Designing Frugal Embodiments



a Skin Diagnostic Device for Uganda

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Glossary

Atopic dermatitis	The most common form of eczema. A chronic, relapsing inflammatory skin disease with dry skin, eczematous lesions and ntense itch.
Clinical officer	Mid level health professional who diagnoses and treats patients. One of the main staff groups at HC III.
Colour temperature (K)	The warmth or coolness of light, in kelvin. Around 5000 K is a cold, white light.
DCPA	Dermatitis cruris pustulosa et atrophicans. A chronic skin condition of the lower legs seen mainly in tropical countries.
Dermatoscope	Handheld magnifier with built in light used to examine the skin.
Eczema	Umbrella term for inflammatory skin conditions. In this thesis it refers to atopic dermatitis.
Edge AI	AI that runs on the device itself rather than on a server, so no internet connection is needed.
Embodiment	The physical form of the device as a whole, including its enclosure, shape, materials, internal layout and the way it is manufactured, assembled and held.
FDM	Fused Deposition Modeling. 3D printing by melting plastic filament layer by layer.
Folliculitis	Inflammation of the hair follicles.
Frugal MedTech	Frugal medical technology: devices designed from the start around the constraints of their context of use.
HC II, III, IV	Tiers of Ugandan public health centres.
Heat set insert	Threaded brass insert pressed into plastic with heat, allowing screws to be fastened and removed repeatedly.
HREC / REC	Human Research Ethics Committee (TU Delft) / Research Ethics Committee (Mbarara University of Science and Technology).
IP54	Ingress Protection rating: protected against limited dust ingress and splashing water.
Lichenification	Thickened, leathery skin caused by chronic scratching.
Likert scale	A rating scale on which respondents state how strongly they agree with a statement, from strongly disagree to strongly agree.
Lux	Unit of illuminance, used here for the light falling on the skin.
PCB	Printed Circuit Board
PETG / PLA	Common plastics for FDM printing.
Power grip	A hold in which the fingers wrap around a handle and the thumb closes against them, like holding a hammer.

Psoriasis	Chronic immune mediated disease that produces thick, scaly plaques.
PUVA	Psoralen plus ultraviolet A light therapy.
RH	Relative Humidity
RtD	Research through Design.
Scarring alopecia	Permanent hair loss caused by scarring of the skin.

Abstract

Skin conditions such as Dermatitis Cruris Pustulosa et Atrophicans, eczema and psoriasis are common in Uganda, yet accurate diagnosis at primary care level is rare. With only 12 dermatologists for over 45 million people, patients at Health Centre III facilities are assessed by non dermatologists such as nurses and clinical officers, and visually similar conditions are frequently misdiagnosed, delaying treatment. This thesis continues three earlier student projects that designed a diagnostic device for DCPA on the lower leg. As a Dutch Industrial Design Engineering student this project is also continued remotely from the Netherlands. Because health practitioners need help telling apart the conditions they actually see, the device now addresses three conditions across the whole body, which changes its physical design. Using Research through Design, the thesis examines how frugal engineering principles can shape the embodiment of this device for HC III. Through iterative prototyping loops, continuously checking with the context of use, the design explored trade offs between local manufacturability, repairability and context fit. The final design direction is turned into a final prototype consisting of an FDM printable handheld device with integrated lighting and distance guide, display and screw fasteners. The thesis contributes a set of generalizable design principles for frugal medical devices in low resource settings: Local users and makers must constantly be involved during the design process, Make designing a shared process, Design around national constraints, Shape the design by local tools and materials, Limit components and enforce behaviour with the embodiment, Let local supplies determine the components, Design for changeable components.

AI Disclosure Statement

During the making of this report Claude (Anthropic) was used to assist with structuring, drafting and refining written text. All content was reviewed, verified and edited afterwards. No AI was used to generate research findings, analyse data, or produce the visual materials included in this report.

Preface

This MSc thesis is conducted as a sub project within a broader PhD project led by M. Galiwango: Image Classification in Dermatology: Real-Time Diagnosis of DCPA using Edge Computing. That project develops and validates an edge based deep learning device to help healthcare practitioners diagnose DCPA, a poorly documented skin condition, and assesses its usability and acceptability in the healthcare system. This thesis contributes by focusing on the physical embodiment of the diagnostic device: its form, materials, manufacturing method and interface. The diagnostic algorithm, clinical validation and other components fall outside the scope of this thesis and are addressed elsewhere within the PhD project.



Figure 1. HC III Waiting Area Photographed by M.Galiwango, 2026.

1. Introduction

This thesis is about designing the physical embodiment of a device that helps healthcare practitioners diagnose skin conditions in Uganda. The device is meant for Health Centre III facilities, where skin conditions are assessed by non-specialists, and it is designed to be produced and repaired locally. The thesis examines how frugal engineering principles can shape this embodiment, and which design principles can be learned from doing so. It is a sub project within a broader PhD project and it was carried out remotely from the Netherlands.

This chapter sets out the clinical and systemic problem, explains the healthcare setting the device is designed for, and shows how this thesis fits within the PhD project and continues earlier work. It then states the aim and research questions and outlines the approach.

1.1 Context and Problem

An estimated 2 billion people are affected by skin disease worldwide (World Health Organization, 2025). It is a health problem across sub-Saharan Africa, including Uganda, where 13.5% of schoolchildren report having had eczema (Mpairwe et al., 2021) and nearly 4% of patients attending the skin clinic at Mbarara Regional Referral Hospital are diagnosed with psoriasis (Lubwama et al., 2025). Dermatitis Cruris Pustulosa et Atrophicans (DCPA) was first described in West Nigeria in 1952 (Clarke, 1952). It is frequently encountered in tropical settings but remains poorly recognised in Uganda (Mulyowa et al., 2026) and is often confused with similar looking conditions (Enechukwu & Ogun, 2024). This thesis focuses on three of these conditions: DCPA, eczema and psoriasis. Specialist care is scarce. Uganda has 12 dermatologists for over 45 million people (Mundeli et al., 2025). Non specialists show markedly lower diagnostic agreement than dermatologists, at 44% compared with 71% (Bourkas et al., 2023), and eczema, psoriasis and DCPA look very similar. Patients with one of these conditions are therefore at risk of misdiagnosis and inadequate care. This creates a need for a tool that supports non specialist health workers in reaching the correct diagnosis.

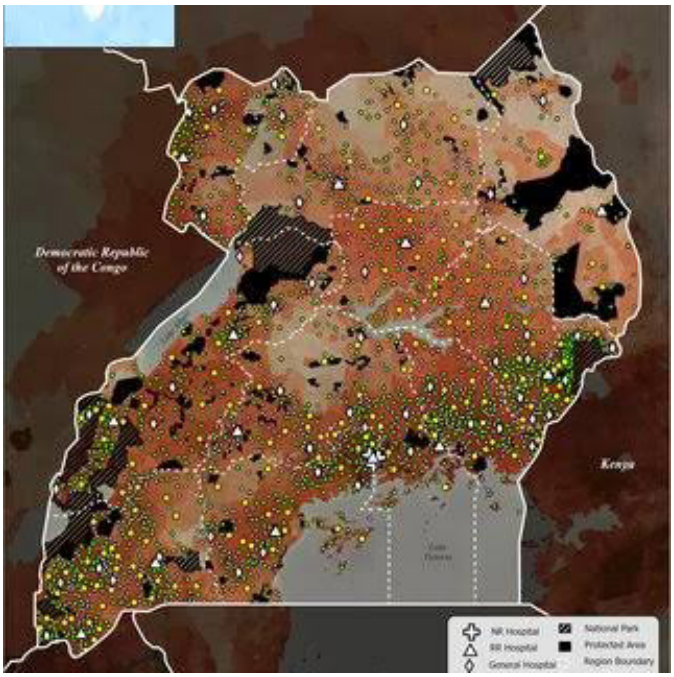


Figure 2. Uganda Healthcare Facility Access Map. From Dowhaniuk (2021).

1.2 The Healthcare Setting: Health Centre III

Uganda's public health facilities are organised in tiers, from village level up to regional and national referral hospitals, according to the population they serve and the services they offer (Ministry of Health, 2019). Health Centres II to IV carry the bulk of primary service delivery. For most Ugandans, a Health Centre II or III is the first point of formal care.

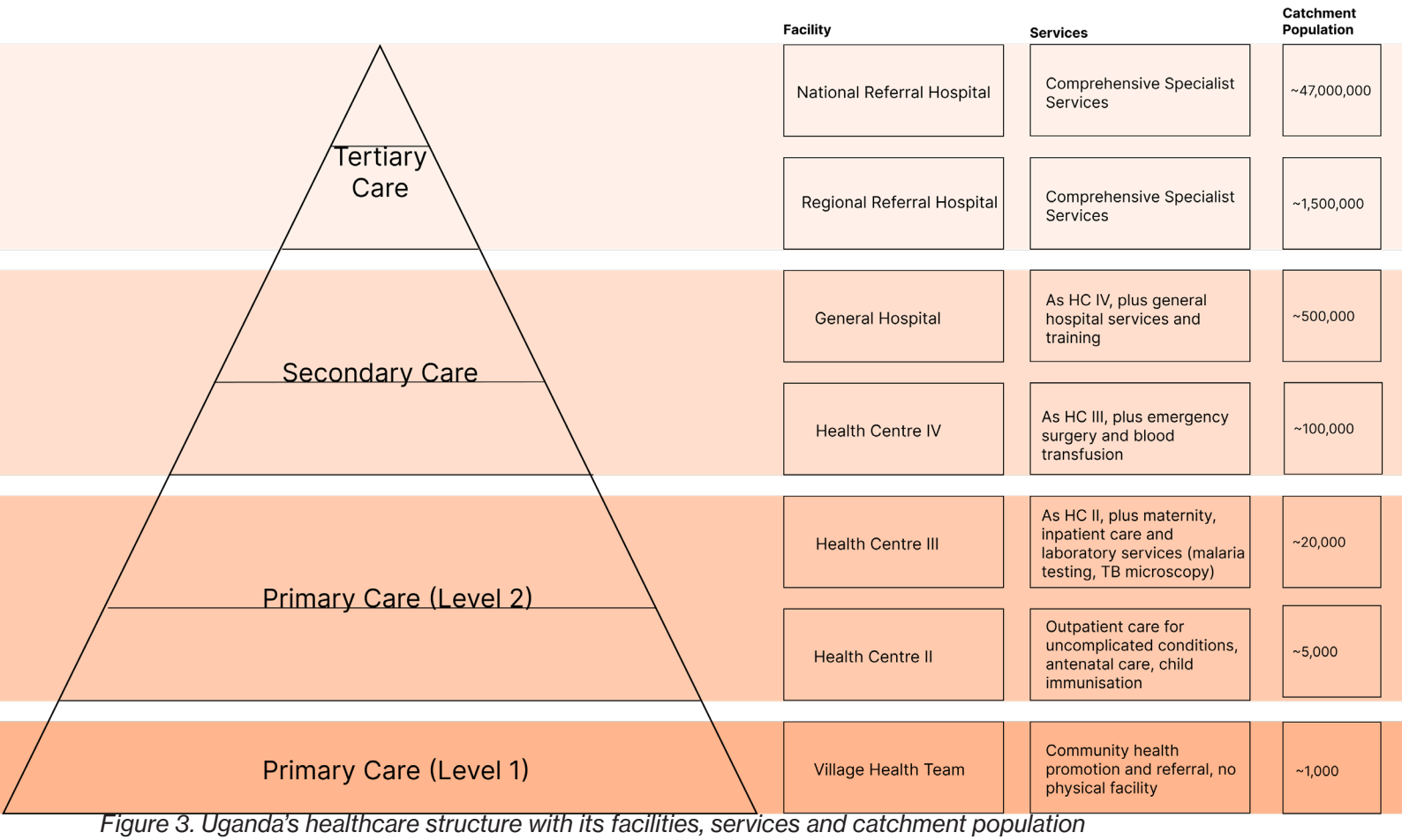


Figure 3. Uganda's healthcare structure with its facilities, services and catchment population

This thesis uses Health Centre III (HC III) as its primary context. HC III is the lowest tier with laboratory and maternity services and is staffed mainly by clinical officers, nurses and midwives. No dermatologist is present, so skin conditions are assessed by general clinical staff, mainly by visual inspection. HC III is treated as a representative case of primary care facilities in Uganda, and the findings are intended to generalise them more broadly, including HC II. Chapter 2 describes the setting in more detail.

1.3 Project Setting and Earlier Work

This thesis is a sub project within a broader PhD project led by M. Galiwango, Image Classification in Dermatology: Real-Time Diagnosis of DCPA using Edge Computing. That project develops and validates an edge based deep learning device to help health workers diagnose skin conditions, and assesses its usability and acceptability in the healthcare system. This thesis contributes by focusing on the physical embodiment of the device: its form, materials, manufacturing method and interface. The diagnostic algorithm, clinical validation and other components are addressed within the PhD project and are treated here as a fixed functional requirement.

Within this project, this thesis continues the work of three earlier student projects. These developed diagnostic device concepts for DCPA at HC III: a handheld device with LED feedback, a tabletop device with a detachable camera and display, and a handheld device with an e-ink display. All three focused on imaging the lower leg. Their experiments and user feedback form the first prototyping loop of this thesis (Chapter 5).

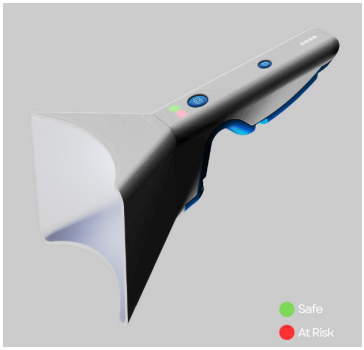


Figure 4. Concept 1


Figure 5. Concept 2


Figure 6. Concept 3

The device has changed since then, and the change drives this thesis. It no longer aims to detect DCPA alone but to help health workers distinguish similar looking conditions, for now focusing on Eczema and Psoriasis as well. These conditions appear on different parts of the body, so the device can no longer be designed around the shin. It must reach the whole body, which affects the entire shape of the embodiment.

The second change is a closer fit to the context. Where earlier projects explored concepts, this thesis works with a constant back and forth between possible solutions and the HC III setting, working towards a more fitting design for the embodiment. As an Industrial Design Engineering student at TU Delft remaining in the Netherlands throughout this project the collaboration with the PhD student was highly valuable. The PhD student being from Uganda and having a close collaboration helped create a design that fits to the context. Learning the context was done through literature, interviews with the PhD researcher and a field evaluation carried out in Uganda by the PhD researcher. Every design choice had to be checked against people who know the setting.

