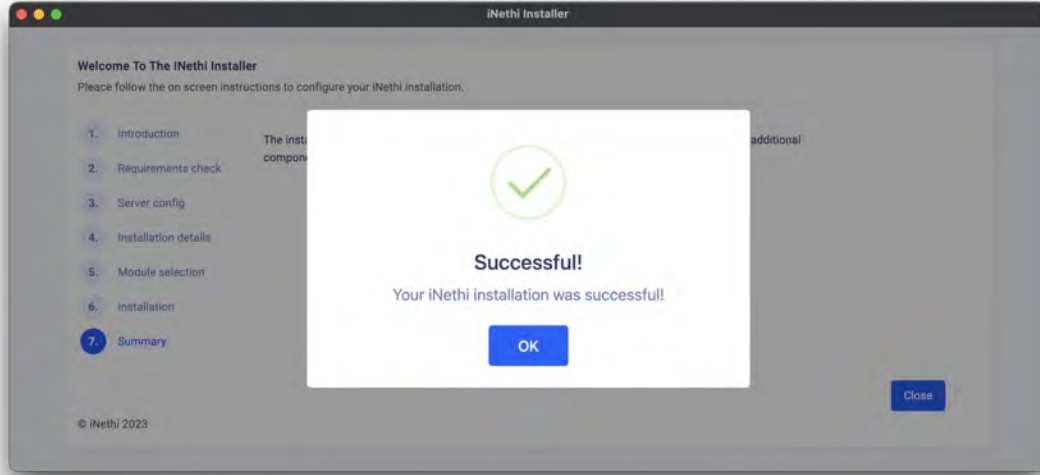


Figure 6.8: Step 7 of the GUI installer: Summary

Through this structured and systematic process, the GUI installer ensures the seamless installation of the iNethi platform on the user's remote machine, providing the user with a high level of control and visibility throughout. The functional and non-functional requirements and use cases that are not mentioned above are satisfied by the application as a whole and cannot be linked to individual steps specifically.

6.3 Result

After the installation has been successfully terminated, the user can list their running Docker containers with the 'docker ps -a' command and is presented with an overview similar to the list depicted in Figure 6.9. For instructions on how to proceed, one can follow the steps outlined on the [GitHub Repository](#) page, or visit the official documentation on the [iNethi Software](#) page. Furthermore, the official release packages for both AMD64 and ARM64 architectures (or source) can be found on the [release](#) page. During the validation in Chapter 8 we will demo the iNethiRadio service to show the effectiveness of the software solution.

6.3 Result



CONTAINER ID	IMAGE	COMMAND	CREATED	STATUS	PORTS	NAMES
a18536100f91	wordpress:latest	"docker-entrypoint.s..."	About a minute ago	Up About a minute	80/tcp	inethi-wordpress
14b462c98e88	mariadb:latest	"docker-entrypoint.s..."	About a minute ago	Up About a minute	3306/tcp	inethi-wordpress-mariadb
f6d0f6d0e42	nextcloud	"/entrypoint.sh apac..."	About a minute ago	Up About a minute	80/tcp	inethi-nextcloud
e885f0e1583	ghcr.io/azuracast/azuracast:latest	"finl -- /usr/local/..."	17 hours ago	Up 17 hours	80/tcp, 2822/tcp, 8000-8999/tcp	inethi-radio
1d93b7ecdcc	linuxserver/jellyfin	"/init"	17 hours ago	Up 17 hours	8096/tcp, 8920/tcp	inethi-jellyfin
387c202c0739	mysql:latest	"docker-entrypoint.s..."	17 hours ago	Up 17 hours	3306/tcp, 33060/tcp	inethi-nextcloud-mysql
21b7a638f47	nginx:latest	"/docker-entrypoint.s..."	17 hours ago	Up 17 hours	80/tcp	inethi-nginx-splash
6847861fdb	traefik:v2.5	"/entrypoint.sh --ap..."	17 hours ago	Up 17 hours	0.0.0.0:80->80/tcp, 0.0.0.0:443->443/tcp	inethi-traefikssl

Figure 6.9: The iNethi Platform: a collection of running Docker containers

6. SOLUTION ENGINEERING

Evaluation of the Methodology

The evaluation of the selected methods and their contribution to shaping the design of the GUI installer is crucial in assessing the effectiveness and impact of the applied ICT4D framework. This framework has provided us with a structured and systematic approach to address the challenges and complexities associated with designing an intuitive and user-centered installer in a low-resource environment. This section evaluates the effectiveness of the applied methods and their contributions to the overall design of the GUI installer.

The ICT4D framework methodology used in this thesis, counting five components, has served as a comprehensive guide throughout the design process. The first component, context analysis, played a vital role in understanding the local context and associated constraints and demands. By extensively exploring the challenges faced by South Africa in general and Ocean View in particular in our background section, including the digital divide, limited internet access, and economic constraints, the context analysis provided valuable insights into the specific requirements and considerations necessary for approaching the design of the installer. Overall, the context analysis by means of a background study contributed significantly to shaping the design by aligning it with the specific needs and realities of the target community.

The second component, needs assessment, focused on understanding the intended user needs and ensuring that the installer delivers value to them. In the case of the GUI installer, the needs assessment was already established through the identified need for an updated installer within the iNethi network. The feedback and requirements gathered from both the development team and individuals facing challenges with the bash installer were instrumental in determining the key features and functionalities of the new GUI installer to increase accessibility of the iNethi system as a whole. By incorporating user feedback, conducting workshops, and iteratively refining the design, the needs assessment

7. EVALUATION OF THE METHODOLOGY

component contributed to the user-centered nature of the installer and its ability to address the identified needs effectively.

The third component, use case and requirements analysis, aimed to develop use cases and define the specific requirements for the installer. Although the use cases were not extensively developed, the focus was on ensuring that the installer guided users through a clear and logical sequence of steps and included the most core functionalities in order to guide the user to the end goal: successfully deploying the iNethi system. Moreover, mock-ups and prototypes were created and facilitated as requirements elicitation and validation. This process allowed for the refinement of end-user needs and ensured completeness of features. The use case and requirements analysis component contributed to the design by providing a solid foundation for the development of the installer, aligning it with the intended goals and functionalities.

The fourth component, developing, testing, and deploying, involved the actual implementation of the installer and its subsequent testing and deployment. This phase included the utilization of the chosen technologies, such as the Electron framework and Ansible deployment software in order to develop a cross-platform installer with a easily manageable deployment as a result. The workshops provided valuable insights into the usability and effectiveness of the installer, leading to iterative improvements and refinements. Moreover, by putting the software up for a final review by the iNethi directors, the more technical, backend related bugs were addressed. Overall, this component has ensured that the installer meets the required technical standards in terms of structure and deployment, while delivering an improved installation experience to the user.

The final component, sustainability analysis, focused on ensuring the long-term viability and continuity of the installer within the iNethi community wireless networks. Although not extensively discussed in this section, sustainability considerations were taken into account through the open-source nature of the project, allowing for community contributions and ongoing maintenance by the iNethi development team and UCT students. A specific example however was the conscious choice for Ansible as the deployment software, as it allows for remote server management, thus enabling remote assistance to rural deployment with no network administrator or a majority of the time disconnection from the internet. Generally, as the installer is part of the larger iNethi ecosystem, the maintenance will adhere to the same principles as the other network components.

The application of the ICT4D framework methodology has proven effective in guiding the design of the GUI installer for the iNethi community wireless networks. The framework's

components, including context analysis, needs assessment, use case and requirements analysis, developing/testing/deploying, and sustainability analysis, provided a holistic approach to address the unique challenges and requirements of the project. We conclude that the framework includes and entails all the required steps to design a software artifact in a low-resource context and is therefore deemed effective.

7. EVALUATION OF THE METHODOLOGY

Validation of the Technical Solution

In this section, we present the validation process which encompasses three key activities: a workshop with University of Cape Town honours students to evaluate usability, a workshop in Ocean View to test effectiveness, and feedback from the iNethi directors to assess completeness. These validation activities aimed to gather insights from both internal and external users. Note that due to the ethics agreement, we were not allowed to share photographs from the workshops to respect the participants' privacy.

8.1 University of Cape Town Honours Students Workshop (Usability)

The workshop with University of Cape Town honours students aimed to evaluate the usability of the GUI installer in a controlled environment. This workshop provided an opportunity to test the installer's functionality, identify potential issues, and gather feedback for further improvements. The workshop was conducted during a lab session led by Melissa Densmore, the local supervisor and facilitator of the workshop.