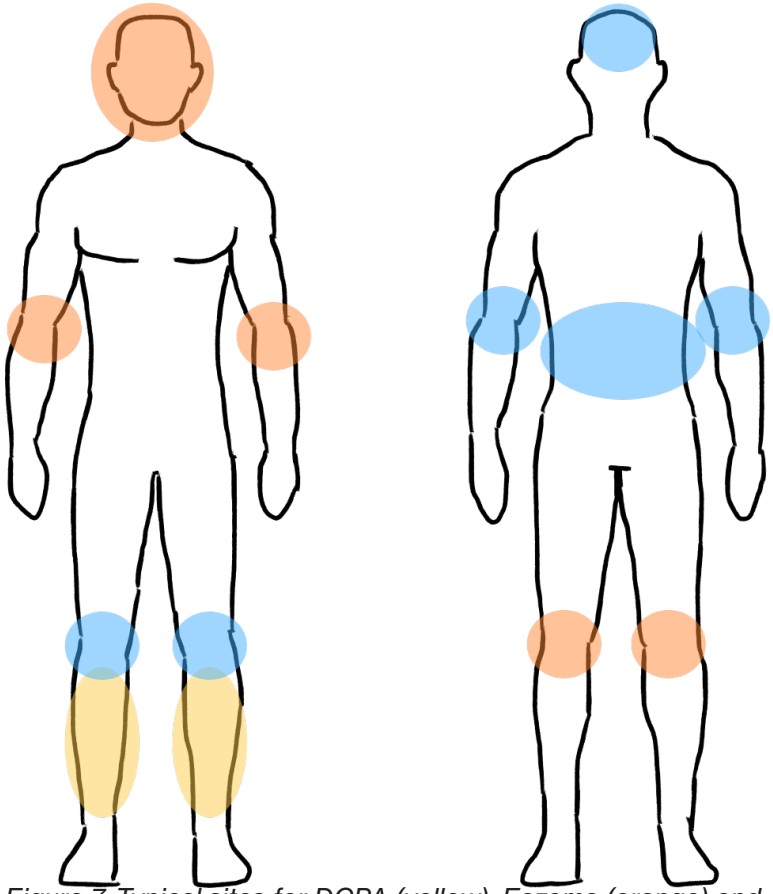


Figure 7. Typical sites for DCPA (yellow), Eczema (orange) and Psoriasis (blue).

1.4 Research Aim and Questions

The aim of this thesis is to investigate how frugal engineering principles can inform the physical embodiment of an AI assisted skin diagnostic device for HC III in Uganda. This focuses on: local producibility, repairability and usability in context. Designing of the device generates knowledge along delivering a product.

RQ1: Which requirements does the Ugandan HC III context place on the embodiment of a diagnostic device?

RQ2: How can an embodiment be designed so that it can be produced and repaired locally, and adapted to changing component availability?

RQ3: What do prototype evaluations with healthcare practitioners and local makers reveal about these design choices?

RQ4: Which design principles from this case can transfer to other frugal medical devices?

1.5 Research Approach

The thesis follows Research through Design (RtD) (Zimmerman et al., 2007), in which knowledge is generated by designing and evaluating prototypes in context (Chapter 4). The work combined four activities:

- **Context and technical foundation.** A literature review and an interview with the PhD researcher covered the three conditions, the Ugandan healthcare system, HC III diagnostic practice and existing diagnostic devices. The electronic system was mapped to identify the constraints it places on the enclosure, and these were translated into design requirements.
- **Prototyping loops.** The three earlier student projects set a first loop of insights. Requirements were then narrowed to a focused subset for exploring the embodiment shape, and two physical prototypes were built, each exploring different design solutions.
- **Field evaluation.** The prototypes were evaluated in Uganda through interviews and testing with healthcare practitioners at health facilities and with local maker facilities.
- **Design refinement.** The findings are combined into a single final design direction, which answers the design solutions tested across the two prototypes and informs the generalizable design principles.

1.6 Thesis Structure

The thesis has nine chapters.

Chapter 2 describes the context of use: Uganda's constraints, the clinical conditions, HC III and gaps in existing tools, answering RQ1.

Chapter 3 builds the theoretical framework of Frugal MedTech and recurring tensions.

Chapter 4 explains the Research through Design approach and prototyping loops.

Chapter 5 turns the learnings of the earlier projects and the technical behaviour of the device into design requirements.

Chapter 6 describes the embodiment design, manufacturing rules, design decisions and the two comparative prototypes, answering RQ2.

Chapter 7 presents the field evaluation, resulting design direction and final prototype, answering RQ3.

Chapter 8 derives generalizable design principles, answering RQ4.

Chapter 9 discusses limitations, future work and concludes the report.

2. Context of Use

This chapter describes the context the device is designed for. It starts with the national constraints of Uganda, the three conditions that shape the design brief, then the healthcare system and HC III, how diagnosis currently happens at HC III, and the gaps in existing tools. Each section ends with an implication for the device. These are collected at the end of the chapter and linked to the requirements of Chapter 5.

2.1 Ugandan National Constraints

The device is intended for healthcare centers in Uganda. Starting with the wider Ugandan setting, four constraints can be identified as relevant for the embodiment's requirements.

Power. Electricity supply in Uganda is both limited and unreliable (Afrobarometer, 2024). Only about 28% of Ugandans are connected to the national grid, and fewer than one in five report a reliable supply, with rural and poorer households least likely to have one (Afrobarometer, 2024). Since an estimated 73.8% of the population lives in rural areas (World Bank, 2022), a device that depends on constant mains power would be fragile.

Climate. Uganda's national average temperature is approximately 22.5–23.5°C with limited seasonal variation (World Bank Group, Climate Change Knowledge Portal, 2024), and humidity is high for much of the year, particularly during the rainy seasons. A design should be made resistant to these conditions.

Figure 8. View of Mbarara, from Also Uganda (n.d.).



Logistics. Poor road and transport infrastructure can make the import of spare parts and specific components unreliable. A design that depends on externally sourced, standardised parts might not be reliably maintained where transport is unreliable.

Language. English is Uganda's official language, but no recent census establishes what share of the population speaks it fluently, and estimates vary widely (Namyalo, 2015). Luganda is the most widely spoken first language. An interface carrying assumptions from a different linguistic context would fail the people actually using it. Implication. The device must run off grid, tolerate heat and humidity, be repairable from locally available parts, and communicate in pictograms along English.

Implication. The device must run off grid, tolerate heat and humidity, be repairable from locally available parts, and communicate in pictograms along English.



2.2 Skin Conditions

Earlier projects looked at DCPA alone. DCPA is easily confused with other similar looking conditions, such as Eczema and Psoriasis. Healthcare practitioners have to separate them, which is why the device now covers all three.

DCPA. Dermatitis cruris pustulosa et atrophicans is a chronic superficial folliculitis of complex aetiology, seen mainly in tropical countries. It mostly affects the anterior shins, with recurrent crops of itchy follicular pustules that eventually leave atrophy and hair loss (Kaimal et al., 2009). Left untreated, it can cause scarring alopecia (Couppoussamy & Devanda, 2024). In southwestern Uganda, most patients are aged 0 to 25 years and 71.9% are female (Mulyowa et al., 2026). No clear treatment guidelines exist; a systematic review of 312 patients found cotrimoxazole, alone or combined with PUVA, to be the most effective treatment (Couppoussamy et al., 2025). Awareness of DCPA is low, so it is probably overlooked (João et al., 2022), and it has received little attention in dermatological literature (Kaimal et al., 2009).



Figure 9. DCPA. Photographed by M.Galiwango, 2026.

Eczema. Eczema is an umbrella term for inflammatory skin conditions, of which atopic dermatitis is the most common form and the one this thesis refers to. It is a chronic, relapsing disease with dry skin, eczematous lesions and intense itch, usually beginning in early childhood (Langan et al., 2020). In urban Uganda, 13.5% of schoolchildren report a lifetime history of eczema (Mpairwe et al., 2021). Affected children are prone to recurrent skin infections, chronic scratching causes lichenification, and severe inflammation can leave scarring or depigmentation (Epps, 2010). Treatment ranges from topical agents and phototherapy to systemic immunosuppressants (MSD Manual Professional Edition, 2025). Because specialist care is scarce (Mundeli et al., 2025), access to advanced treatment is likely to be limited, which makes early recognition at primary care level important. In older children and adults, atopic dermatitis typically affects the flexural areas, such as the inner elbow and the back of the knee, as well as the head and neck (Peters & Peters, 2019).



Figure 10. Eczema. From WebMD (2026)

Psoriasis. Psoriasis is a chronic immune mediated disease that produces thick, scaly plaques (Armstrong & Read, 2020). At the skin clinic of Mbarara Regional Referral Hospital, nearly 4% of patients had psoriasis, most commonly chronic plaque psoriasis (Lubwama et al., 2025). Unlike eczema, it is a systemic inflammatory disorder associated with myocardial infarction, stroke, hypertension, diabetes, dyslipidaemia, obesity and metabolic syndrome (Hu & Lan, 2017). Mild disease is usually treated topically, whereas moderate to severe disease needs phototherapy or systemic therapy (Armstrong & Read, 2020). Access to such treatment in Uganda is likely to be limited, so a correct diagnosis is the first step to care. Plaque psoriasis typically appears on the extensor surfaces of the elbows and knees, the scalp and the lower back (Nair & Badri, 2023).



Figure 11. Psoriasis. From Everyday Health (2025).

All three conditions are chronic and need long term management, and each can cause lasting harm if misdiagnosed or untreated: scarring in DCPA, lichenification and infection in eczema, and systemic complications in psoriasis.

Implication. The typical locations of these conditions span the whole body, so the embodiment must allow imaging across varied body sites and positions. Their visual resemblance makes them hard for non specialists to tell apart, so the device must capture consistent, comparable images across skin tones and lighting conditions.

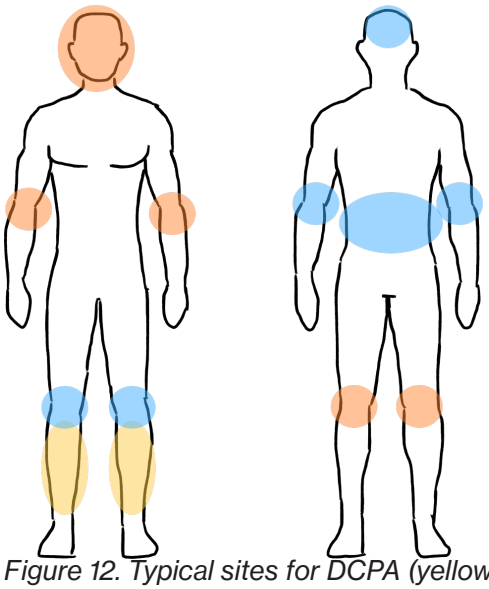
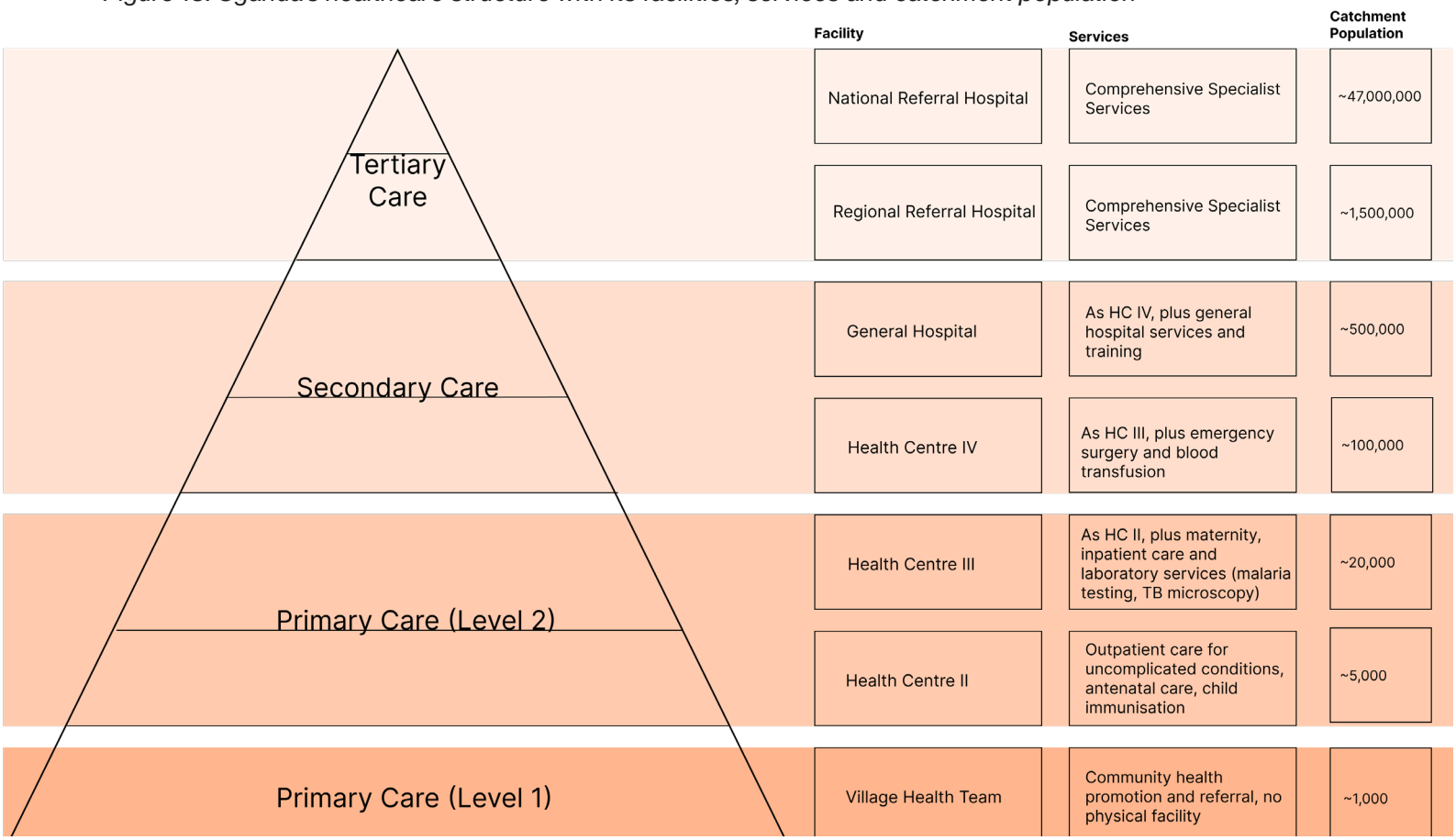


Figure 12. Typical sites for DCPA (yellow), Eczema (orange) and Psoriasis (blue).

2.3 Uganda Healthcare System

Ugandan health facilities are organised in tiers by catchment population and services offered (Ministry of Health, 2019).

Figure 13. Uganda's healthcare structure with its facilities, services and catchment population



Health Centres II to IV carry the bulk of primary service delivery (Namaganda et al., 2015). Facilities are unevenly distributed and skewed towards the Central region (Odokonyero et al., 2017). The system is underfunded: public spending was about USD 12 per capita, against more than USD 28 needed to deliver the national minimum health care package (Lukwago, 2016). Staffing is also short. In a study of 136 facilities, all three types of health centres had fewer nurses (42–70%) and midwives (53–67%) than required, and these showed high workload pressure (30–58%) (Namaganda et al., 2015).

HC III is staffed mainly by clinical officers, nurses and midwives, with national norms allowing one clinical officer post per facility (Namaganda et al., 2015). No dermatologist is present, so skin conditions are assessed by general clinical staff, mainly by visual inspection. Staffing pressure further reduces the time available for careful assessment.

Implication. The device must be usable by a clinical officer or nurse with no dermatology training, under time pressure and without specialist backup.

2.4 Current Diagnostic Situation at HC III

This section draws on interviews with the PhD researcher, based on his experience and research in health centre settings.

Where diagnosis fails. Using DCPA as an illustrative case, patients typically delay formal care because travel is costly. They try home remedies or locally bought medicine first, and then choose a facility by proximity, usually HC II or HC III. There, specialist expertise and tools are absent and non specialists have lower diagnostic agreement (44% against 71% for dermatologists; Bourkas et al., 2023). Some patients lose trust and wait for referral or skip the local level. Even after a correct diagnosis, medicines may be unavailable: government spending on essential medicines was about USD 2.4 per capita, against an estimated requirement of USD 12, and the gap is financed by development partners and out of pocket payments (HEPS-Uganda, 2016).

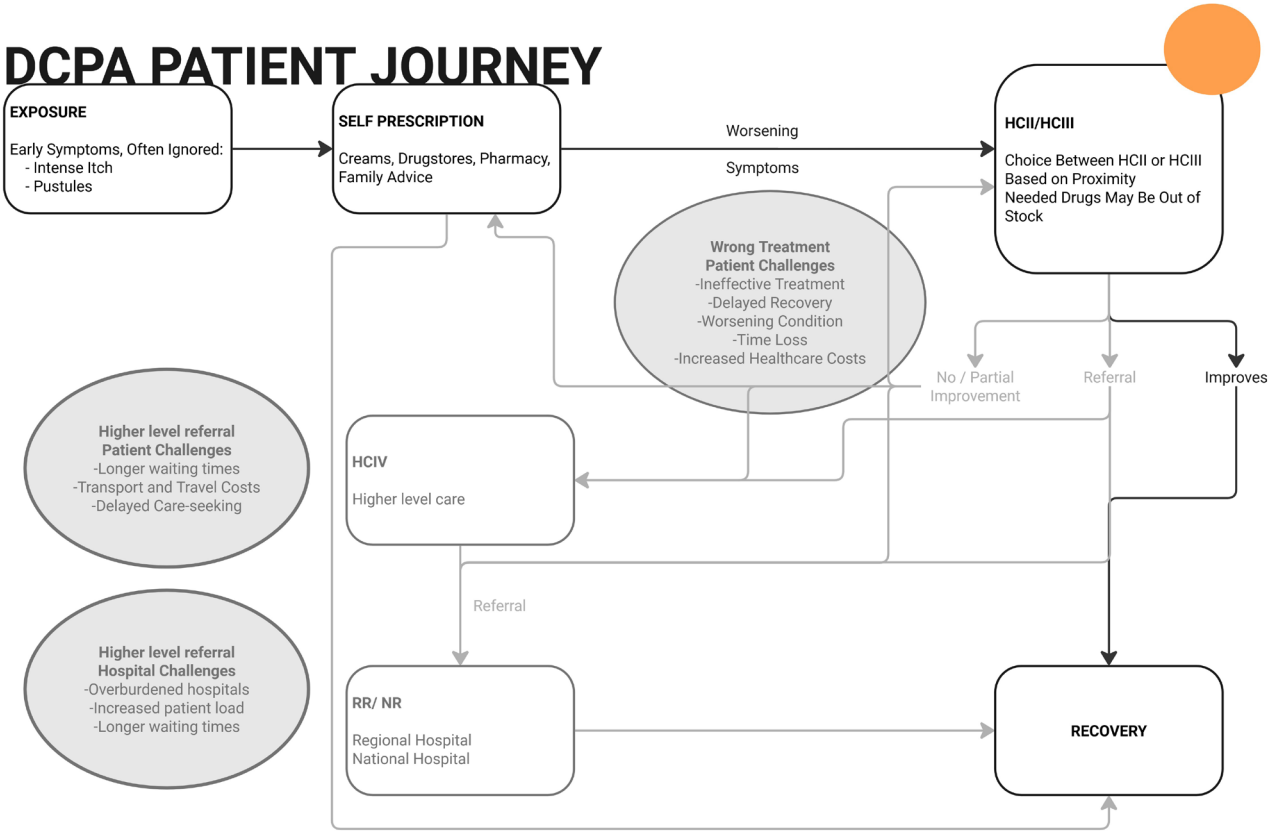


Figure 14. DCPA patient journey, the orange dot indicates where a diagnostic device could be implemented and the greyed out steps show what can therefore be avoided.

Implication. Delay, self treatment, misdiagnosis and cost reinforce each other along the pathway. The device's value lies at the first point of contact, where an accurate assessment can interrupt this sequence.



Figure 15. : Healthcare Centre III Facility in Mbarara

Operating conditions. HC III runs 24/7. Staff cover inpatient, outpatient and maternal care plus weekly outreach, and midwives are on call overnight. Emergencies regularly interrupt scheduled work, and paper based reporting takes further time. Skin conditions are a low frequency task, roughly one patient per day, usually seen by general nurses or trainees with little dermatology training, which leaves staff with low diagnostic confidence.

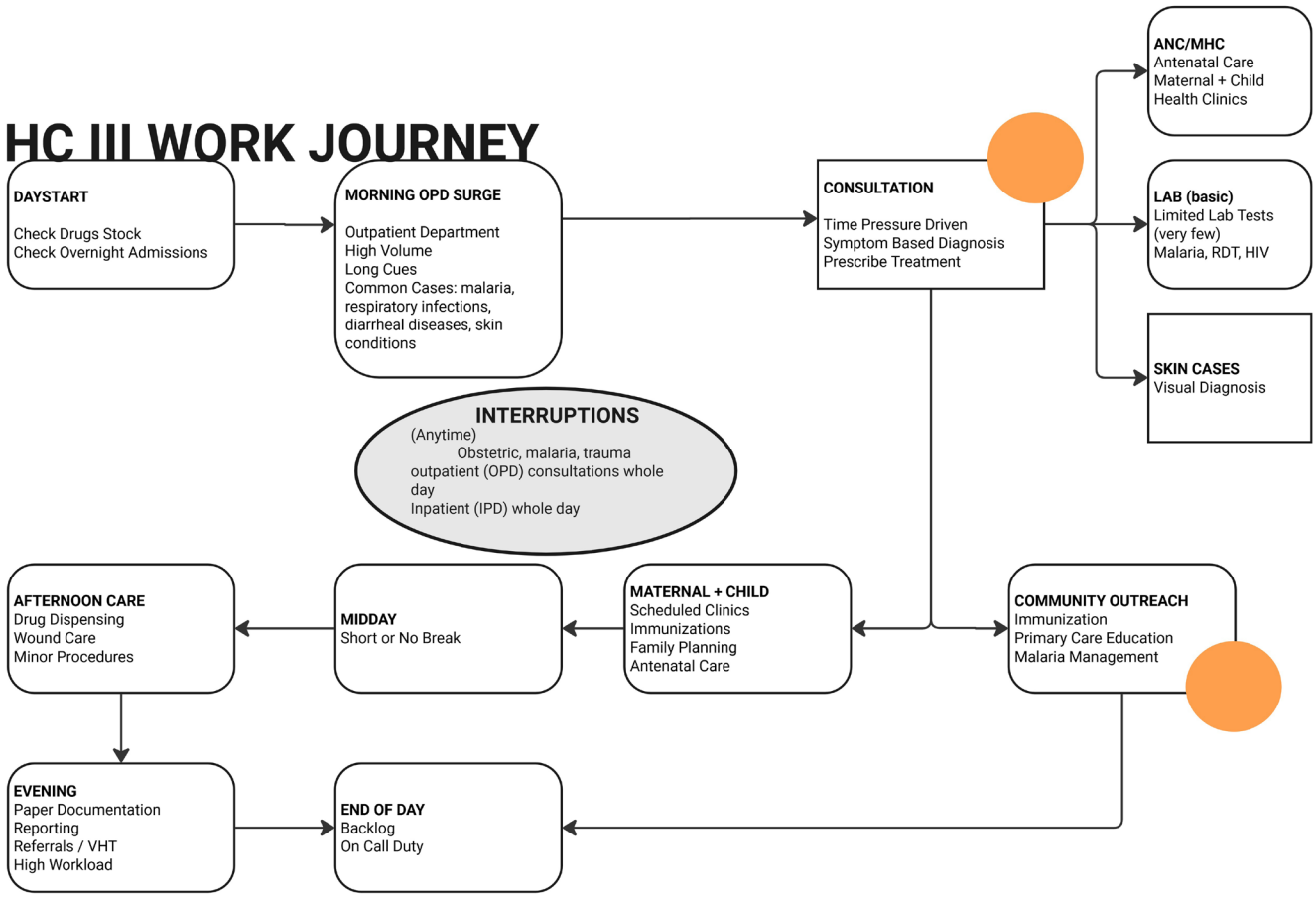


Figure 16. Work journey in a HCIII, the orange dots show where a diagnostic device could be implemented.

Implication. Skin assessment competes with urgent work for time and attention, so the device must be quick to learn and fast to operate.

The consultation room. In HCIII, patients move through a fixed sequence of waiting area, triage, consultation and, optionally, the drug store. Diagnosis takes place in the consultation room, so its conditions set the device's working limits. Open windows expose the room to dust, which threatens electronics and complicates hygiene. Gloves are intended but often unavailable, and equipment is cleaned with an alcohol cloth rather than sterilisation equipment. Furniture is basic, and patients are often seated on a chair or bed. The wall is usually covered with informational and instructional posters.

Implication. The device needs resistance to dust and moisture, operability with and without gloves, cleaning by alcohol wipe, and instructions that fit on a poster.

Figure 17. : A general layout of a HC III facility, showing the sequence a patient would move through the facility.



Figure 18. Consultation room of a HCIII in Mbarara with newly constructed waiting area.



2.5 Existing Diagnostic Tools and Gaps

Dermatoscopes are standard clinical tools, but studies in high income settings report that primary care use is limited mainly by lack of training (Jones et al., 2019). Available smartphone applications such as SkinVision (Udrea et al., 2020) and Scarletred Vision (SCARLETRED Holding GmbH, n.d.) are built mainly for skin cancer risk assessment or for monitoring skin changes in clinical research. None of those reviewed target inflammatory or tropical conditions such as DCPA. At HC III, staff are also reluctant to use personal phones for clinical work, and a shared work phone would become a valuable, multipurpose item at risk of misuse.

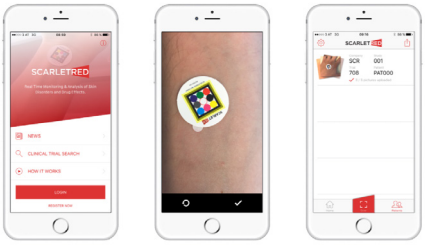


Figure 20. Scarletred Vision, a mobile app with calibration skin patches to capture, standardize, and analyze skin conditions for clinical evaluation. from ScarletredVision (n.d.)

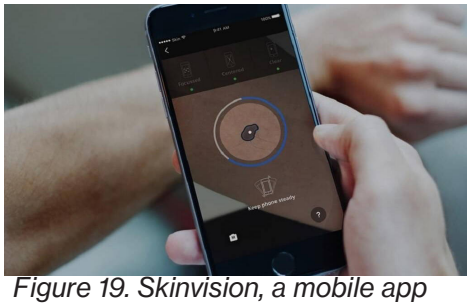


Figure 19. Skinvision, a mobile app for early skin cancer detection and skin health monitoring. from Skinvision (n.d.)

Implication. These gaps support a dedicated, purpose built device designed around the constraints above. A device that improves diagnostic confidence at HC III also has effects beyond the consultation room: faster and less costly treatment for patients, reduced dependence on specialist referral, and less congestion further up the referral system, which benefits national health expenditure and public health surveillance.

2.6 Summary

This chapter describes the context the device is designed for. Uganda has unreliable power, hot and humid climate, difficult logistics and multilingual population. DCPA, eczema and psoriasis look alike and occur across the body, so the device must be able to image any body site. At HC III, non specialist staff diagnose visually under time pressure in a consultation room with basic equipment, existing tools do not fit this setting. Table 2.1 summarises each implication to the requirements of Chapter 5.

Table 2.1: Implications and the requirements they feed

Source	**Implication**	**Requirements**
Clinical context	Imaging across varied body sites	R4
Clinical context	Consistent, comparable images across skin tones and lighting	R1, R2, R3
Healthcare system	Usable by non specialists without backup	R7, R8
National constraints	Off grid operation, heat and humidity tolerance	R18, R19
National constraints	Local production and repair	R21, R25
National constraints	Instructions supported by pictograms	R8
Diagnostic situation	Quick to learn and fast to operate	R7, R8, R10
Diagnostic situation	Gloved and bare hand operation	R10
Diagnostic situation	Alcohol wipe cleaning	R14, R15
Diagnostic situation	No dedicated furniture (handheld)	R9
Diagnostic situation	Information presented on a poster	R13
Diagnostic situation	Rests stably on a flat surface with the display readable	R12
Diagnostic situation	Dust and moisture resistance	R16
Existing tools	Dedicated device rather than phone	Entire device brief



Figure 21. a HCIII Photographed by M.Galiwango, 2026.

3. Theoretical Framework

With the context established, this chapter sets out the theoretical lens through which the embodiment design is approached: frugal medical technology, or Frugal MedTech. It defines the concept and names four tensions that recur throughout frugal medical device design

3.1 Defining Frugal Innovation and Frugal MedTech

Frugal innovation is best understood not as a reduced cost version of an existing product, but as a distinct design orientation. It creates durable, functional solutions under real resource constraints, often through resourceful improvisation rather than extensive research and development (Radjou, Prabhu, & Ahuja, 2012). Frugal medical devices are not simply low cost versions of devices built for richer settings, but are built from the start to be durable, fitting and easy to maintain. A frugal device starts with the constraints of its context (Piaggio et al., 2021).

This reframing matters because frugal medical devices rarely fail on clinical performance. They tend to fail in two other ways. The first is a lifecycle problem: Malkin (2007) identifies capital cost, lack of spare parts and lack of consumables as the three main failure points to medical device adoption in low resource settings. The second is a fit problem. A systematic review of medical device design for low resource settings (Aranda-Jan et al., 2016) found that design processes often fail to study how a device will actually be used (by whom, where, and under what conditions) before the design is finalised. The WHO's compendium of innovative health technologies for low resource settings reflects both points: its technologies are assessed not only on clinical performance, but on affordability, ease of use, and suitability for the infrastructure and users they are intended for (World Health Organization, 2022).

A frugal device should, where possible, be producible from materials that are locally available, affordable to source repeatedly, and compatible with manufacturing methods already present in the context, rather than materials that must themselves be imported (Malkin & von Oldenburg Beer, 2013). Lifecycle, cost, manufacturing and fit are what this thesis treats as the defining character of Frugal MedTech.

Figure 22. Photo of HCIII from Mayuge (n.d.)



3.2 Core Tensions in Frugal MedTech

Four tensions, drawn from the literature above, recur throughout this thesis. These are relevant to making design decisions.

Cost versus robustness. Lower cost components and simpler manufacturing methods can reduce durability or precision. Frugal design seeks a deliberate balance.

Standardisation versus local adaptability. A design optimised for mass production may not tolerate the variability of local manufacturing conditions. Frugal design favours margins and geometries that remain functional across less controlled production.

Component dependency versus supply resilience. Designing around one specific, sourced component creates a single point of failure if that component becomes unavailable. This tension motivates an adaptable layout.

Generic solutions versus contextual fit. A device designed around general assumptions about users and environments often overlooks what works in the actual context.

This chapter introduced Frugal MedTech as designing from the start around a context's infrastructure, manufacturing capacity, repair capability and users. Such devices tend to fail on lifecycle and on fit, not on clinical performance. Four tensions play a role in the design decisions: cost versus robustness, standardisation versus local adaptability, component dependency versus supply resilience, and generic solutions versus contextual fit

Figure 23. Photo of street in Kampala



4. Research Method

This chapter explains why Research through Design was chosen, how the design work is structured as prototyping loops, and how data was collected and by whom, including the author's own role in the field evaluation.

4.1 Research through Design

This thesis uses Research through Design (RtD) as its research method. RtD treats designing (proposing, building and evaluating artefacts) as a way of generating knowledge, different from research that only describes or only analyses (Frayling, 1993; Zimmerman et al., 2007). Knowledge comes not only from the final product but from the process of getting there. What a prototype shows when it is built, used and evaluated counts as evidence in its own right (Stappers & Giaccardi, 2017).