The primary objective of this workshop was to validate the installer's usability in various installation scenarios, particularly focusing on "dirty" installations, where the system may not be in an ideal "clean" state. These scenarios aimed to mimic real-world situations where the installer would be used to upgrade or install the iNethi platform on existing systems. During the workshop, several challenges were encountered, with most occurring during the system requirements check phase. Due to the variability in operating systems and architectures among the participants' machines, the system requirements check script did not account for all potential edge cases. As a result, some installations experienced issues and got stuck at this stage. To address these challenges, additional instructions were

8. VALIDATION OF THE TECHNICAL SOLUTION

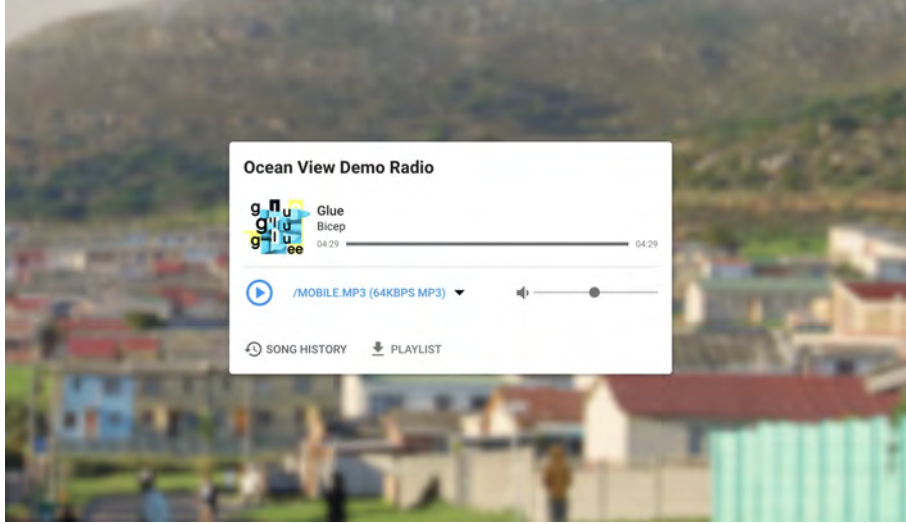


Figure 8.1: iNethiRadio: an Ocean View tailored demo setup

provided to guide participants in manually installing the required libraries and resolving compatibility issues. Participants who encountered these challenges were able to complete the system requirements check successfully after following the revised instructions. Another known compatibility issue was related to the KeyCloak service, which was not compatible with ARM64 machines. Participants were informed about this issue during the workshop, and feedback received regarding this concern was categorized as UI-related (usability) feedback. Participants suggested enhancing the visual guidance or disabling the KeyCloak option for ARM64 machines to improve the overall user experience. The feedback and suggestions gathered from this workshop were carefully considered and implemented, contributing to the iterative refinement of the installer’s user interface and overall user experience.

8.2 iNethiRadio Workshop (Effectiveness)

The second workshop, hosted in Ocean View, aimed to validate the effectiveness of the GUI installer in a real-world setting and showcase the iNethiRadio module. This workshop served as a crucial phase in the overall development cycle, demonstrating that the installer successfully installed the iNethiRadio module and setting it up within the bounds of the installer’s capabilities, i.e. no module specific configurations. The three-day workshop was attended by six participants from the Ocean View community. The objectives of the workshop were two-fold:

8.2 iNethiRadio Workshop (Effectiveness)

The primary focus of this workshop was on the effectiveness of the installer, particularly in the installation and setup of the iNethiRadio module. The workshop successfully demonstrated the installer's effectiveness in installing the iNethiRadio module and configuring the necessary settings for a workshop demo environment. Moreover, this validation showcased the capability of the installer to perform successfully in the intended and real-world environment. For this demo we tailored the AzuraCast default instance to the Ocean View community, primarily in order for the attendees to relate, and be more engaging as the interactions are more personalized. See Figures 8.1 and 8.2

While the primary objective of this workshop was to validate the installer's effectiveness, the feedback and discussions with the workshop participants also provided valuable insights into their perceptions, needs, and expectations regarding the iNethiRadio module. As per the community workshop guidelines drafted by the University of Cape Town, we first used a number of "social icebreakers" for everyone to introduce themselves and explore their role within the community and their potential future relation to iNethiRadio. After this, we primarily aimed at sparking the conversation on the potential of iNethiRadio, in order to foster content creation, generate employment opportunities, and restore the community's identity, which has been impacted by the forced relocation during the apartheid era. These conversations were impactful and extremely valuable in terms of gathering new ideas and feedback, and will be utilized to further refine and enhance the iNethiRadio module in near future iterations.

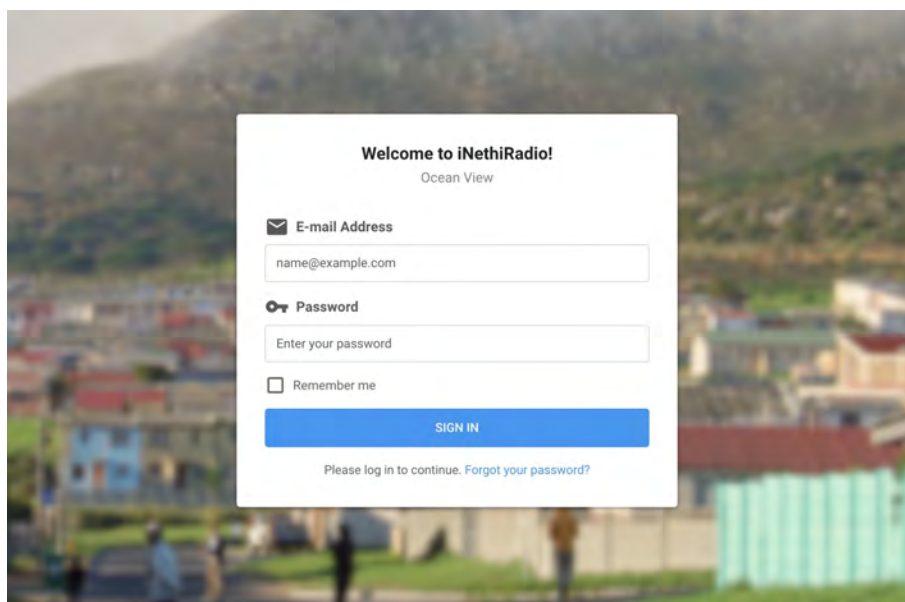


Figure 8.2: iNethiRadio Login Page: an Ocean View tailored demo setup

8. VALIDATION OF THE TECHNICAL SOLUTION

Notably, in order to host this workshop, an ethics approval application was submitted to the ethics board of the University of Cape Town, as it involved interaction with the community members of Ocean View. This application underwent multiple revisions and an extended period of review before receiving final approval. The ethics approval and consent form can be found in Appendix C. Initially, we planned for a number of workshops in Ocean View. However, due to the extended period of review we were limited to this single three-day workshop. This is a valuable lesson in organizing workshops and gathering user feedback in general in low-resource environments where ethics approvals are and should be a priority.

8.3 iNethi Directors Feedback (Completeness)

In addition to the workshops with the University of Cape Town honours students and the Ocean View community members, feedback was also gathered from the iNethi directors, who are also part of the active developers team. The aim of this feedback session was to assess the completeness of the GUI installer's features and address any remaining issues or concerns. The iNethi directors, possessing extensive experience and expertise in community wireless networks, played a crucial role in evaluating the installer from a technical and practical standpoint. Their feedback was invaluable in ensuring that the installer aligned with the overall objectives and requirements of the iNethi project.

During the feedback session, the directors thoroughly tested the installer and provided detailed input on various aspects of the application. They reviewed the architecture builds, discussed issues related to application distribution strategies, and proposed solutions for optimizing the installation process. Through these discussions, the installer was fine-tuned to meet the specific needs and standards of the iNethi project.

One of the key outcomes of the feedback session was the resolution of bugs related to the architecture builds, in part related to the core KeyCloak module. Additionally, discussions around application distribution strategies led to the renaming of the created repositories to align them with the overall distribution structure of other network repositories. This standardization of naming conventions and repository organization ensures consistency and ease of maintenance within the iNethi ecosystem for both internal and external developers. The feedback from the iNethi directors played a crucial role in validating the application as a whole and specifically assessing the completeness of the GUI installer's features and refining the application to meet the specific requirements of the iNethi project.

8.4 Validation Groups Rationale

The selection of the honours students, iNethi directors, and Ocean View workshop participants for validation is based on careful considerations. As the intended users, community network administrators, are relatively scarce, alternative groups were chosen to represent users with comparable IT skill levels. The honours students were deemed suitable for testing usability, given their technical proficiency. The iNethi directors, on the other hand, provided valuable feedback on completeness due to their extensive involvement in the project. The workshop in Ocean View did not require participants with any background knowledge, but represent a typical user of the iNethi system and the iNethiRadio module specifically. This provided an opportunity to engage with the local community and validate the effectiveness of the installer. While the selected validation groups may not directly represent the ultimate end-users, their feedback and insights significantly contribute to understanding the usability, effectiveness, and completeness of the GUI installer.

8.5 Results

The validation process revealed positive outcomes, indicating the successful validation of the GUI installer. Feedback from both internal and external users played a crucial role in shaping the installer's final enhancements and improvements. By incorporating feedback from the honours students, workshop participants, and the iNethi directors, the installer underwent a number of iterative refinements. The usability validation with the University of Cape Town honours students provided valuable insights into potential issues during installation and guided us in addressing these challenges. The workshop in Ocean View validated the effectiveness of the installer by successfully installing the iNethiRadio module and having participants access the module from their personal devices, similar to a real-world setting. Lastly, feedback from the iNethi directors confirmed the completeness of the installer, leading to discussions on architecture builds and application distribution strategies. Together, they affirmed the readiness of the GUI installer for deployment. The collected feedback and improvements made based on validation outcomes have contributed to enhancing the installer's overall usability, effectiveness, and completeness.



9

Discussion

In this section we provide an analysis of the direct implications of the proposed artifact on communities adopting this new network component, and its indirect implication and its contribution to current and future research in the field of designing ICT solutions for low-resource environments. We will first discuss the results, and will conclude with a summary of what future work should focus on.

9.1 Results

In this subsection, we evaluate the outcomes and findings of the study, focusing on the answers to the research questions outlined in the introduction. We will first answer our sub-research questions, as they lead up to our main research question.

Research Question 1: What are the specific challenges and constraints encountered when deploying ICT services in low-resource environments?

During the design process we identified several challenges and constraints that may frequently be encountered when designing ICT solutions for low-resource environments. These include limited access to reliable internet connectivity, power interruptions (such as load shedding), limited technical expertise among users, and general economic constraints. The constraints of the low-resource environment have emphasized the importance of designing solutions that are resilient, adaptable, and accessible to users with varying levels of technical knowledge. Moreover, there should be general awareness around interacting with communities in these low-resource environments, as they are vulnerable to exploitation and manipulation. A good practice should therefore be to include a ethics approval with

9. DISCUSSION

guidelines, or an equivalent thereof.

Research Question 2: What is the best approach to design and deploy an ICT service in a low-resource environment in a sustainable way?

During the development of our installer, both the ICT4D framework and general user-centered design principles have played a crucial role in structuring and creating a comprehensive design, consequentially ensuring the successful adoption and usability of the installer. By iteratively involving end users of varying backgrounds throughout the design process, their needs, preferences, and limitations are considered and incorporated into the installer's design. The iterative nature of user-centered design allows for continuous feedback and refinement, ensuring that the installer meets the requirements and expectations of the community. The user-centered approach fosters a sense of ownership and empowerment among users, increasing their engagement and willingness to adopt the iNethi platform, increasing its sustainability. By placing users at the center of the design process, the GUI installer becomes more intuitive, accessible, and effective in facilitating the installation and deployment of the community wireless network. By making the code base publicly available and doing a handover session with the iNethi team, the project is set for further development and is now the default installation method.

Research Question 3: What ICT solution uses this approach and satisfies the encountered constraints, and how do we design this solution?

The effective leveraging of existing technologies has been a key aspect of designing the GUI installer as an intuitive and accessible network deployment solution. The utilization of the Electron framework, with its key feature of cross-platform compatibility, has enabled the installer to run on different operating systems, expanding its accessibility to a wider user base. The integration of Ansible playbooks has automated and streamlined the installation process, making it more efficient and user-friendly. The selection and integration of these technologies have contributed to the creation of an intuitive and accessible network deployment solution that addresses the specific challenges and constraints of low-resource environments. As discussed, a key takeaway and focus during software selection research should be to use open-source software.

Main Research Question: How to deploy ICT services in low-resource environments, specifically in South African Townships?

The approach and efforts that have been taken in this thesis towards the design of the GUI installer for the iNethi community wireless network have successfully addressed this research question. By adopting Design Science and Action Research methods, the installer prioritizes the needs and preferences of the end users. Through extensive user research, workshops, and iterative design processes, the installer has been tailored to the specific context of low-resource environments, considering in the field experienced factors such as limited technical expertise, unreliable infrastructure, and power interruptions. In addition, applying the ICT4D 3.0 framework methodology provides a structured and comprehensive approach to designing and implementing the needs that have resulted from the requirements elicitation, that is, the outcome of context and user-centered research. Adhering to the guidelines set up by this framework, and applying them to the context-specific low-resource constraints, the researcher is assisted in and guided through a step of crucial steps towards designing a ICT artifact that has taken into account all context-relevant aspects. Specific to this thesis, the design of the GUI installer demonstrates the successful application of a this approach in designing an ICT solution for a community wireless network in a low-resource environment. This is attested by the evaluation, which have respectively shown the appropriateness of the research methods for the nature of this research. Second, this is attested by the validation in the field in a South African Township, which has successfully proven that the produced results align with the requirements and needs, and that the solution has proven successful for a variety of users in a low-resource environment.

Overall, our results indicate that the GUI installer for the iNethi community wireless network has successfully addressed the research questions, demonstrating the effectiveness of the applied methods and design choices. The user-centered approach, coupled with the effective leveraging of existing technologies, has resulted in an intuitive, accessible, and user-friendly installer that is tailored to the needs of low-resource environments.

9.2 Future Works

The successful development and validation of the GUI installer for the iNethi community wireless network opens up opportunities for future research and improvements in several areas. Note that some of the suggested future research areas have a demanding and required

9. DISCUSSION

nature: as this research has yielded a produced and deployed software artifact, it should be maintained to adhere to changing protocols and align with developing technologies and environments.

1. **Expanding compatibility:** While the GUI installer has been designed to run on various operating systems, further exploration can be done to ensure compatibility with a wider range of hardware configurations and network environments. As of yet, the software is limited in its functionalities as a result of the diverse operating system and CPU architecture landscape. A primary focus should be to make the installer fully compatible with Windows users and finetune the MacOS deployment to ensure an even wider user adoption. This moreover includes considering the challenges posed by different network infrastructures, such as limited bandwidth and intermittent connectivity, and developing mechanisms to adapt the installer accordingly.
2. **Feature enriching:** As the deployment has been developed in a time-constrained setting, there are numerous features to be implemented to improve on its effectiveness and efficiency. For example, since the current deployment makes use of Ansible, this opens up the opportunity to remotely deploy, maintain and monitor instances of the iNethi network. This would allow for external support, or even a centralized management center. By combining experience from a variety of context and aggregating network data from a range of networks, valuable insights can be obtained. This would also eliminate the need for physical on-site assistance, increase the networks management efficiency.
3. **Integrating monitoring and maintenance tools:** To support the long-term sustainability of the community wireless networks, the GUI installer can be extended to include monitoring and maintenance functionalities. This could involve integrating network performance monitoring tools, automatic update mechanisms, and troubleshooting features to ensure the stability and smooth operation of the installed network. Ultimately, the installer should be built as a native installer for each operating system. This however includes obtaining licenses and certificates, a daunting task that was out of scope for this thesis.
4. **Further enhancing usability:** Although the GUI installer has successfully been designed with a user-centered approach, continuous improvements can be made to enhance its usability further. Gathering feedback during future deployments in other communities from the community network administrators who will be the primary

users of the installer can provide valuable insights for refining the user interface, simplifying the installation steps, and addressing specific user needs.

5. **Collaborative development and knowledge sharing:** As the iNethi community wireless network expands and reaches more communities, fostering collaboration and knowledge sharing among network administrators and developers from these communities becomes crucial. Future work can focus on creating platforms or spaces for collaboration, where network administrators can share their experiences, best practices, and customized solutions for specific community needs.