RtD fits this project because it answers two questions at once: what this device should look like, and what can be generally learned about designing frugal medical devices. It also fits the back and forth between designing and checking it against its context. A possible solution is proposed, set against the context of use, and revised.

4.2 Prototyping Loops

The RtD process in this report is structured as two prototyping loops. In each loop a design question is framed, prototypes embodying different answers are built and evaluated, and the evaluation is reflected on. The insight from one loop becomes the starting question for the next.

Table 4.1: Overview of prototyping loops

	Loop 1: Prior Iterations	**Loop 2: Comparative prototypes**
Explored	How the device is held, communicates a result and keeps imaging distance	Overall view on implementation, preferred grip angle, display size, battery feedback, button placement and distance guide shape. Checking local production possibilities.
Evidence	Experiments and informal user feedback from three earlier student projects	Interviews and comparative prototype preference testing in Uganda, plus maker consultation
Outcome	Design rules: integral distance guidance, results shown on a display, a compact handheld form with a power grip, built in lighting, water and dust protection, and no skin contact or easy to clean contact parts	Preference for smaller design, larger display, icons on buttons. Need information on positioning and the severity of condition, other potential matches and minimize skin contact. Makers print in PLA on 0.4 mm printers with unreliable power and order electronics from Kampala.

Loop 1 was carried out during the earlier student projects and analysed during this project. Loop 2 was designed during this project and evaluated in the field by the PhD researcher, leading to a final design direction ready for another loop of evaluation.



Figure 24. Early Prototypes

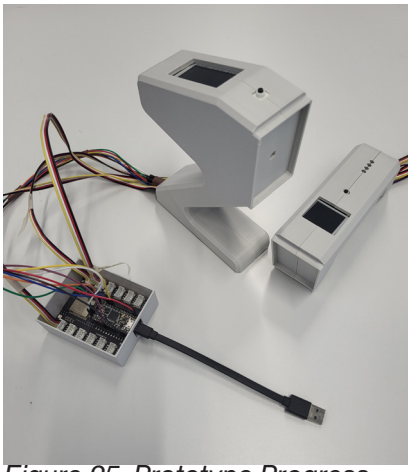


Figure 25. Prototype Progress

4.3 Research Collaboration

The Loop 2 field evaluation was conducted in Uganda by the PhD researcher leading the wider research programme (see Preface), rather than by the author, who remained in the Netherlands. The author designed the two comparative prototypes and the evaluation questions, and analysed the resulting documentation, video recordings, interview material and observations.

This division is consistent with the frugal design orientation of Chapter 3. The PhD researcher's connection with Uganda, rather than a short visit by the embodiment designer, allows the evaluation to be led by someone embedded in the context, with existing relationships at the health centres and local maker facilities. This thesis is just one stage within a longer project, making it more fitting to divide the roles and stay in the Netherlands. The findings still are a direct analysis of data collected by a collaborator.

4.4 Summary

The thesis uses Research through Design in two loops. Loop 1 is a retrospective analysis of three earlier student projects. Loop 2 is a comparative evaluation of two prototypes, carried out in Uganda by the PhD researcher, while prepared for in the Netherlands and analysed from recordings, questionnaires and notes. Chapter 5 begins with the findings of Loop 1.

5. From Insights to Requirements

This chapter translates the context of Chapter 2 into requirements the embodiment must meet. It first extracts what the three earlier student projects learned, then analyses the device's operating sequence and subsystems and explains why the internal layout is defined by an adaptable layout. These inputs are combined into design requirements, which is then focused to a subset for the start of Loop 2. Together they answer RQ1.

5.1 Insights from Previous Projects

Three earlier student projects developed diagnostic device concepts for DCPA at HC III. They focused on imaging the lower legs rather than the entire body. Concept 1 was a handheld device with LED feedback and a detachable distance module. Concept 2 was a tabletop device with a detachable camera and a display. Concept 3 was a handheld device with an e-ink display. The concepts themselves are not repeated here, instead the focus is on what they learned from bench experiments and informal feedback sessions with healthcare practitioners.

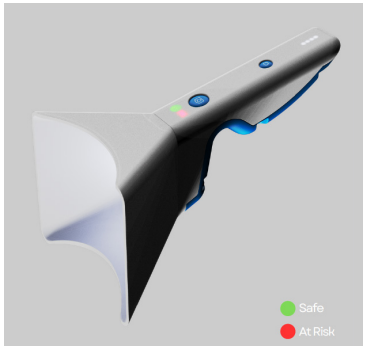


Figure 26. Concept 1


Figure 27. Concept 2


Figure 28. Concept 3

5.2 Data Collection and Evaluation

The data are experiments and informal user feedback sessions from three earlier student projects, covering lighting, watertight 3D printed connections, grip comfort, electronic component selection and power consumption. These findings are gained from reviewing the project reports.

Table 5.1: Learnings from user feedback

Learning	Evidence	Requirement
Results are preferred on a display, not as LED signals	The LED only concept (1) was compared with the display concepts (2, 3); users preferred screens	R6
Compact handheld is preferred over bulky, attached formats	Feedback on all three concepts	R9
Distance guidance should be built in	The detachable cone was judged unnecessary and risked loss and damage	R1
Skin contact should be avoided or the contact part made easy to clean	Staff cannot easily clean devices between consultations	R14, R15

Table 5.2: Learnings from experiments

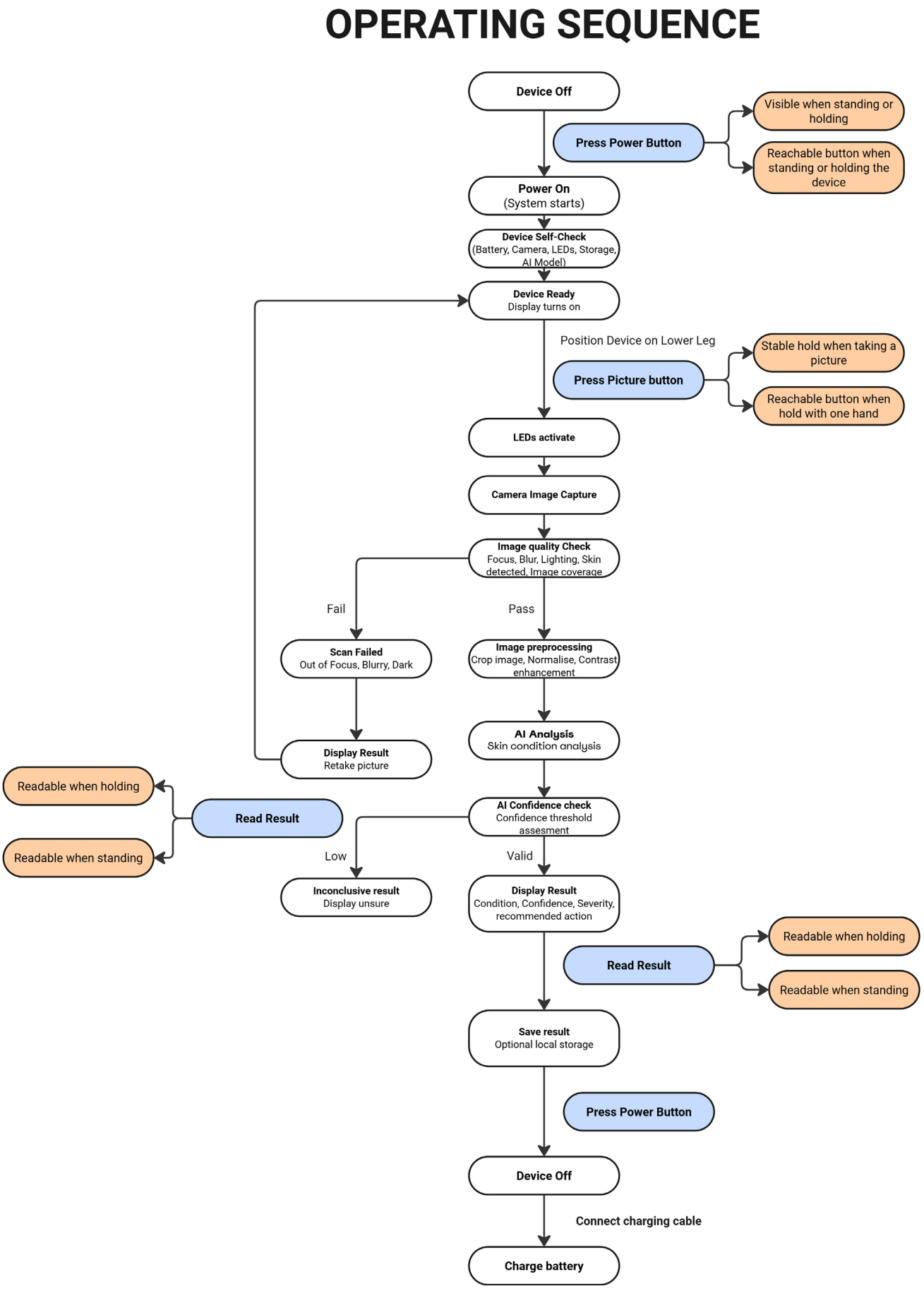
Topic	Finding	Requirement
Capture distance	The distance between subject and camera matters most for higher AI confidence. It depends on the focus range of the camera used.	R1
Lighting	A well lit subject gives higher AI confidence. Cold lighting, around 5000 K, is best.	R3
Water and dust proofing	Should conform to IP54. A 3 mm diameter PLA/PETG O-ring was successful in reaching IP54.	R16
Grip comfort	A power grip was the most comfortable way to hold the device during diagnosis.	R9

Implication. The device should show results on a display, build distance guidance into the housing, and avoid or simplify skin contact. It also needs integral lighting, water and dust protection and a power grip handle. These learnings come from a lower leg focus design. Widening the device to three conditions across the whole body leaves them valid but adds a new requirement: reaching body sites the earlier concepts never had to (R4).

5.3 Device Operating Sequence and Subsystems

The operating sequence is short: power on and self check, display of start, position against the skin, capture (triggering image sensor and lighting), display of result, return to ready state or power off. While which specific components to be used is outside the scope of this project, it does matter for the embodiment what this implies physically: a stable hold during capture, power and capture controls that stay visible and reachable, and a display that is legible once a result is ready.

Figure 29. Devices operating sequence with in blue the user actions and in orange connected its design implications.



Implication. The enclosure must support a stable hold, keep the controls visible and reachable, and make the display readable once a result is ready (R2, R6, R9, R10).

The device is organised into four functional subsystems: processing (AI inference and system logic), power (storage and regulation), input (user interaction) and output (result display and feedback). Power flows from the battery through a charge controller and voltage regulator to the processing, imaging and output subsystems, gated by a central load switch. This functional map, rather than any specific component list, determines the internal layout. It shows where heat is generated, where the largest volume sits and where the critical control point is, independent of which parts fill each role.

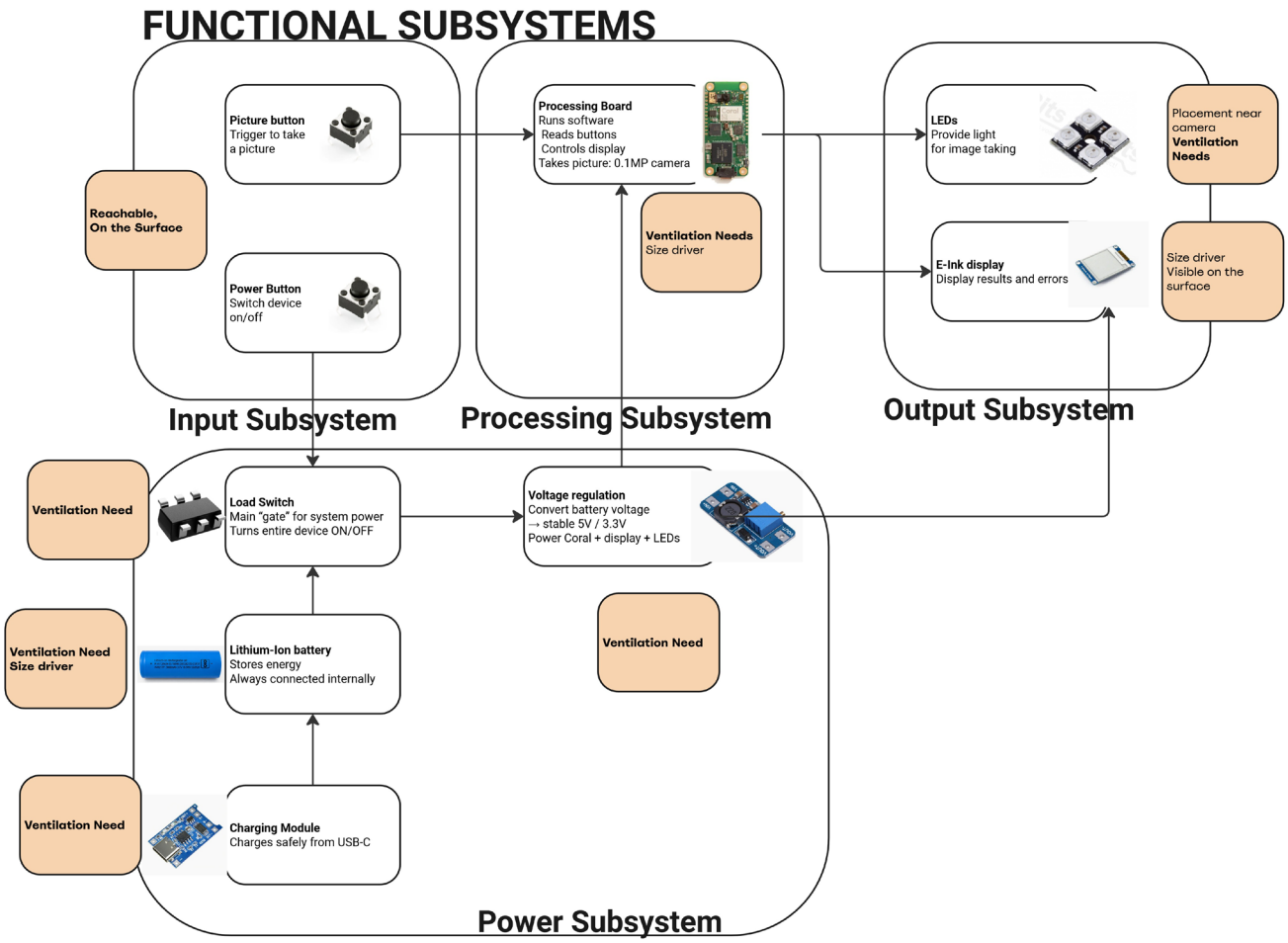


Figure 30. : functional subsystem of the device, showing the connections between the subsystems and components. Its design implications are connected in orange.

Table 5.3: What each function asks of the embodiment

Function	Implication for the embodiment	Requirements
Processing	Runs on device AI inference and system logic. Generates heat under load and needs a stable power supply.	R27, R29, R31
Imaging	Captures the skin image. Sensitive to motion blur, distance variation, lighting and angle misalignment.	R1, R2, R4, R5
Power	Provides portable power. Voltage drops gradually during discharge, heat is generated under load, and over or undercharging carries safety risks. Need to show when it needs power or is fully charged.	R19, R20, R28, R29
Charging and regulation	Manages safe charging and supplies regulated voltage to processing and output. Both generate mild heat.	R20, R16 (ports)
Output	Displays the result. A display with low battery consumption and high outdoor readability is preferred, on a flat, stable surface, readable when standing and holding the device.	R6, R11, R30
Illumination	Provides uniform light for capture and visual feedback. Intensity depends on angle and diffusion, and poor placement risks glare.	R3
Input controls	Power and capture buttons wear mechanically over time and must give clear tactile feedback, including through gloves.	R9, R10

Implication: Layout is driven by the relative sizes and ventilation needs of components rather than specific dimensions, with heat sources, larger components and the power control point deciding the arrangement.

The embodiment needs mounting points for all components, shock protection for the processing module and a fixed battery location.

For heat control, spaces are left between components and empty internal air space acts as a buffer.

Ergonomics depend on the imaging module's working distance and stability requirement, and input controls should be glove compatible.

Manufacturing and repair require an FDM producible model with independent access to the components.

5.4 Designing for Interchangeable Parts

At this point of designing the embodiment the electronic components needed for the device are not set. As the embodiment shapes the electronic components needed and the electronic components shape what the embodiment should look like. Additionally the processing module's supply proved unreliable during this project. The intended component for use: the Google Coral Dev Board Micro, has been discontinued and its software is no longer updated. This board can potentially still be used but it also shows that a fixed hardware dependency is a supply risk in this context. For this reason the internal layout is focused around an adaptable layout, mounting pattern and thermal clearance, so the embodiment can be adjusted to different components.

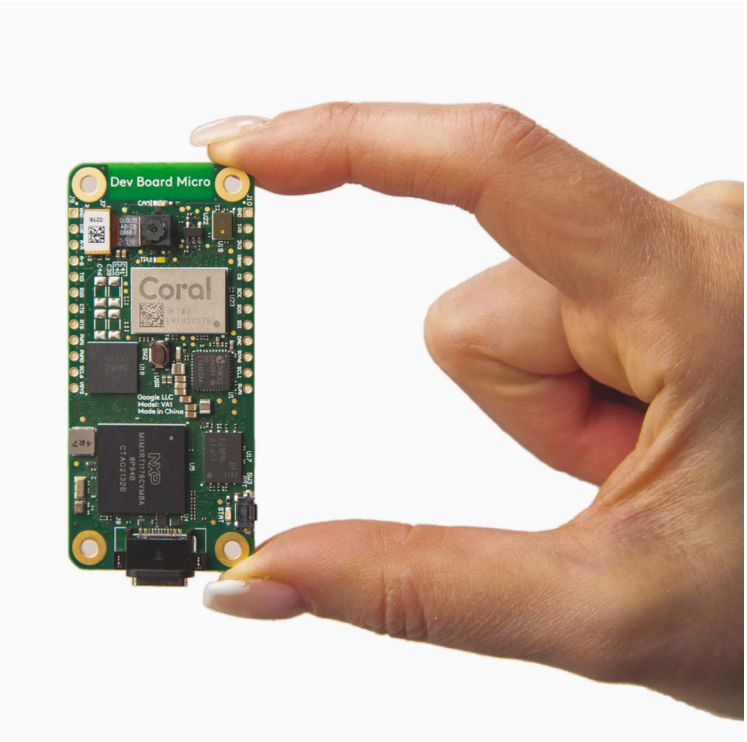


Figure 31. Google Coral Board Dev Micro from Google (n.d.)

Implication. The embodiment should have an adaptable layout so it can accommodate different components (R27).

5.5 Design Requirements

The requirements come from four sources, named in the Origin column: L1 (the learnings and experiments of the earlier projects), C (the clinical and healthcare context of Chapter 2), SYS (the system analysis) and A (defined in this thesis). Numeric targets tagged L1 were set by the earlier project teams or taken from standards and aimed to verify in loop 2. Priority: M = must, S = should.

Table 5.4: Design requirements

ID	Requirement	Target	Origin	Pri.
Imaging				
R1	The device holds the camera at a fixed working distance.	A built in guide sets distance equal to the camera's focus range.	L1, SYS	M
R2	The device keeps the camera steady during capture.	A centre of mass near the grip holds angle deviation to ≤2°. A power grip of Ø50-60 mm handle for stability.	L1, SYS	M
R3	The device lights the skin evenly, independent of room light.	Built in cold light gives 400-700 lux at 5000-7000 K with ±10% variation.	L1	M
R4	The device images any body site.	A grip angle between 0° and 90° downwards from the image point allows capture of all typical sites named in the clinical context.	C, SYS, A	M
R5	The device takes clear images.	A clear imaging path allows parts to be 45° away from the camera.	A	M

Use by non specialists				
R6	The device shows the result on a display.	A 20-45° tilt toward the user keeps the screen readable at ≥10,000 lux.	L1, STD (ISO 9241-5)	M
R7	The device supports use without prior training.	≥80% of first time users complete a capture unaided after ≤5 min of instruction.	C, A	M
R8	The device communicates through pictograms and local language.	Icons and local language support convey every essential step.	C	M
R9	The device fits one handed use with either hand.	A Ø50-60 mm handle keeps wrist deviation ≤15° and lets ≥95% of users reach all controls.	L1	M
R10	The device responds to gloved and bare hands.	Buttons of Ø11-15 mm need an actuation force of 0.5-1.5 N.	L1, C	M
R11	The device shows the battery status.	A visible indicator shows ≥3 charge levels before shutdown.	L1, SYS	M
R12	The device rests stably on a flat surface with the display readable.	The display is at a tilt of 20-45° when standing flat.	C	S
R13	The device can be understood from instructions on a poster.	The instructions of the device fit on a poster.	C	S

Hygiene				
R14	The device keeps skin contact parts easy to clean.	One alcohol wipe cleans them in ≤10 s.	L1, C	M
R15	The device withstands cleaning with alcohol wipes.	Surfaces keep their finish after ≥200 wipe cycles.	L1, C	M
Durability and Environment				
R16	The device protects its components from dust and splashes.	Sealed embodiment reaches IP54.	L1, C	M
R17	The device absorbs impact from drops.	Shock protection on the PCB survives 3 drops from 0.8-1.2 m.	L1, SYS	M
R18	The device operates in Ugandan climate conditions.	Function holds at 5-40 °C and ≤85% RH with a surface temperature ≤50 °C.	L1, C	M
Power				
R19	The device runs off grid.	One charge lasts ≥8 h or ≥50 sessions.	L1, C	M
R20	The device charges and stores power safely through USB-C.	Charging takes ≤4 h and the battery keeps ≥80% capacity after 300 cycles.	L1, SYS	M
Local Production and repair				
R21	The device can be produced locally by FDM printing.	Common printers print all parts in PLA/PETG following the manufacturing rules of Chapter 6.	A, C	M

R22	The device comes apart without permanent bonds.	Screw joints allow full disassembly in ≤15 min with ≤2 standard tools.	L1, A	M
R23	The device gives direct access to serviceable parts.	Visible fasteners allow access in ≤2 steps, with ≥90% using the same driver.	L1	M
R24	The device lets users replace modules independently.	The battery, PCB and camera each swap without needing to remove the others.	L1, SYS	S
R25	The device can be repaired locally.	≥80% of likely repairs need only local tools and parts.	A, C	S
R26	The device suits low volume production.	A pilot run of ~50 units uses 3-4 enclosure parts and ≤20 min of assembly each.	L1, A	S
Internal Architecture				
R27	The device houses the processing module in a defined zone.	The zone fits the largest anticipated footprint, with a mounting pattern and thermal clearance.	A, SYS	M
R28	The device secures the battery in an isolated zone.	A fixed location away from heat sources sets the minimum device thickness.	A, SYS	M
R29	The device dissipates heat from its modules.	Spacing or dust protected vents around heat sources keep the enclosure unsealed.	SYS	M
R30	The device mounts the display on a flat, rigid surface.	A flat front surface carries the display at the tilt set in R6.	SYS	M
R31	The device provides mounting points for all major modules.	Heat set inserts at every module location allow repeated reassembly.	SYS, A	M

5.6 Focus of Prototype Loop 2

This project narrowed the requirements to a Loop 2 subset focusing on the core function and contextual fit centred on embodiment shape. The embodiment must enforce correct imaging conditions, house the functional subsystems and remain locally producible. The focus is:

A controlled imaging distance (variable to the component) with angle stabilisation (≤2°) and integrated, consistent lighting.

A single enclosure housing all subsystems, portable enough for outreach use, with a comfortable grip, able to be positioned on any place of the body.

FDM printable using only parts and tools available in Uganda.

Loop 2 varies and tests R1, R2, R4, R5, R6, R9, R10 and R11 directly: the distance module and body site reach (R1, R4, R5), grip angle and stability (R2, R4, R9), display size and tilt (R6), button placement (R10) and battery feedback (R11). R3, R12, R21, R24 and R27 to R31 are built into both prototypes but not varied. R7, R8, R13 to R17, R22, R23, R25 and R26 are explored only through interviews or maker consultation, or deferred to a later loop.

5.7 Summary

This chapter turned the context and earlier learnings into 31 requirements. The earlier projects contributed design rules, results on a display, built in distance guidance, a compact handheld form with a power grip, integrated lighting, dust and water protection, and avoiding or simplifying skin contact. The subsystem analysis showed that the internal layout should follow heat sources, larger component zones and the power control point, defined by function rather than a part number because components can change. Widening the scope from DCPA to three conditions changes the intended use covering the whole body (R4). Loop 2 tests a subset: controlled distance and stability, integrated lighting, a single handheld enclosure and FDM producibility.

In answer to RQ1: the HC III context asks for a handheld device that non specialist staff can use quickly and without backup, that can image any body site, that tolerates dust, heat and humidity and runs off grid, that is cleaned with an alcohol wipe, and that is produced and repaired locally. These demands form the 31 requirements above.

6. Embodiment Design

This chapter turns the requirements of Chapter 5 into physical prototypes. It starts with the manufacturing rules for FDM production. It then establishes design decisions and describes the two comparative prototypes built to explore these design decisions. The prototypes were designed for field evaluation, and the results follow in Chapter 7.

6.1 3D Printing Manufacturing Rules

Because the device is intended for local production via Fused Deposition Modeling (FDM) 3D printing, its geometry follows established rules for functional 3D printing (Rahix, 2026): overhangs kept under 45° from vertical, wall thicknesses as exact multiples of nozzle width, filleted edges on the print bed for smoother prints, 0.2–0.3 mm clearance on snug fit joints, and brass heat set inserts or embedded nuts at all structural screw points so the device can be disassembled and reassembled repeatedly.

Implication. Every geometry in the model of the embodiment is checked against these rules, R21 and R31 cite them directly.

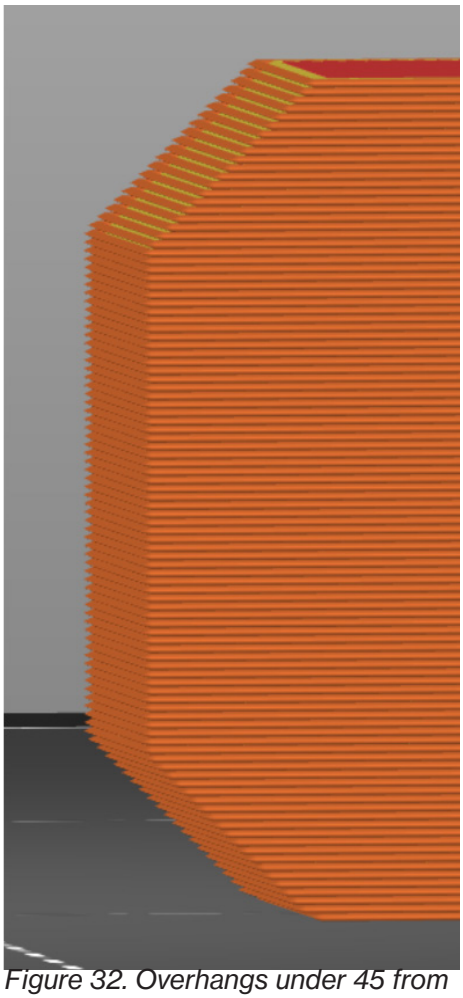


Figure 32. Overhangs under 45 from Rahix (2025.)

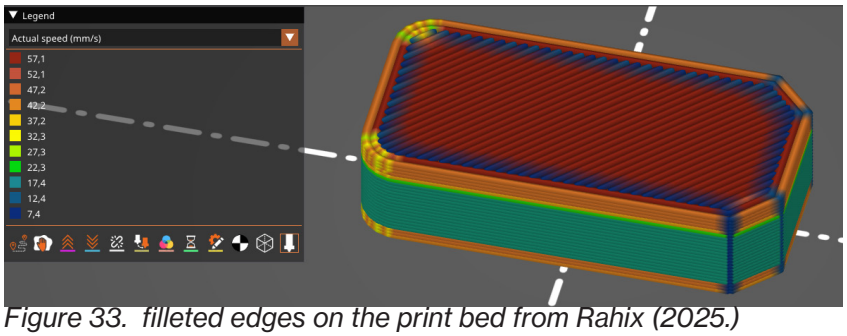


Figure 33. filleted edges on the print bed from Rahix (2025.)

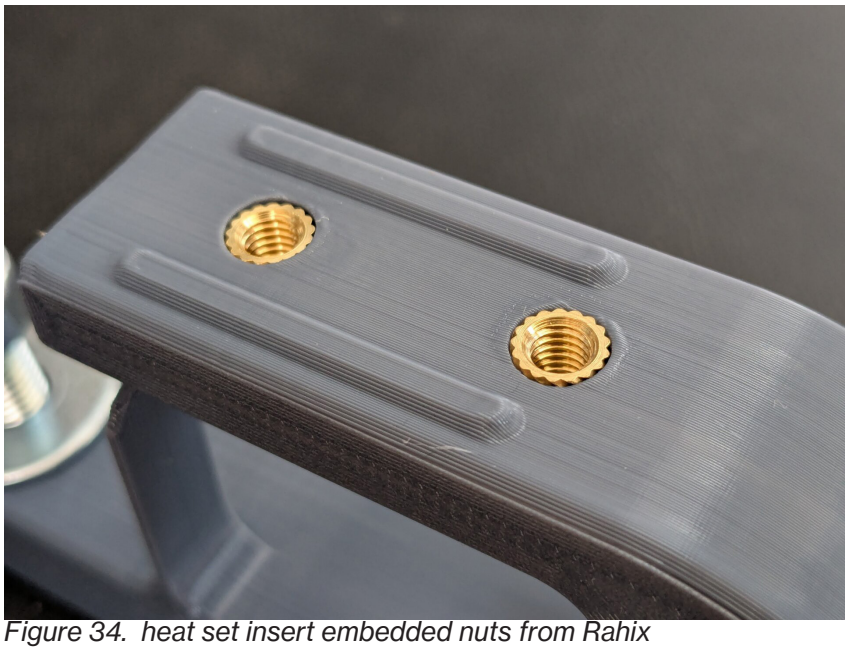


Figure 34. heat set insert embedded nuts from Rahix (2025.)

6.2 Design Decisions and Prototypes

6.2.1 From Requirements to Design Decisions

The requirements and the Loop 2 focus lead to seven design decisions that define the embodiment:

1. **Handheld form.** HC III consultation rooms typically have a chair or bed for the patient, but no examination table or fixed positioning equipment for the device. With the patient seated, the clinician must move the device to the body site. This also supports community outreach, where no furniture can be assumed at all.
2. **FDM production.** 3D printing can be done and repaired locally without specialist infrastructure, consistent with frugal design principles (Tran & Ravaud, 2016; Malkin, 2007). This constrains the enclosure to multiple printable parts, flat surfaces, minimal overhangs and screw fastened joints.
3. **Distance management.** A physical, non electronic module enforces the imaging distance. It needs no power and adds no electronic complexity, making it the most robust and lowest cost way to meet the requirement. Following the earlier projects, it is integral to the housing rather than detachable.
4. **Integrated lighting.** lighting is built into the imaging head around the camera aperture, so image quality does not depend on environmental lighting.
5. **Display angled to the user's natural grip.** The display is tilted 20-45° towards the user so the result is readable without repositioning the hold. The range follows the optimal gaze zone in ISO 9241-5 (International Organization for Standardization, 1998).
6. **Centre of mass at the grip.** Electronics are distributed so the centre of mass sits at or near the grip point. This lowers tilt during one handed use and improves imaging stability independent of user skill.
7. **Simple interaction.** A two button interface (power, capture) fits the pace of an HC III consultation, prioritising speed and ease of understanding over feature richness.