By addressing these future directions, the GUI installer can continue to evolve and adapt to the changing needs and challenges of low-resource environments, ultimately contributing to the sustainable development of community wireless networks and bridging the digital divide.

9.3 Living Lab: Context Awareness

In this section, we will share our experience of developing the installer and discuss the contextual challenges that have not only impacted the overall research process but also our development workflow. We will first delve into the technologies used in terms of hardware and software during the development and testing phases and how we adapted to the environment. Subsequently, we will highlight the infrastructural challenges encountered, including the impact of load shedding and the challenges associated with a less efficient operating government. Note that these are rather specific cases related to more contextual general challenges and that this section is in no way exhaustive.

9.3.1 Technological Challenges

During the development of the installer, various hardware and software technologies were employed. Initially, the development was initiated on a Mac with an Apple Silicon M1 Pro CPU, which operates on the ARM64 architecture. However, it was decided to switch to a Linux-based system to better represent the production and deployment environment. Consequently, a Raspberry Pi Model 3B, running on the ARM64 architecture, was acquired. Subsequently, due to architectural compatibility issues with certain application services, development was continued on an Intel (AMD64) Mac, utilizing a virtual machine running Ubuntu 22.04 LTS. This setup allowed us to develop and test on a frequently encountered machine operating system and hardware configuration in the production space.

9. DISCUSSION

9.3.2 Contextual Challenges

One of the significant challenges encountered during the development process was load shedding. Generally, load shedding affected the availability of the internet in various locations, hindering smooth communication and access to online resources necessary for development and research activities. With a severely increasing and tighter load shedding schedule throughout the development phase, it necessitated careful planning and coordination to ensure optimal use of internet connectivity during periods when power was available. Moreover, it resulted in an unfortunate incident where an Intel NUC computer experienced a power surge and broke down. This incident highlighted the importance of power management and the need to consider backup power solutions to mitigate the risks associated with power interruptions. More specifically, there was an experience where load shedding also impacted the functionality of university laboratory doors, causing difficulties in accessing the workspace. This challenge required implementing alternative measures to ensure uninterrupted progress, such as working from power uninterrupted locations and acquiring backup power devices at home.

Other than infrastructural challenges, we encountered more fundamental challenges related to the functioning of the government. Specifically, we faced a situation where visa renewals became a pressing issue due to a overwhelmed government department. The Department of Foreign Affairs announced their inability to process all visa renewal applications, leading to a short notice requiring soon-to-expire tourist visa holders to leave the country. As our research was not yet finalized, this situation necessitated an additional return trip between South Africa and the Netherlands in order to obtain a visa renewal. This unexpected challenge highlighted the importance of being aware of potential disruptions caused by less efficient government processes and the need for researchers to consider the implications of such circumstances on their work.

By sharing these experiences and contextual challenges, we hope to shed light on the realities of conducting research and designing ICT solutions in low-resource environments. These insights can serve as valuable lessons for future researchers and practitioners, emphasizing the significance of adaptability, resilience, and foresight when addressing challenges and building technological solutions.

Conclusion

In this thesis, we have delivered on our promise to provide significant contributions to the field of ICT4D, and community wireless networks more specifically, by designing and building and successfully deploying a user-friendly, intuitive Graphical User Interface installer for the iNethi platform. Our contributions have been validated through iterative feedback gathering in the field and have provided valuable insights for further development and implementation.

First and foremost, we have successfully developed a user-friendly and intuitive GUI installer for iNethi, effectively lowering the barrier to entry for users with varying levels of digital literacy. By adopting a user-centered design approach and incorporating feedback from end users, we have created an installer that is accessible, easy to navigate, and requires minimal technical expertise. This achievement aligns with our objective of designing an ICT solution that empowers users in low-resource environments.

We have also conducted a comprehensive evaluation of the performance and effectiveness of the developed installer. Through workshops with University of Cape Town students and the Ocean View community, we have gathered valuable feedback on the installer's usability, effectiveness, and ability to meet the needs of users. This evaluation process has provided us with insights and opportunities for further refinement and improvement. The has resulting in a working application that is now the standard for installing the iNethi network system.

Our research has moreover critically examined the methods used in the design and implementation of the GUI installer. By applying the ICT4D 3.0 framework and leveraging user-centered design principles, we have demonstrated the importance of considering the specific challenges and constraints of low-resource environments. This evaluation of our methods contributes to the body of knowledge in designing ICT solutions for similar contexts, providing valuable insights and recommendations for future research. We can

10. CONCLUSION

conclude that our approach of Design Science and Action Research has proven successful and can be considered a working example of designing ICT services in low-resource environments.

Lastly, we have underscored the significant impact of technology choices and design decisions on the usability and accessibility of the installer within a community wireless network context. Through careful selection of technologies such as Electron, Ansible, and Node.js, we have created a solution that is cross-platform compatible, efficient, and adaptable. These technology choices, combined with user-centered design principles, have ensured the usability and accessibility of the installer, enabling users to easily deploy and maintain the iNethi platform.

We can now safely claim that our contributions have fulfilled the promises outlined in the introduction. We have successfully designed, developed and deployed a user-friendly, intuitive GUI installer for iNethi, validated its performance and effectiveness successfully, examined the methods used in its design and implementation with success, and demonstrated the impact of technology choices on usability and accessibility. These contributions have not only advanced the field of community wireless networks but also provided valuable insights and recommendations for future research. The developed GUI installer is now validated and has become the standard approach for installing the iNethi system, marking its success and significance in bridging the digital divide and empowering communities in low-resource environments.

References

- [1] MUJAAHID MULLAGEE AND LINAMANDLA PIKISA. **Building and Monetizing a Digital Community Radio Station on the iNethi Radio Network.** Unpublished, 2022. vii, 22, 28
- [2] KEEGAN WHITE, DAVID JOHNSON, MELISSA DENSMORE, AND HAFENI MTHOKO. **Bootstrapping the Development of Services for Wireless Community Networks.** In *Proceedings of Southern Africa Telecommunication Networks and Applications Conference*, Winterton, South Africa, November 2021. vii, 10, 11, 24, 25, 26
- [3] JAN VAN DIJK. *The digital divide.* John Wiley & Sons, 2020. 1
- [4] SONESH SURANA, RABIN PATRA, SERGIU NEDEVSCI, MANUEL RAMOS, LAKSHMINARAYANAN SUBRAMANIAN, YAHIEL BEN-DAVID, AND ERIC BREWER. **Beyond Pilots: Keeping Rural Wireless Networks Alive.** pages 119–132, 04 2008. 1
- [5] KRISH CHETTY, LIU QIGUI, NOZIBELE GCORA, JAYA JOSIE, WENWEI LI, AND CHEN FANG. **Bridging the digital divide: measuring digital literacy.** *Economics E-Journal*, **12**, 04 2018. 1, 3, 5, 14
- [6] ELIREA BORNMAN. **Information society and digital divide in South Africa: results of longitudinal surveys.** *Information, Communication & Society*, **19**:1–15, 07 2015. 1
- [7] LISA FINDLEY AND LIZ OGBU. **South Africa: From Township to Town.** *Places Journal*, November 2011. 1
- [8] BART BRAEM, CHRIS BLONDIA, CHRISTOPH BARZ, HENNING ROGGE, FELIX FREITAG, LEANDRO NAVARRO, JOSEPH BONICIOLI, STAVROS PAPATHANASIOU, PAU