Together, these decisions define the base of the embodiment: a lightweight, self contained, mechanically stabilised handheld tool. What remained open, and what the two prototypes were built to test, was how these requirements should be physically arranged.

6.2.2 Design Solutions

The decisions left several variables open: the angle between handle and imaging head, the placement of the buttons, the geometry of the distance guidance and the size of the display. These choices are based on exploration and component availability, not from user evaluation. They define the alternatives that Loop 2 then tests with healthcare practitioners in Uganda.

Grip angle. Because the device must now reach the whole body rather than the lower leg alone, the angle between handle and imaging head became the central question. Two extreme configurations were compared: an in line handle (0°) and a perpendicular handle (90°). The handles were 3D printed and tried on four body sites (lower leg, upper leg, chest and inner elbow) and ranked on how naturally straight the wrist stayed while positioning the device. The 0° handle performed well for the lower leg, chest and inner elbow but failed for the upper leg. The 90° handle performed well for the upper leg, chest and inner elbow but failed for the lower leg. Because neither extreme was clearly better, the angle was set between them: Prototype A uses 22.5° and Prototype B uses 45°, so the evaluation can show which part of the range healthcare workers prefer.



Figure 35. wrist position test with the in line handle of 0°



Figure 36. wrist position test with the perpendicular handle of 90°

Free standing use. At HC III, nurses record the diagnosis on paper. The device therefore needed to stand on a desk on its own with the screen readable, so the nurse can read the result while writing it down. Both prototypes stand stably on the base of the handle or on the bar.

Button placement. Buttons were not set as an independent variable. Their position follows from the shape of each prototype and from where the thumb or finger falls in the grip.

Display size. Sizes were chosen by availability: 1.54 inch and 2.13 inch displays are common (Waveshare Electronics, n.d.). This follows the supply resilience logic of the adaptable layout, the design adapts to what can be obtained locally and does not depend on one part.



Figure 37. 1.54 Inch E-paper Display from Waveshare (n.d.)



Figure 38. 2.13 Inch E-paper Display from Waveshare (n.d.)

Battery feedback. Battery state can be shown on the display or with a separate LED row. The larger display has room for it, so for the smaller display an LED row was added.

Distance guidance. The distance module has its edges at 45° to the camera's viewing axis to keep the guide out of the image. Three possible guide designs were printed and tested for visibility while positioning the device on the same body sites. Experimenting with different locations showed that part of the guide has to be on top for visibility during use. The two prototypes differ in edge profile, depending on where the camera sits in the device.



Figure 39. three options for a physical distance module



Figure 40. visibility test with square distance module



Figure 41. visibility test with three pointed distance module



Figure 42. test with lower edge distance module

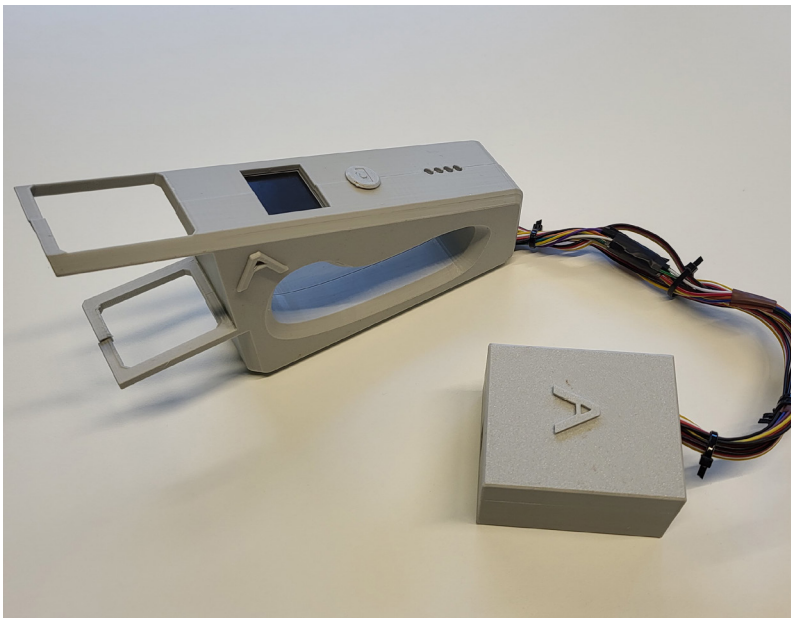
6.2.3 Two Comparative Prototypes

Two prototypes were built to embody different answers to the same variables. Building two prototypes allows healthcare practitioners to give more feedback and help with shaping the design. This comparison is also coherent with the frugal orientation of designing with rather than for the intended users.

Both share the same core system, interaction logic and FDM optimised construction, and both implement the same flow: power on (ready state shown), position and capture (lighting flash, processing state, a retake prompt, result and likelihood shown), power off. This sequence is used for testing the prototypes in the field. In both, a separate box holds the microcontroller that connects all electronic components.

Table 6.1: The two prototypes and the basis for each choice

Variable	**Basis for the choice**	**Prototype A, Linear**	**Prototype B, Crossbar**
Form	Exploration of 0° and 90° extremes	Flat, elongated handle, 22.5° between handle and imaging head	imaging head on top of the handle bar with an angle of 45°
Button placement	Follows from shape and reach	Power button at the end, picture button on top of handle	Power button on top, picture button on top of handle
Distance guide	45° away from camera view	Slanted edge on top, straight edge below	Straight edge on top, slanted edge below
Display	Availability	1.54 inch, integrated into the handle body	2.13 inch, placed on top of the handle
Battery feedback	Display size	Dedicated LED row	Shown on display only





START state



PRESS POWER BUTTON



FRAME 1



PRESS PHOTO BUTTON



FRAME 2



FRAME 3



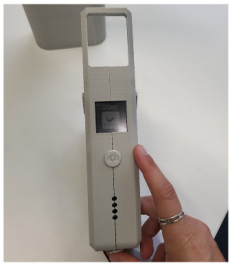
PRESS PHOTO BUTTON



FRAME 4



FRAME 5



PRESS POWER BUTTON



FRAME 6



OFF STATE

Figure 43. Prototype A and its interface

Prototype B

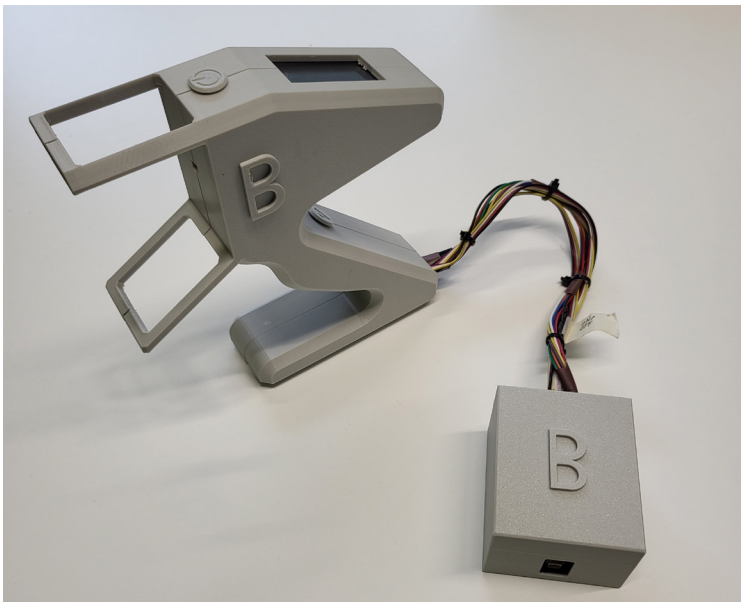




Figure 44. Prototype B and its interface

What each variable is designed to test:

Grip angle (22.5° vs. 45°): which angle healthcare workers find more comfortable and stable during one handed capture.

Display size (1.54 inch vs. 2.13 inch): the trade off between a compact display and a larger one that can carry more information, including battery status.

Battery feedback (dedicated LEDs vs. display only): whether the battery state needs an independent, always visible indicator or whether showing it on the display is enough.

Distance guide edge profile (straight vs. slanted on top): how well each supports positioning on the target, holding distance and keeping the angle stable.

The prototypes also generate broader implementation feedback. Along these variables they allow the evaluation to ask whether healthcare workers would use a device of this shape in daily work, whether minimal on device feedback (result, likelihood, battery) is sufficient, and verifying whether potential skin contact is acceptable.



Figure 45. Prototype A with marked target



Figure 46. Prototype B with marked target

6.3 Summary

The embodiment should be a lightweight, self contained, mechanically stabilised handheld tool produced under a consistent set of FDM rules. Design decisions were made on grip angle, display size, battery feedback and distance guide edge. These were shaped differently in two prototypes, A (22.5° handle, 1.54 inch display, LED row) and B (45° handle, 2.13 inch display, display only), so practitioners can compare real alternatives instead of approving a single design.

In answer to RQ2: an embodiment can be produced and repaired locally and adapted to changing components by combining an adaptable layout organised by function, geometry that follows general FDM rules, and screw joints with independent access to each component.

7. Field Evaluation and Design Direction

This chapter reports the Loop 2 field evaluation. Two studies were run in Uganda: feedback from healthcare practitioners on the two prototypes (Study 1) and visits to local maker facilities (Study 2). The chapter describes how they were set up, reliability of the data, what each study found and the design direction that follows. This chapter answers RQ3.

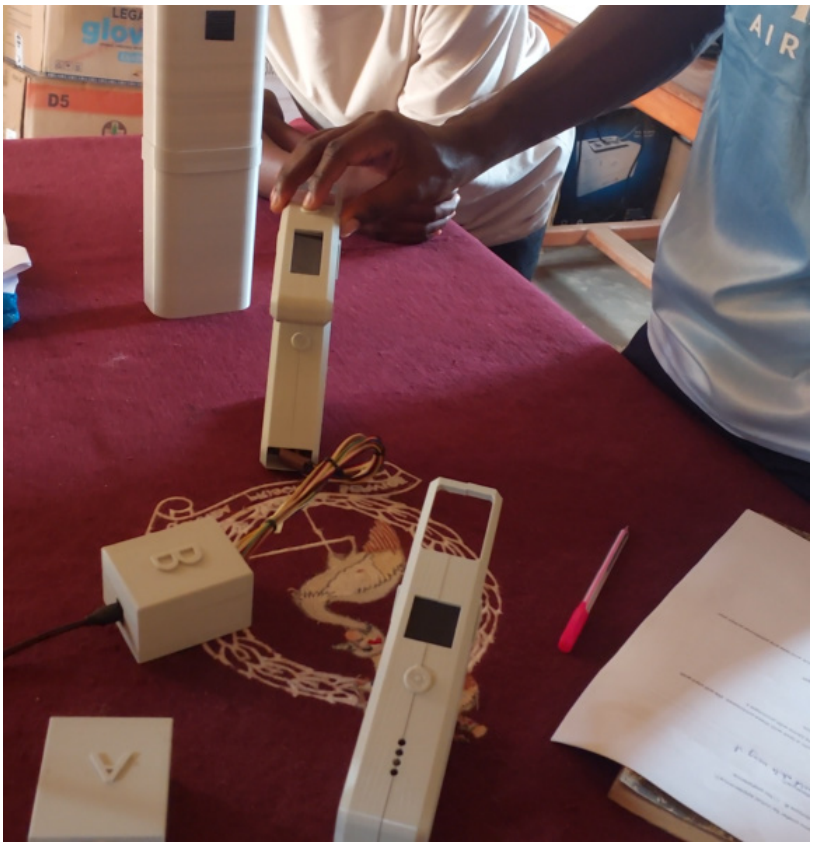
7.1 Evaluation Setup

Both studies were run in Uganda by the PhD researcher. Study 1 compared Prototypes A and B in the hands of healthcare practitioners, to learn their preferences on the look, feel, working and implementation of the device. Study 2 visited local manufacturing places, to learn what is possible in producing such a device locally.

7.1.1 Study 1: Healthcare Practitioners

Five practitioners took part: one from a general hospital, two from an HC III and two from an HC II. They were a doctor, two nurses, a clinical officer and a health educator, with 3 to 10 years of experience (5 on average). Two had formal dermatology training, two had learned on the job and one had none. None used a diagnostic device for skin conditions at work. Each practitioner gave first impressions of the two prototypes, performed a capture task with both, rated them, and answered questions on using such a device in practice. Observation notes recorded positioning, button errors and result interpretation. The interview questions and study protocol can be found in the Appendix.

Figure 47. Prototype Test Setup at a HCII



This analysis is based on video recordings, questionnaires and observation notes. These observations and answers were grouped and compared against the tested variables (grip angle, distance guide shape, display size, battery feedback) and the requirements of Chapter 5. With five participants the results are reported as counts, to show where opinions agree or split.

7.1.2 Study 2: Local Maker Facilities

Study 2 asked what local production can do and what it relies on, focusing on the local production and repair requirements. The PhD researcher visited three maker facilities with a questionnaire on 3D printing, electronics work, component supply and power: FundiBots Makerspace and two university labs at Mbarara University of Science and Technology (MUST), one at the Faculty of Applied Science and Technology and one at Centre for Innovation and Technology Transfer (CITT). Analysis in this report is derived from the completed questionnaires.



Figure 48. Bulding of MUST tPhotographed by M.Galiwango, 2026.



Figure 49. Fundibot Space Photographed by M.Galiwango, 2026.

7.1.3 Approval and Consent

Ethical approval was obtained from the Human Research Ethics Committee (HREC) at TU Delft and the Research Ethics Committee (REC) of Mbarara University of Science and Technology, where the evaluation questions were approved as an amendment to the wider PhD projects existing approval. The interview questions avoid collecting identifying personal information such as names or home addresses, and responses were recorded anonymously. Sessions were video recorded to support analysis, but recordings exclude participants' faces, and no visual material that could identify a participant is distributed or retained beyond the research team. Participants received an informed consent form approved by both committees prior to the interview.

7.2 Limitations of the Findings

In this chapter the analysis of Loop 2 is generated from recordings and questionnaires, not in person. Study 1 had multiple constraints. The field test included a mock up prototype with microcontrollers connected but outside of the prototypes, making them less visually appealing and more difficult to handle. The marked target to take an image of was on a 3D stand instead of a human subject. Causing only one position where the participants used the device on. Prototype B failed electronically in two sessions, so those participants rated its display and result without using them. One task video of Prototype A is missing. And with five participants, one opinion carries a significant weight.

Study 2 relies on three facilities and on short, handwritten questionnaires that are sometimes hard to read, and no trial print or repair of the device itself was done. Both studies therefore give direction for the next design stage but can not be seen as strong evidence.

7.3 Study 1 Results: Healthcare Practitioners

7.3.1 Shape and Handling

Before handling the devices, three of five preferred Prototype B, because it looked easy to use and had a bigger screen. After the task, three preferred A and two preferred B. Only one participant changed their choice, but the reasons shifted from appearance to handling. Those who preferred A named comfort while B was described as bulky.