REFERENCES

- ESCRICH, ROGER BAIG VIÑAS, AARON L. KAPLAN, AXEL NEUMANN, IVAN VILATA I BALAGUER, BLAINE TATUM, AND MALCOLM MATSON. **A Case for Research with and on Community Networks**. *SIGCOMM Comput. Commun. Rev.*, **43**(3):68–73, jul 2013. 2
- [9] CARLOS REY-MORENO AND MICHAEL GRAAF. **Map of the Community Network Initiatives in Africa**. 12 2016. 2
- [10] CARLOS REY-MORENO. *Supporting the Creation and Scalability of Affordable Access Solutions: Understanding Community Networks in Africa*. Internet Society, 2017. 2
- [11] INETHI COMMUNITY. **iNethi: Building Community Networks**. <https://inethi.net/>, 2023. 2
- [12] ANNA BON, HANS AKKERMANS, AND JAAP GORDIJN. **Developing ICT Services in a Low-Resource Development Context**. *Complex Systems Informatics and Modeling Quarterly*, No **9** (2016):84–109, 12 2016. 3, 5, 6, 24, 31
- [13] DONALD A NORMAN AND STEPHEN W DRAPER. **User-centered system design: New perspectives on human-computer interaction**. 1986. 5
- [14] CHADIA ABRAS, DIANE MALONEY-KRICHMAR, JENNY PREECE, ET AL. **User-centered design**. *Bainbridge, W. Encyclopedia of Human-Computer Interaction*. Thousand Oaks: Sage Publications, **37**(4):445–456, 2004. 5, 31
- [15] JONATHAN HYSLOP. **Political Corruption: Before and After Apartheid**. *Journal of Southern African Studies*, **31**:773–789, 2005. 9
- [16] STATISTICS SOUTH AFRICA. **Beyond unemployment – Time-Related Under-employment in the SA labour market**, May 2023. Accessed: June 18, 2023. 9
- [17] SUSAN MOSES. **Does space and place matter? perspectives from girls growing up in a Cape Town neighbourhood created under apartheid**. Technical report, University of Cape Town, 2005. Available at OpenUCT: <https://open.uct.ac.za>. 10
- [18] AMREESH PHOKEER, MELISSA DENSMORE, DAVID JOHNSON, AND NICK FEAMSTER. **A First Look at Mobile Internet Use in Township Communities in**

REFERENCES

- South Africa.** In *Proceedings of the 7th Annual Symposium on Computing for Development*, ACM DEV '16, New York, NY, USA, 2016. Association for Computing Machinery. 11
- [19] ANDRE VAN ZYL AND DAVID LLOYD JOHNSON. **INethi: Locked down but Not Locked Out.** *XRDS*, **27**(2):54–57, dec 2020. 11
- [20] SAURABH JAIN AND D.P. AGRAWAL. **Wireless community networks.** *Computer*, **36**(8):90–92, 2003. 14
- [21] PIETER HOPPENBROUWERS. **Software Design for Community Wireless Networks in the Global South, A Literature Study.** Unpublished literature study, 2023. 14, 15
- [22] MARIA ROSA LORINI, MELISSA DENSMORE, DAVID JOHNSON, SENKA HADZIC, HAFENI MTHOKO, GANIEF MANUEL, MARIUS WARIES, AND ANDRE VAN ZYL. *Localize-It: Co-designing a Community-Owned Platform: European Conference, ECML PKDD 2018, Dublin, Ireland, September 10–14, 2018, Proceedings, Part III*, pages 243–257. 01 2019. 14
- [23] CARLOS REY-MORENO AND MICHAEL GRAAF. *Map of the Community Network Initiatives in Africa.* 12 2016. 20

REFERENCES

Appendix A




GUI Installer Mockups

	Welcome to the iNethi installer
<div><div>1</div> Introduction</div> <div><div>2</div> Server config</div> <div><div>3</div> Module selection</div> <div><div>4</div> Installation</div> <div><div>5</div> Summary</div>	<p>You will be guided through the steps necessary to install this software.</p> <p>By installing this application, you are accepting the Terms of Service and Privacy Statement and are consenting to receive communications, updates, and upgrades for iNethi services. iNethi may collect usage data and personal information, such as your email address, from your computer or device for the operation of the iNethi service.</p> <div><div>Back</div><div>Next</div></div>
© iNethi 2023	

	Server config
<div><div>1</div> Introduction</div> <div><div>2</div> Server config</div> <div><div>3</div> Module selection</div> <div><div>4</div> Installation</div> <div><div>5</div> Summary</div>	<p>Please enter the requested details from the server where you want to install iNethi. The installer will attempt to connect to the server, after which upon success the installation will continue.</p> <div><div>Server IP address</div><div>192.168.0.1</div><div>Server username</div><div>root</div><div>Server password</div><div>oooooooo</div></div> <div><div>Back</div><div>Next</div></div>
© iNethi 2023	

	Server config
<div><div>1</div>Introduction</div>	<div>Please enter the requested details from the server where you want to install which upon</div> <div>Connecting to server</div> <div><div></div><div></div><div></div><div></div></div>
<div><div>2</div>Server c</div>	
<div><div>3</div>Module s</div>	
<div><div>4</div>Installati</div>	
<div><div>5</div>Summar</div>	
© iNethi 2023	<div>BackNext</div>

	Server config
<div><div>1</div>Introduction</div>	<div>Please enter the requested details from the server where you want to install which upon</div> <div>Connecting to server</div> <div><div>✓</div></div>
<div><div>2</div>Server c</div> <div><div>3</div>Module s</div> <div><div>4</div>Installati</div> <div><div>5</div>Summar</div>	<div><div>Back</div><div>Next</div></div>
© iNethi 2023	

	Module selection
<div><div>1</div> Introduction</div> <div><div>2</div> Server config</div> <div><div>3</div> Module selection</div> <div><div>4</div> Installation</div> <div><div>5</div> Summary</div>	<p>Please select the modules you want to install during on your iNethi service. Modules can also be installed afterwards. Note: Installing modules requires the installation of docker and docker-compose. If these are not installed, these will be installed additionally. Moreover, the installation requires a few required modules for the system to function properly.</p> <div><div> Jellyfin</div><div> WordPress</div><div> AzuraCast</div></div> <div><div>✓</div><div></div><div>✓</div></div>
© iNethi 2023	<div>BackNext</div>

	Installation
<div><div>1</div> Introduction</div> <div><div>2</div> Server config</div> <div><div>3</div> Module selection</div> <div><div>4</div> Installation</div> <div><div>5</div> Summary</div>	<div>Please wait while the selected modules are being installed on your server.</div> <div><div></div></div> <div>Installing docker-compose-7.8.1...</div> <div><div>►</div> See logs</div>
© iNethi 2023	

1 Introduction

2 Server configuration

3 Module selection


4 Installation

5 Summary

Summary

The installation was successful. You can now close this window.

Installation successful

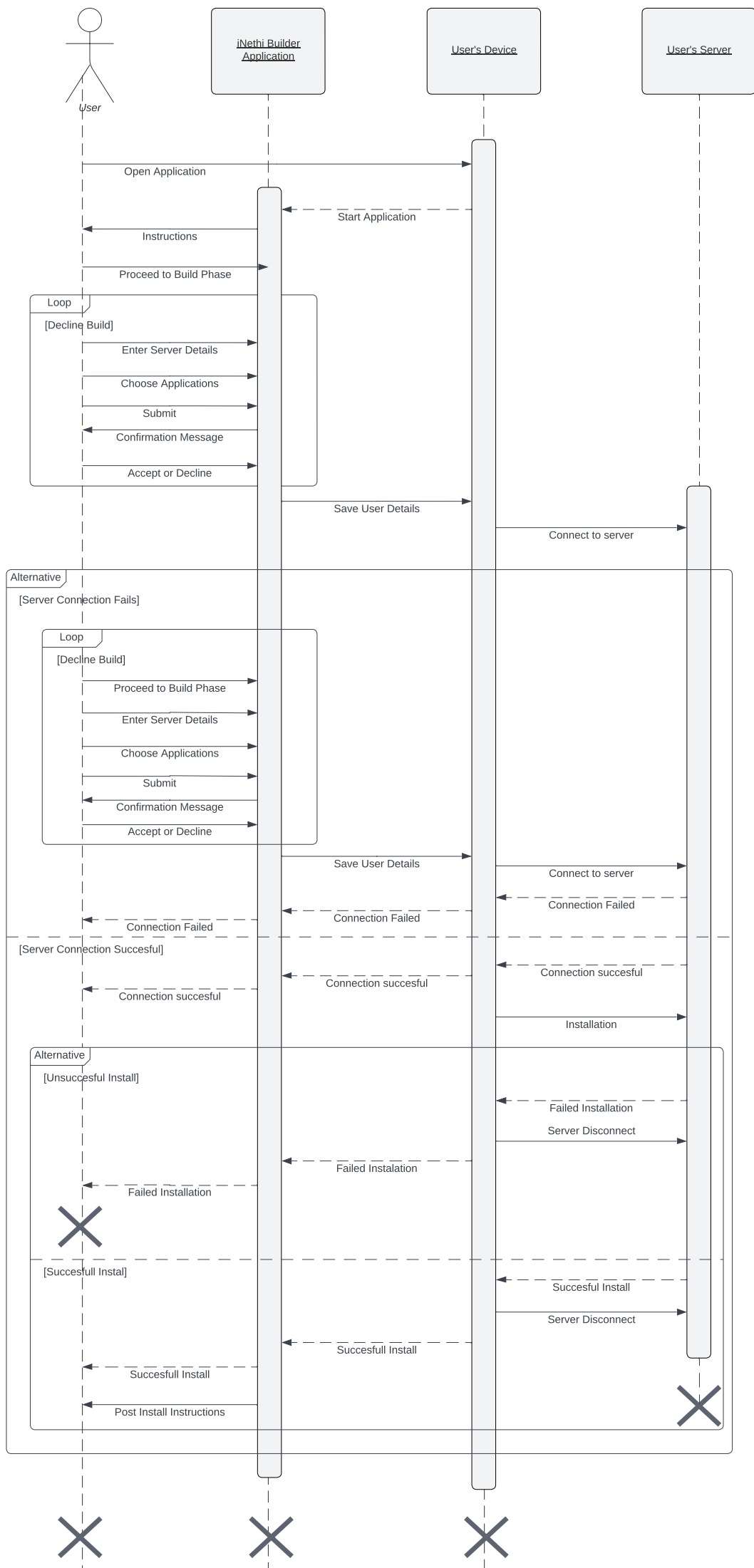


Close

© iNethi 2023

Appendix B

Installer Sequence Diagram



Appendix C

iNethiRadio Workshop Ethics Application

UNIVERSITY OF CAPE TOWN
SCIENCE FACULTY RESEARCH ETHICS STATEMENT

Application to the Science Faculty Research Ethics Committee for research involving human subjects

All applicants

Please submit the form (in the original MS Word format) to <https://universityofcapetown.submittable.com/submit>

This form must be completed electronically (i.e. typed) by students and supervisors, and submitted as a Word document as indicated above. The fields are expandable (horizontally and vertically). Use Enter when you get to the end of the page, to prevent the fields from spilling too far on the horizontal axis. Attachments will not be considered except as specified in the form.

For more information on apply for clearance to proceed with research involving human subjects, please visit the [Science Faculty website](#).

Questions?

Please send queries to your departmental contact or directly to sci-rec@uct.ac.za

Chair: A/Prof Melissa Densmore, melissa.densmore@uct.ac.za

Servicing Officer: Ka Wai Cawood, sci-rec@uct.ac.za

Computer Science Subcommittee: csethics@cs.uct.ac.za

Environmental and Geographical Science Subcommittee: egsethics@uct.ac.za



A. STUDENT AND SUPERVISOR DETAILS

A.1	Applicant personal particulars (required): <i>You may enter more than one name here, if this is a group project.</i>		
	Title and name(s): Holly Judge; Pieter Hoppenbrouwers		
	Email(s): jdghol001@myuct.ac.za		
	Telephone:	071 492 2346	Mobile number: 071 492 2346
	Department(s): Department of Computer Science		
A.2	Supervisor or Principal Investigator particulars (required):		
	Staff no: 01445055		
	Title and name(s): Prof. Melissa Densmore		
	Telephone:	021 650 4315	Mobile number: 0796721262
	Email: melissa.densmore@uct.ac.za		
	Department: Department of Computer Science		
A.3	Collaborators (optional): This will include any external collaborators or research assistants that are involved in this project.		
	Title and name	Institution	Role
	Ganief Manuel Esona Makinana	Black Equations	Local Facilitator and Collaborator Local Facilitator and Collaborator
A.4	Project (required): <i>The title of the project should be suitably descriptive of the work entailed.</i>		
	Title		iNethiRadio
	Project duration (month/year – month/year)		04/2023 – 10/2023
	Purpose (tick)		
	Honours Project		✓
	Masters by coursework and dissertation		
	Masters by dissertation only		
	PhD thesis		
	Academic research		
	Contract-funded research		
	Other research (please specify)		✓ Exchange program - masters



B. PRE-REQUISITES (all answers required)

B.1	<p>Have you read the UCT Research Ethics Code for Research Involving Human Participants?</p> <p>Yes <input checked="" type="checkbox"/> No <input type="checkbox"/></p>
B.2	<p>Are you applying for expedited review?</p> <p>Computer Science and Environmental and Geographical Science: You are only eligible for expedited review if your project meets the criteria detailed on p.1 of this form</p> <p>Yes <input checked="" type="checkbox"/> No <input type="checkbox"/></p>
B.3	<p>Is your research making use of human participants or subjects as sources of data?</p> <p>Human subject means a living individual about whom an investigator (whether professional or student) conducting research obtains (1) data through intervention or interaction with the individual, or (2) identifiable private information, which includes a subject's opinion on a given topic.</p> <p>Yes <input checked="" type="checkbox"/> No <input type="checkbox"/></p>
B.4	<p>Is your research making use of third-party data?</p> <p>If yes, please (i) give details in section C1 about the nature of the data, how it was acquired, and any restrictions on its use, (ii) answer section B5 below with respect to the custodian/source of the data, (iii) ensure you address in sections C and D the ethical issues related to your use of the data, including the process by which permission was sought from participants for the anonymised use of their data. If free and prior informed consent was NOT sought by the custodian of the data, please provide an explanation and briefly reflect on the ethical implications of this for your own research.</p> <p>Please note that a clearance certificate is not required by the FSREC for use of <u>anonymised</u> third party data, although you should still consider ethical implications of your work and seek proper permissions from the custodian of the data for its use. However, if the data custodian or another entity requires ethics clearance, please clearly state the reasons for the requirement in B5. If you are using <u>non-anonymised</u> data, please detail your data storage and protection procedures in C1.</p> <p>Yes <input type="checkbox"/> No <input checked="" type="checkbox"/></p>
B.5	<p>Does your research require express permission from a third party, such as governments, property owner(s), occupier(s) or manager(s), or other institutions?</p> <p>Yes <input type="checkbox"/> No <input checked="" type="checkbox"/></p> <p>Please state from whom permission is required:</p> <p>Not applicable.</p> <p>Have you received permission to proceed?</p> <p>If yes, please attach or append a copy of the permission, or explain the nature of the permission received. If no, please provide an explanation.</p> <p>Yes <input type="checkbox"/> No <input type="checkbox"/></p> <p>Not applicable.</p>



B.6	<p>Is your research being conducted within a National Park or Nature Reserve (or similar) or any other area for which a permit is required?</p> <p>Yes <input type="text"/> No <input checked="" type="checkbox"/></p> <p>Please state from whom permission is required:</p> <p>Not applicable.</p> <p>Have you obtained the required permit?</p> <p>If yes, please attach or append a copy of the permit. If no, please provide an explanation.</p> <p>Yes <input type="text"/> No <input type="text"/></p> <p>Not applicable.</p>
B.7	<p>Does your research intend to make use of UCT students or staff as participants?</p> <p>For research involving UCT students you must send a DSA100 form with your clearance certificate to the Executive Director of the Department of Student Affairs (DSA) for approval to conduct this research. For research involving UCT staff, you must submit the HR194a or HR194b form with your certificate to the Executive Director of the Human Resources Department for approval to conduct the research. You will need to first receive ethical clearance from the Science Faculty Research Ethics Committee (FSREC). For more information, please see the UCT Research Support Hub.</p> <p>Yes <input type="text"/> No <input checked="" type="checkbox"/></p>