Comparative Criterion	Preferred Prototype A	About the Same	Preferred Prototype B	Dominant Preference
More comfortable to hold	3	2	0	Prototype A (60%)
More stable while taking an image	3	1	1	Prototype A (60%)
Easier to know how to perform	3	2	0	Prototype A (60%)
Clearer presentation of	2	2	1	Prototype A (40%), Prototype
Better fit with usual workflow	3	1	1	Prototype A (60%)

Figure 50. Prototype Comparance Table

The Likert ratings agree. Four of five agreed that A was easy to use, comfortable and easy to read, against three of five for B on ease and comfort. All five agreed that the display instructions were clear on both prototypes. The comparison is weakened where B's screen failed, but not on comfort or stability, which do not depend on the screen. The edge of the distance module on top, slanted on A and straight on B, made no consistent difference for the angle of holding the device.

Figure 51. Prototype A Evaluation Table

Evaluation Criterion	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Dominant Rating
Easy to perform task	0	0	1	0	4	Strongly Agree (80%)
Comfortable to hold	0	0	1	0	4	Strongly Agree (80%)
Felt stable when positioning	0	1	0	2	2	Agree (40%) Strongly Agree (40%)
Clear display instructions	0	0	0	0	5	Strongly Agree (100%)
Easy to understand result	0	0	1	0	4	Strongly Agree (80%)

Evaluation Criterion	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Dominant Rating
Easy to perform task	0	1	1	0	3	Strongly Agree (60%)
Comfortable to hold	0	2	0	0	3	Strongly Agree (60%)
Felt stable when positioning	0	0	1	3	1	Agree (60%)
Clear display instructions	0	0	0	1	4	Strongly Agree (80%)
Easy to understand result	0	0	0	2	3	Strongly Agree (60%)

Figure 52. Prototype B Evaluation Table



Figure 53. Photo of a participant comparing the prototypes Photographed by M.Galiwango, 2026.



Figure 54. Photo of participant task with prototype A Photographed by M.Galiwango, 2026.

7.3.2 Usability

Looking at handling the prototypes specifically, positioning and aiming showed difficulties. Focusing on the target, holding the right distance and in one case holding the device backwards. The controls caused confusion on both prototypes, such as difficulty finding the power switch and pressing the capture button when meaning to power off. The information shown, a result with its confidence, was enough for diagnostic confidence, and one participant valued that the screen stays visible while an image is taken. The distance guide was also the weakest part physically, the one on Prototype B was damaged in transport.



Figure 55. Prototype B being held wrongly Photographed by M.Galiwango, 2026.



Figure 56. Participant Investigating Prototype A (Photographed by M.Galiwango, 2026.

7.3.3 Implementation

When asking about the implementation of such a device Four of five were likely or very likely to use such a device and one was unsure. Participants were also asked to comment on what such a device would need for it to be a good addition to their workday. One mentioned the need of seeing the stage or severity of the condition for more accurate treatment and drugs prescription. Another commented on wanting to see the confidence of more than one condition, since practitioners usually give a primary and a secondary diagnosis. Two commented on wanting a larger screen. Including to display the image that was taken and be able to zoom in on the image. Three participants mentioned concerns about power and expressed the need for a backup battery. A single request was also for a storage and transport bag. No participant commented on the way the battery feedback was displayed.

Skin contact was the most consistent concern. Four of five participants feared that touching the patient's skin could transfer disease to the next patient, and the fifth asked for a smooth, easy to clean enclosure.

Figure 57. Table 7.2: What the evaluation says about each tested variable

Variable	Prototype A	Prototype B	Finding
Grip angle	22.5°	45°	The 22.5° handle was preferred after handling.
Display size	1.54 inch	2.13 inch	Mixed: a bigger screen attracted some, yet most preferred A.
Battery feedback	LED row	Display only	No evidence either way.
Distance guide edge	Slanted on top	Straight on top	No consistent difference.
Button placement	Power on the end, picture ontop of handle	Power on top, picture on top of handle	Confusion on both: icons needed. The picture button on the handle works.

7.4 Study 2 Results: Local Maker Facilities

The three maker facilities visited all used 3D printers, they print in PLA on standard 0.4 mm nozzles, model in SolidWorks, order electronics from Kampala or Amazon, and all dealt with interrupted prints due to power outages. These findings are counts of what three facilities reported.



Figure 58. 3D Printer aat CITT Photographed by M.Galiwango, 2026.



Figure 59. 3D printer at MUST Photographed by M.Galiwango, 2026.

Table 7.3: What the three facilities reported

Topic	What the facilities reported	Implication for the design
3D printing	All use 3D printers, two Creality K1. All print in PLA on standard 0.4 mm nozzles. Two of three prefer to use supports.	Wall thicknesses in multiples of 0.4 mm. Supports are accepted practice, so an occasional overhang is no barrier, but the 45° rule stays the default for smooth print and to keep print time short.
3D model	All mostly model in SolidWorks.	Build the CAD model in SolidWorks so local makers can open and adapt it.
Power	All experience power outages or fluctuations, which interrupt prints. One has a backup generator.	Focus on short print times, split up parts.
Electronics supply	None keeps electronics in stock. Two order from Kampala (18 hours after requisition, or 1 to 7 days) and one from Amazon (1 to 2 weeks).	Choose components widely available, can be sourced in Kampala or ordered, and keep a layout that accepts alternatives.
Electronics work	Two of three have fine tip soldering tools. The facilities that answered have moderate experience wiring micro components.	Local assembly is possible but not everywhere, soldering should be kept minimal and allow for little precision.

These visits just show what local production has to work with, it is yet to be tested if a 3D modelled design will work.



Figure 60. Space overview of MUST Photographed by M.Galiwango, 2026.

7.5 Final Design Direction

The findings of both studies combine into one design direction for the next stage.

Table 7.4: From findings to design direction

Theme	Direction	Basis
Shape	Start from Prototype A focus on making it smaller	A was preferred after handling, B seen as bulky
Shape	Make the distance guide stronger	The guide on B broke during transport
Shape	Straight or slanted edge on top, free to choose	No consistent difference
Usability	Put icons on the power and picture buttons, picture button can stay on the handle	Confusion on both prototypes, picture button placement was clear
Usability	Give extra instruction on positioning (on the device, display or a poster)	Positioning was the main difficulty
Display	Remove the battery LED row	Using minimal components
Hygiene	Design for use without patient contact, with smooth, wipeable contact points	Four of five raised cross contamination
Information	Show the stage or severity of the condition	Helps practitioners give more accurate treatment
Information	Show the confidence of more than one condition, not only the most likely	Practitioners usually give a primary and secondary diagnosis
Manufacturing	Model in SolidWorks with wall thicknesses in multiples of 0.4 mm, short print times, widely available components	Study 2, available software, nozzles, components and power outages

Not every request is taken forward in this design direction, and two tensions of frugal design show in these choices. Durability against accessibility, PLA is what local makers use, but the device is printed in PETG, which is more durable, accepting a material that is harder to source. Simplicity against features, the design stays simple, so there is no battery LED row, no image shown on the screen and no memory function even though this was requested.

7.6 Final Prototype

To end this project and prepare it for the next loop a final prototype has been created. Here the findings are realized by making a mock up prototype of the device. Integrating all electronic components within the embodiment as compared to the loop 2 prototypes which had the microcontroller sticking out. Refining the prototype more.

This prototype contains: waveshare 2.13 inch display, LiPo battery, Feather S3(D) microcontroller board, Neopixel LED, Two buttons, 6 Heat set inserts and screws m3 and 7 heat set insert and screws m2.5.

The shape has been adjusted to implement these heat set inserts, screws and the electronics more accurately. Additionally a loop of drop tests has been performed to improve the embodiment's shape and make the distance guide stronger. These edges have been moved to the top and bottom of the embodiment so the camera can be placed more freely on a spot in the front.



Figure 61. Final Prototype

Making this prototype also showed that fitting the electronic components accurately in the embodiment comes very precise, making an adjustable mounting pattern for components hard to integrate into a model. Therefore this part was not focused on designing for this model. The overall shape rather than these connection points were focused on. The embodiment is split through the middle into two separate parts and the components are placed in this middle parting line. This allows the components to stay all in line even when a component is swapped or when the overall size of the device changes.

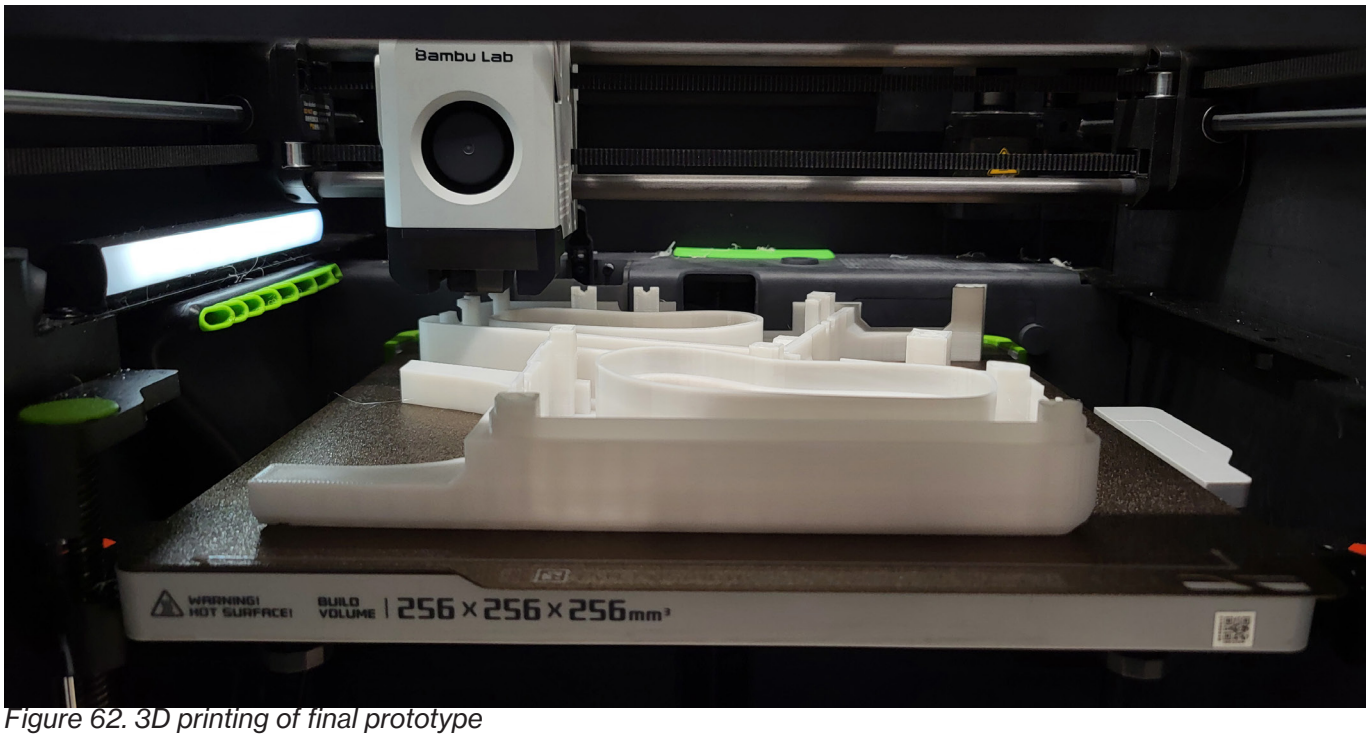


Figure 62. 3D printing of final prototype

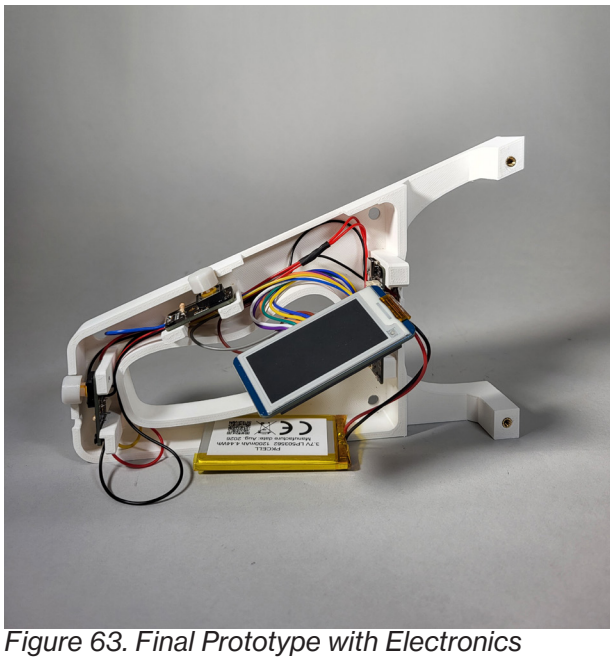

Figure 63. Final Prototype with Electronics


Figure 64. Heat Set Inserts in Final Prototype

In this prototype the information feedback is also integrated. Now showing the top match and its severity and also showing the match to other skin conditions the device detected.
This result information is placed on two different screens so all information can be displayed. To keep minimal components the picture button is also intended to swap in between these screens. On the interface a block with next and back is shown to indicate pressing the button performs these actions.


Power On



Ready Frame


Press Handle Button

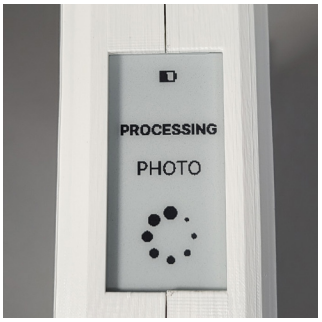


Processing Frame



Retake Photo Frame


Press Handle Button



Processing Frame



Results Frame 1


Press Handle Button



Results Frame 2


Press Power Button



Power Off Frame

Figure 65. Interface of Final Prototype

7.6 Summary

Study 1 didn't reveal a clear shared preference for the two prototypes but did show both were viewed positively. Overall there was a slight preference for prototype A after handling the prototypes. The next design therefore starts from A, keeping its shape, button position and icons and minimal screen information. It also integrates a larger screen, a stronger integrated distance guide and removes battery LEDs. Study 2: the makers print with FDM, lose prints to power outages and order electronics from Kampala, so the design must be FDM printable, consist of parts with shorter print times and use components widely available or in Kampala.

Answer to RQ3. The evaluations show that practitioners find it important that the device is smaller (making it easy to handle), and has a larger display (showing more information). On the other hand they had concerns about the device touching the skin, missing information on the severity and other possible conditions and struggled with accurately positioning the device without further instructions. Through observations it was shown that the shape of the distance guide did not matter for how the device was held and that a minimal interface was sufficient for participants to know what to do next without reading instructions on the task they have to perform.
Local makers show that FDM printing, SolidWorks, unreliable power, sourcing widely available components and minimal fine tip soldering experience are the conditions the design must fit.

8. Design Principles

This chapter focuses on widening the insights for this specific case to broader design principles for other frugal medical devices. These principles are therefore suggestions drawn from this case.

1. Local users and makers must constantly be involved during the design process. From the start ideas and decisions should be checked against the intended context. Having local users and makers involved throughout steps and decision making rather than verifying a final design. Letting them compare real alternatives allows for more input and highlights parts that would be a better fit for their feedback and shows what would work in practice. A mockup prototype can mimic the interaction a user would have with such a device

2. Make designing a shared process. Local users and makers must constantly be a part of the design process but this does not mean that the designer has to be in the country during the entire process. As this case showed it was a collaborative effort that mattered for the creation of the design direction. Where this design exploration was a short part of the larger PhD project making it crucial to share all knowledge and insights and make the design a collaborative effort within the team. This meant that as the designer I did not go to Uganda myself. Instead we were able to divide these responsibilities and work together on gaining insights and designing. This approach allowed to combine local expertise and connections with insights from a different angle as a Dutch Industrial Design Engineering student. A focus on sharing all knowledge and having a shared responsibility is important for the continuation of any such project.