C. RESEARCH FOCUS (required, maximum 500 words, may not exceed this page)

C.1	<p>In the space below state your research aim and objectives (or questions); briefly outline your plans for data collection and indicate the nature/type of information you will be seeking from the participants in your research. <u>Please clearly indicate the number of participants you envisage and how you will recruit them for your research.</u> Do NOT submit additional documents. Your proposal will be evaluated on information in this form alone.</p> <p>Please note that ethics applications are reviewed by a multi-disciplinary committee and should be written in a manner that does not assume specialist knowledge. For this reason, acronyms/ abbreviations should be written out in full the first time they are used, followed by the shortened version in brackets.</p> <p>Overview: iNethi is a software platform that supports local service hosting and network management of community wireless networks. iNethi offers residents low-cost access to the internet as well as access to several local services, of which iNethiRadio will be one. The radio service is an instance of AzureCast.</p> <p>Research aims: This research aims to understand community requirements around features, content creation and ownership of iNethiRadio. We will work with several organizations and communities in South Africa that have expressed interest in digital community radio (Ocean View, Cape Town; Sweetwaters, KZN; Ga-Dikgale, Limpopo; and Khayelitsha, Cape Town) to deploy iNethiRadio and onboard the community in using the service. A global iNethiRadio will also be developed, syncing locally hosted radio content to AWS, which can in turn be synced to other local instances of iNethiRadio. The research also aims to discover how the community radio is bolstering existing local mechanisms of empowerment, it's usability and the engagement with the platform. The overarching research questions of this study are: <i>What are community-centred requirements for a locally hosted community radio?</i> and <i>What approaches foster engagement with a locally hosted community radio?</i></p> <p>Data collection: Workshops will be held with each community to demonstrate the radio, co-design and get feedback. Furthermore, this study will monitor the use of the radio throughout the duration of the study. As far as possible, the timing and format of the workshops will be community-led. Workshop participants will include DJs, music artists, community leaders, and content creators. We will work with our local partner organizations to recruit participants. Initially, participants will be compensated for travel costs and given an incentive. But later workshops, organized by the community, will not necessarily entail remuneration; this is to ensure that ongoing participation is intrinsically motivated.</p> <p>Approximate dates for workshops are as follows:</p> <ol style="list-style-type: none"> 1. 20 May-22 May <ul style="list-style-type: none"> - Discussion of current music sharing practices, needs, ethics, ownership and global iNethiRadio. Training and introduction to iNethiRadio. Initial content creation. 2. 22-23 July <ul style="list-style-type: none"> - Evaluation and feedback of the platform following deployment. Ongoing training and content creation. Demonstrate and deploy global iNethiRadio. 3. 5-6 August <ul style="list-style-type: none"> - Evaluation and feedback on the platform. Training and deployment of new version (if necessary). 4. 19-21 August <ul style="list-style-type: none"> - Evaluation and feedback on the platform. Handover- ongoing community ownership and maintenance of system. Feedback on findings. <p>The workshops will all be from 10am-4pm with a lunch break at 1pm. It is difficult to be explicit about the numbers in each workshop, but we will try to keep workshop numbers relatively small (7-10 participants), holding more workshops if additional participants would like to participate, but also encouraging community members to organize their own events related to the service. Workshops are an explicit data collection point, but this research will also be ethnographic in the sense that this will be an ongoing engagement with each community.</p>



D. PARTICIPANT PROCEDURES (all answers required)

D.1	<p>Information</p> <p>Will research participants have reasonable and sufficient knowledge about you, your background and location, and your research intentions?</p> <p>By ticking the 'Yes' box, you declare that you have completed and will use the informed consent form appended to this statement, and that <u>whether you are seeking written or verbal consent</u>, you will explain the content of the consent form verbally to each participant. Any other information you want to provide to strengthen your application with respect to the provision of information may be included in the box below. If your answer is 'No', please provide justification.</p> <p>Yes <input checked="" type="checkbox"/> No <input type="checkbox"/></p> <p>Clear details of the study and its purpose will be explained prior to consent being requested.</p> <p>How will you provide feedback to the participants or other stakeholders in your study? Ideally this might be in direct communication at the end of your study, in a feedback workshop. Feedback should be shared in a way that is accessible to your participants (e.g. a suitable summary rather than a copy of the dissertation).</p> <p>The researcher and the broader team working on the iNethi honours project will host a feedback workshop with the community, inviting all those who participated and other community members who are interested in the findings. The decision to host a workshop is because this project directly affects these communities, and a high-level summary sent to the community leaders of the iNethi project is less likely to reach a broader population. Investment in an additional workshop provides a better means to express gratitude to the community for their participation than an impersonal summary can offer. At this point in the project, community members will also be familiar with workshops as opposed to receiving and having to read abstract written reports. For these reasons, an in-person feedback workshop feels more respectful of the community and their contribution.</p>
D.2	<p>Consent</p> <p>Will you secure the free and prior informed consent of all participants in the research?</p> <p>Please provide your procedure for securing informed consent of all participants in the box below and that you complete the informed consent form at the end of this document with the particulars of your project or include the form or script you will use. You are not obligated to use the template provided but should use and include something appropriate for participants and your research methods. If you choose to use the template please complete the header with your contact details and ensure that you replace all content in <i>[square brackets]</i> with information specific to your project.</p> <p>By ticking the 'Yes - Written' or 'Yes - Oral' box, you declare that you:</p> <ul style="list-style-type: none"> commit to ensuring that each participant understands the informed consent statement, agrees to participate, before any research begins retain a record of informed consent, either by keeping a copy of the signed form, or in the case of oral consent, recording time and place of consent in writing with the signature of a witness, or on an audio device will give the participant a copy of the signed form and keep a second copy for yourself (in the case of written consent) <p>Yes - Written <input checked="" type="checkbox"/> Yes - Oral <input type="checkbox"/> No <input type="checkbox"/></p> <p>All applicants must complete the box below.</p> <p>If you ticked 'No', also explain why waiver of prior informed consent is required.</p>



	<p>Any other information you want to provide with regard to consent may also be included in the box below, including any plans required to translate the form or oral informed consent script into the language of research participants, and a brief motivation for oral consent if applicable</p> <p>At the start of workshops, there will be a briefing about the project, it's aims, as well as the expectations of the participants and researchers. Researchers will be identified as well as the fact that UCT is sponsoring this research. Researchers will iterate the key aspects of informed consent: that participants can withdraw at any time, that all data collected is confidential, the benefits and risks to the participant, and contacts in case of questions or issues. This briefing will happen at each workshop in case additional participants join a workshop without attending the previous one. A more specific briefing will then happen regarding the workshop taking place: what this workshop in particular aims to do and what is expected of researchers and participants in that workshop. Participants will be provided with a consent form reiterating what has already been said. The floor will then be opened for questions where the researchers should provide additional information when requested. At this stage, participants will be equipped with enough information to complete the consent form.</p>				
D.3	<p>Recording</p> <p>Will you take photographs, audio recordings or videos of your participants?</p> <p>Photographs, audio, and video recordings contain personally identifiable information, even if the face is not visible, and may also be prohibited by certain individuals and cultures or violate people's rights to privacy.</p> <p>By ticking the 'Yes' box, you declare that you:</p> <ul style="list-style-type: none">• will commit to asking permission prior to initiating any photograph or recording• will not photograph or record participants who have declined• will seek the free and informed consent of participants prior to using any recordings or photographs in publications, project websites, presentations, social media or other means of dissemination. <p>If yes, please provide (i) a rationale for using such material in your research, (ii) the procedure for securing consent for recordings (this may entail modifications to the consent form), (iii) an explanation of how you intend to use the material and (iv) how you will store the recordings.</p> <p><i>Please ensure that the content of this section aligns with the informed consent statement at the end of this form.</i></p> <table border="1"><tr><td>Yes</td><td><input checked="checked" type="checkbox"/></td><td>No</td><td><input type="checkbox"/></td></tr></table> <p>Pictures will be taken during workshops if paper prototypes or sketches are created. However, identifying pictures will not be taken. We will ask for permission prior to taking any photos and seek approval of any photos taken. These photos may be shared amongst the participants.</p> <p>Audio recordings will be taken during interviews for data analysis purposes. Consent will be requested orally prior to the interview and those who do not consent will not be recorded. Recordings will be stored on the recording device until transcribed, after which they will be deleted. Audio recording allows for a more smooth and natural conversation to take place as note taking can distract participants.</p>	Yes	<input checked="checked" type="checkbox"/>	No	<input type="checkbox"/>
Yes	<input checked="checked" type="checkbox"/>	No	<input type="checkbox"/>		
D.4	<p>Confidentiality</p> <p>Are you able to offer privacy and confidentiality to participants, if they wish to remain anonymous?</p> <p>The default requirements of the Science Faculty Research Ethics Committee are to assure that either:</p> <ul style="list-style-type: none">(a) study data are de-identified (identifiers are stripped or separated), or(b) data are collected without identifiers (anonymous).				



	If you wish to use the names and organisational affiliations of participants in your research:		
	(i) tick 'No', (ii) provide a reasoned motivation in the box below why you are adopting this approach, indicating why this does not have ethical implications for the participants, and (iii) modify the appended prior informed consent form appropriately so that it reflects a participant's agreement that you may use his or her name and/or affiliation together with the information they provided.		
	If there are any aspects of your research where there might be difficulties or problems with regard to protecting the confidentiality and rights of participants, and honouring their trust, explain this in detail below.		
Yes	<input checked="checked" type="checkbox"/>	No	<input type="checkbox"/>
The researcher will anonymise the data collected.			



D.5	<p>Potential harm for participants</p> <p>Outline any foreseeable risks of legal, physical, psychological, or social harm or suffering to participants and/or the environment, which might result from, or occur in the course of, this research.</p> <p>Please include what these risks might be and what preventative steps you plan to take to avoid or minimise such harm from being suffered and include a summary of these risks in the appended prior informed consent form. Residual risks are to be balanced by your response to question D.8 below (on the benefits of the research). If there are no foreseeable risks beyond what your participants may encounter in everyday life, state that this is the case.</p> <p>The researchers are working with underserved communities, and discussions regarding the factors that have resulted in bandwidth constraints (such as unemployment and poverty) may arise. Sensitive topics regarding unemployment and poverty, by way of example, may cause stress, emotional pain, or make the community members feel insulted and that we are limiting their identity to that of “disadvantaged”. Awareness and sensitivity on the part of the researchers. Careful use of language, avoiding triggering adjectives that the community may not identify with. Seeking the guidance of qualified counsellors in the event of psychological harm. Participants will also be informed that they can leave the study at any point if they feel it is causing harm.</p> <p>Power differentials that may arise due to the researchers being outsiders to the communities and the researchers coming from a university setting. The researchers will seek the support of local facilitators from the communities. The local facilitators will assist in co-facilitating workshops and assist with the interview process. This collaboration both brings an insider and familiar voice to the process and creates an opportunity to build capacity so that the facilitators may continue the work in the future should they choose to.</p> <p>Building expectations that may not be met. Constant engagement with partners and participants to manage expectations. This engagement will be in the form of open discussions about the study and anticipated outputs. The researchers will encourage participants and community partners to share any concerns as they arise, and the researchers will reciprocate this effort.</p>					
D.6	<p>Potential for harm to UCT or other institutions</p> <p>Are there any foreseeable risks of harm to UCT, or to other institutions, that might result from or occur in the course of the research, for example, legal action resulting from the research; or the image of the university or another institution being adversely affected by association with the research (such as a school being compromised in the eyes of the Department of Education)?</p> <p>If your answer is ‘Yes’, give details below (to be balanced by your response to question D.8 below).</p> <table border="1" data-bbox="347 1525 895 1581"> <tr> <td>Yes</td> <td><input type="text"/></td> <td>No</td> <td><input checked="" type="checkbox"/></td> <td></td> </tr> </table> <p>Not applicable.</p>	Yes	<input type="text"/>	No	<input checked="" type="checkbox"/>	
Yes	<input type="text"/>	No	<input checked="" type="checkbox"/>			
D.7	<p>Other conceivable ethical issues</p> <p>Are there any other ethical issues that you think might arise during the course of the research (e.g., with regard to conflicts of interest amongst participants and/or institutions)?</p> <p>If your answer is ‘Yes’, give details in the box below and say what you plan to do to minimise any adverse consequences (to be balanced by your response to question D.8 below).</p> <table border="1" data-bbox="347 1832 895 1888"> <tr> <td>Yes</td> <td><input type="text"/></td> <td>No</td> <td><input checked="" type="checkbox"/></td> <td></td> </tr> </table> <p>Not applicable.</p>	Yes	<input type="text"/>	No	<input checked="" type="checkbox"/>	
Yes	<input type="text"/>	No	<input checked="" type="checkbox"/>			
D.8	<p>Benefits to science, to participants and others</p> <p>Summarize the benefits of your research.</p>					




	<p>The core task of research ethics committees is to balance the benefits of research against risks or potential harm that may ensue, as per sections D.5, D.6, and D.7 of this form. In the space below summarise the benefits of your research.</p>
	<p>Benefits to participants: The desired benefit of the research is that community members in Ocean View, and potentially the other communities where iNethi is deployed, will be able to run and engage with a web-based community radio where they can distribute local content. The goal is for the community to benefit from this service.</p> <p>Benefits to research: This research aims to understand community desires around features, maintenance, and sustainability of the iNethiRadio. Furthermore, the research aims to explore approaches that will enhance the engagement with and sustainability of the iNethiRadio, and thus contribute to the broader Human Computer Interaction research on uptake of ICT projects in underserved communities.</p> <p>Previous research in the community has shown that a community radio is an in-demand service. However, it cannot yet be determined that the radio service meets the community needs, and if it fails to meet those needs, the radio will not be used. The researcher will tailor the radio to better meet those needs of the community when issues arise. However, should the radio still prove to not be useful or useable by the community by the end of the project's duration, the benefits of the research will have been to discover the real needs of the community members with regards to a web-based radio station hosted on a community wireless network in a low-income area, and where this project fell short. The benefits will also be to see what approaches do not work in encouraging engagement. Suggestions for further study will be offered and hopefully the research is continued by other students and academics.</p>



D.9	Publication of results			
	Research projects ideally result in publication of the results. Have you and your supervisor/PI read and agreed to the principles regarding authorship as set out in the UCT Authorship Practices Policy ?			
	Yes	<input checked="" type="checkbox"/>	No	<input type="checkbox"/>

E. SIGNATURES

E.1	Endorsement by Applicant			
	Title and Names	Miss Holly Judge and Mr Pieter Hoppenbrouwers		
	Signature		Date	21 April 2023
E.2	Endorsement by Supervisor or Principal Investigator			
	By signing below, I certify that I have assisted the applicant to identify ethical issues pertaining to his or her research; that I have reviewed this ethics application, including the informed consent form overleaf, and am satisfied that it is accurate and adequately communicates information about the proposed research			
	Comments			
	Title and Names			
Signature		Date		

DEPARTMENT OF COMPUTER SCIENCE

UNIVERSITY OF CAPE TOWN
PRIVATE BAG X3
RONDEBOSCH 7701
SOUTH AFRICA

RESEARCHER/S: Holly Judge
TELEPHONE: +27 71 492 2346
E-MAIL: jdghol001@myuct.ac.za
URL: <https://sit.uct.ac.za>



Informed Voluntary Consent to Participate in Research Study

Project Title: iNethi Radio

Invitation to participate, and benefits: You are invited to participate in a research study conducted with Ocean View community members. The study aim is to invite community members to engage with the new radio service and discuss the usability of the radio and ways in which it can be improved. The study aims to understand how and if the community radio is beneficial to the community. I believe that your experience would be a valuable source of information, and hope that by participating you may gain useful knowledge.

Procedures: During this study, you will be asked to participate in workshops and discuss how the iNethi radio could work in your community.

Recording: We may take photographs and/or record audio/video as part of the study. These will be used to capture any sketches or paper prototypes made during the workshops so we can better understand how to improve the radio. If you object to this, please indicate below.

Risks: There are no potentially harmful risks related to your participation in this study.

Feedback: You will receive feedback about the results of this research through a feedback workshop hosted at the end of the project.

Disclaimer/Withdrawal: Your participation is completely voluntary; you may refuse to participate, and you may withdraw at any time without having to state a reason and without any prejudice or penalty against you. Should you choose to withdraw, the researcher commits not to use any of the information you have provided without your signed consent. Note that the researcher may also withdraw you from the study at any time.

Confidentiality: All information collected in this study will be kept private in that you will not be identified by name or by affiliation to an institution. Confidentiality and anonymity will be maintained as pseudonyms will be used.

What signing this form means: By signing this consent form, you agree to participate in this research study. The aim, procedures to be used, as well as the potential risks and benefits of your participation have been explained verbally to you in detail, using this form. Refusal to participate in or withdrawal from this study at any time will have no effect on you in any way. You are free to contact me, to ask questions or request further information, at any time during this research.

I agree to participate in this research (tick one box)	<input type="checkbox"/> Yes	<input type="checkbox"/> No _____ (Initials)
I agree to be photographed	<input type="checkbox"/> Yes	<input type="checkbox"/> No _____ (Initials)
I agree to be audio-recorded	<input type="checkbox"/> Yes	<input type="checkbox"/> No _____ (Initials)
I agree to be video recorded	<input type="checkbox"/> Yes	<input type="checkbox"/> No _____ (Initials)
I agree to the use of anonymized photographs/audio recordings/videos in publications, presentations, and websites	<input type="checkbox"/> Yes	<input type="checkbox"/> No _____ (Initials)

Name of Participant

Signature of Participant

Date

Name of Researcher

Signature of Researcher

Date