3. Design around national constraints. Looking at the broader context can highlight crucial aspects to account for. In this case power interruptions, climate, logistics and language give design inputs from a national level. Power is here the clearest example, affecting the device in use and the printers that make it.

4. Shape the design by local tools and materials. When starting with the design of an embodiment the tools, materials and skills available locally decide how the embodiment is made. These set rules for how the embodiment can be shaped. As in this case the geometry, wall thicknesses and tolerances follow what local printers can do, so production stays within reach of local makers instead of asking them to meet a specification. This applies to any device made where production capacity differs from the designers' context.

5. Limit components and enforce behaviour with the embodiment. Every component adds cost, a point of failure and something to source. Where possible, let the form enforce the behaviour that matters, such as in this case distance and stability, instead of electronics or training. Support what remains with icons and minimal instruction. This applies to any device intended to be handled by users without specialist training.

6. Let local supplies determine the components. Choose components that are accessible locally, parts that must be imported can be unreliable and may also delay both production and repair. Choosing components should not only rely on what is the best and most cost efficient but also on what is available locally.

7. Design for changeable components. The layout should be defined by function, not by part. Reserving zones and thermal clearance lets one component be replaced by a similar one when supply changes or a part fails. This applies to any device whose electronics come from a supply chain the maker does not control.

In answer to RQ4: Local users and makers must constantly be involved during the design process, Make designing a shared process, Design around national constraints, Shape the design by local tools and materials, Limit components and enforce behaviour with the embodiment, Let local supplies determine the components, Design for changeable components.

9. Discussion and Conclusion

This chapter reflects on the results, states the limits of the process, proposes the next steps and concludes the thesis.

9.1 Discussion

The case supports the central claim of Chapter 3, frugal devices are shaped by who uses them and where, more than by cost. These tensions of that chapter appeared in every stage of the design and are worth reflecting on for the contribution of this thesis.

Cost versus robustness

This tension was relevant for design decisions on materials and components. Choosing to use PETG instead of the commonly used PLA, and minimal electronics in the device. This also still leaves questions open such as whether local printers and makers can work with PETG reliably and whether this material is also durable.

Standardisation versus local adaptability

Designing an embodiment started with looking at which tools are available locally and connecting those to standard rules applicable to these. While the focus is on resourcing locally as much as possible throughout the world materials and components will always have to be imported. Uganda is no exception. Therefore the focus has also been on standard components such as heat set inserts, screws and filament which may not be produced locally or are always in stock in Kampala but are widely available.

Component dependency versus supply resilience

Throughout the project the original intended processing board was discontinued. While this may still be used for the further development of the device it did show that components may have a weak point of supply resilience. Along with the uncertainty of what the actual final list of components will be, the focus was on making an adaptable design. Created by intended zones and thermal clearance.

Generic solutions versus contextual fit

Loop 2 has been created by user and context insights, while this did take the contextual fit into account it did also lead to making generic decisions. Such as the handle of the device and the information shown on the display. Actually letting intended users test with the prototypes allowed to get to a closer contextual fit. For now the manufacturing of the device also includes generic components such as heat set inserts, screws and the button and LED.

During the test with the comparative prototypes feedback revealed the working of the device was not yet in line with their needs. This agrees with the criticism that design processes often fail to study use before a design is finalised (Aranda-Jan et al., 2016), and it supports designing with rather than for users (Tran & Ravaud, 2016). A decision based on looks alone would have slightly favoured prototype B, while after handling the prototypes this shifted to prototype A.

The change in scope also showcases the connection to frugal design. The device moved from DCPA alone to three conditions because healthcare practitioners have to tell them apart in practice. That decision shaped the design. Frugal design here did not mean a cheaper version of the earlier concepts, but a different device, drawn from what really fits in the context.

9.2 Limitations

Three limits come from the process as a whole. First, the design was made from a distance. As the designer for this part I did not visit the context or was present at the sessions in person. Relying on the PhD student for most contextual insights, limiting a nuanced view. Additionally the loop 1 findings were also second hand information, relying on the student projects work. Second, the evidence is small and covers shape, handling and local production practice. Requirements on durability, cleaning, IP54 and repair were set but not tested. This means the studies generated insights but can not be relied on too heavily and are also missing crucial aspects to be tested. Third, the broader intended design principles come from the case study of one device in one country, so their transfer is argued, not shown. The study specific constraints of the field evaluation are described in Chapter 7. Finally, the diagnostic accuracy, electronics and software of the device and its use on patients fall outside this thesis, so the embodiment has not been tested together with a working algorithm or has been able to be designed with the actual electronics inside.

9.3 Future Work

The next loop starts from the design direction of Chapter 7. This was embodied in a new prototype which can be tested and experimented with. It should be tested at local maker facilities, with a trial PETG print, assembly of heat set inserts, screws and connecting the electronics even though they may not be the final ones. This can provide better insights about the capacity of manufacturing such a device. The next loop should also be evaluated with more practitioners and at more facilities, in a more accurate setting. Handling the device on human subjects at different body placements and testing the changes made to interface information and shape. Finally, the future design also needs to be combined with the parts outside the scope of this project, the final electronics and software.

This table gives an overview of all requirements and what remains open to be tested.

Table 9.1 overview of all requirements

Group	Requirements	Status	How to test next
Explored in Loop 2, targets not measured	R1, R2, R5, R6, R9, R10, R11	Qualitative feedback only	Measure working distance, angle deviation (≤2°), display at ≥10,000 lux, button force and reach, battery indicator

Group	Requirements	Status	How to test next
Body-site reach	R4	Not tested in the field	Handling trials on human subjects at several body sites
Built in, not evaluated	R3, R12, R24, R27–R31	Designed only	Lux and colour temperature check, stability on a desk, module swap, thermal and mounting check with real electronics
Local production	R21, R22, R23, R25, R26	Deferred	Trial PETG print at a maker facility, disassembly time, repair trial, pilot run of ~50 units
Hygiene and durability	R14, R15, R16, R17	Deferred	10 s wipe test, 200 wipe cycles, IP54 test, 3 drop tests with electronics inside
Use by non-specialists	R7, R8, R13	Deferred	Unaided capture after ≤5 min instruction (≥80%), pictogram and local-language comprehension, poster comprehension
Climate and power	R18, R19, R20	Not tested	5–40 °C and ≤85% RH operation, ≥8 h or ≥50 sessions per charge, ≤4 h charging and 300-cycle capacity

9.4 Conclusion

This thesis asked how frugal engineering principles can inform the physical embodiment of an AI assisted skin diagnostic device for HC III in Uganda as a Dutch Industrial Design Engineering student. It continued three earlier student projects and widened the device from DCPA on the lower leg to three conditions across the body, because healthcare practitioners need to distinguish them. Throughout was a constant back and forth between design and context, helped by the PhD student being originally from Uganda. This produced two comparative prototypes and tested them with healthcare practitioners and local makers.

The answer has two parts. For the device, the design direction is a smaller handheld shaped device, with a display, integrated lighting and distance guide, produced locally by FDM printing, a model open to be adapted to varying component availability and easy to open and repair. For frugal medical devices more generally, seven principles follow: Local users and makers must constantly be involved during the design process, Make designing a shared process, Design around national constraints, Shape the design by local tools and materials, Limit components and enforce behaviour with the embodiment, Let local supplies determine the components, Design for changeable components.
The device may not yet be finished but what can be concluded from this project is the importance of checking each design decision against the conditions it will be used in.
The report started with 4 research questions which have been answered throughout. To conclude, below is the overview of the questions, its answers and where their answers can be found.

Table 9.2: Answers to the research questions

Research question	**Short answer**	**Where**
RQ1: Which requirements does the HC III context place on the embodiment?	A handheld device that non-specialists can use quickly, images any body site, has integrated lighting and a distance guide, tolerates dust, heat and humidity, runs off grid, cleaned with an alcohol wipe, and is produced and repaired locally.	Chapters 2 and 5
RQ2: How can an embodiment be produced and repaired locally and adapted to changing components?	An adaptable layout organised by function and ventilation needs, a 3D printable model with geometry that follows generic FDM rules, closed with screws on the surface and independent access to each component.	Chapter 6
RQ3: What do the evaluations reveal about these choices?	Practitioners preferred a smaller design, larger display, icons on buttons and were missing information on the severity of condition and other potential matches. The weak points were the distance guide, positioning and skin contact. Makers print in PLA on 0.4 mm printers with unreliable power and order electronics from Kampala.	Chapter 7
RQ4: Which principles can transfer to other frugal medical devices?	Local users and makers must constantly be involved during the design process, Make designing a shared process, Design around national constraints, Shape the design by local tools and materials, Limit components and enforce behaviour with the embodiment, Let local supplies determine the components, Design for changeable components.	Chapter 8

References

Afrobarometer Dispatch AD912 (2024), “Despite government efforts, most Ugandans still lack reliable electricity. https://www.afrobarometer.org/publication/ad912-despite-government-efforts-most-ugandans-still-lack-reliable-electricity/

Also Uganda. (n.d.). Mbarara. Retrieved October 21, 2026, from https://alsouganda.com/mbarara-2/

Aranda-Jan, C. B., Cruickshank, H., & Moultrie, J. (2016). Putting medical devices in context: A systematic review of evidence on design targeting low-resource settings. International Journal of Design Engineering, 6(2), 127–149. https://doi.org/10.1504/IJDE.2016.080036

Armstrong, A. W., & Read, C. (2020). Pathophysiology, clinical presentation, and treatment of psoriasis: A review. JAMA, 323(19), 1945–1960. https://doi.org/10.1001/jama.2020.4006

Bourkas, A. N., Barone, N., Bourkas, M. E. C., Gulliver, W. P., & Alhusayen, R. (2023). Diagnostic reliability in teledermatology: A systematic review and meta-analysis. BMJ Open, 13(8), e068207. https://doi.org/10.1136/bmjopen-2022-068207

Clarke, G. H. (1952). A note on dermatitis cruris pustulosa et atrophicans. Transactions of the Royal Society of Tropical Medicine and Hygiene, 46(5), 558–559. https://doi.org/10.1016/0035-9203(52)90048-X

Couppoussamy, K. I., Chellamuthu, L., Devanda, R., & Mary, J. J. F. (2025). Clinical characteristics, histopathological features, and treatment options of dermatitis cruris pustulosa et atrophicans: A systematic review. Clinical Dermatology Review, 9(2), 151–160. https://doi.org/10.4103/cdr.cdr_89_24

Couppoussamy, K. I., & Devanda, R. (2024). Dermoscopic features of dermatitis cruris pustulosa et atrophicans: A retrospective study from a tertiary care center in South India. Indian Dermatology Online Journal, 15(5), 801–804. https://doi.org/10.4103/idoj.idoj_712_23

Dowhaniuk, N. (2021). Exploring country-wide equitable government health care facility access in Uganda. International Journal for Equity in Health, 20(1), Article 38. https://doi.org/10.1186/s12939-020-01371-5

Enechukwu, N. A., & Ogun, G. O. (2024). Tropical dermatology and neglected tropical skin diseases: Diagnostic challenges in low-resource primary care. Dermatologic Clinics, 42(2), 215–227. https://doi.org/10.1016/j.det.2023.11.004

Epps, R. E. (2010). Special considerations in dark-skinned children. Current Opinion in Pediatrics, 22(4), 423–429. https://doi.org/10.1097/MOP.0b013e32833bb203

Everyday Health. (2025, April 8). What Black patients need to know about the effects of psoriasis. https://www.everydayhealth.com/psoriasis/what-black-patients-need-to-know-about-the-effects-of-psoriasis/

Frayling, C. (1993). Research in art and design Royal College of Art Research Papers (Vol. 1, No. 1).

Google. (2026, May 19). Datasheet. Google for Developers. https://developers.google.com/coral/products/SL2610-dev-board

HEPS-Uganda. (2016). Government commitment to provide essential medicines Policy Brief. Coalition for Health Promotion and Social Development.

Hu, S. C.-S., & Lan, C.-C. E. (2017). Psoriasis and cardiovascular comorbidities: Focusing on severe vascular events, cardiovascular risk factors and implications for treatment. International Journal of Molecular Sciences, 18(10), Article 2211. https://doi.org/10.3390/ijms18102211

International Organization for Standardization. (1998). Ergonomic requirements for office work with visual display terminals (VDTs) – Part 5: Workstation layout and postural requirements ISO Standard No. 9241-5:1998.

João, A. M., Canto, A. M., & Lupi, O. (2022). Dermatitis cruris pustulosa et atrophicans: An underdiagnosed tropical entity. Anais Brasileiros de Dermatologia, 97(4), 512–516. https://doi.org/10.1016/j.abd.2021.08.009

Jones, O. T., Ranmuthu, C. K., Hall, P. N., Funston, G., & Walter, F. M. (2019). Dermoscopy for melanoma detection and triage in primary care: A systematic review. BMJ Open, 9(8), e027529. https://doi.org/10.1136/bmjopen-2018-027529

Kaimal, S., D'Souza, M., & Kumari, R. (2009). Dermatitis cruris pustulosa et atrophicans. Indian Journal of Dermatology, Venereology and Leprology, 75(4), 348–355. https://doi.org/10.4103/0378-6323.53127

Korotkiy, V., Shagova, Y., & Aksenenko, A. (2023). Skinive: AI-based dermatology decision support for primary care practice. Healthcare Technology Letters, 10(3), 65–72. https://doi.org/10.1049/htl2.12048

Langan, S. M., Irvine, A. D., & Weidinger, S. (2020). Atopic dermatitis. The Lancet, 396(10247), 345–360. https://doi.org/10.1016/S0140-6736(20)31286-1

Lubwama, H., Mulyowa, G. K., Mirembe, S. K., Katungi, T J., & Male, M. (2025). Psoriasis: Prevalence, clinical variants and quality of life among patients attending the skin clinic at Mbarara Regional Referral Hospital, Uganda. Psoriasis: Targets and Therapy, 15, 117–126. https://doi.org/10.2147/PTT.S501102

Lukwago, D. (2016). Health spending in Uganda: Implications on the National Minimum Health Care Package ACODE Policy Briefing Paper No. 32.

Malkin, R. (2007). Design of medical devices for the developing world. BMJ, 335(7619), 568–570. https://doi.org/10.1136/bmj.39323.511389.AD

Malkin, R., & von Oldenburg Beer, K. (2013). Diffusion of novel healthcare technologies to resource poor settings. Annals of Biomedical Engineering, 41(9), 1841–1850. https://doi.org/10.1007/s10439-013-0852-5

Mayuge Town Council. (n.d.). Health centre III [Image]. https://mayugetc.go.ug/file/health-centre-iiijpg-0

Ministry of Health Uganda. (2019). National Health Facility Inventory 2018/2019. Government of Uganda.

Mpairwe, H., Ndibazza, J., Webb, E. L., Nampijja, M., Muhangi, L., & Elliott, A. M. (2021). Risk factors associated with rhinitis, allergic conjunctivitis and eczema among schoolchildren in Uganda. Clinical & Experimental Allergy, 51(1), 108–119. https://doi.org/10.1111/cea.13769

MSD Manual Professional Edition. (2025). Atopic dermatitis (Eczema). Merck & Co., Inc.
Mulyowa, G. K., Engwau, T., Galiwango, M., Kamuganga, F., Mirembe, S. K., Aloyo, G. O., Mwavu, R., Wasswa, W., Kaggwa, F., & Obua, C. (2026). Clinical features and risk factors of dermatitis cruris pustulosa et atrophicans in southwestern Uganda: A cross-sectional study. Clinical, Cosmetic and Investigational Dermatology, 19, 123–134. https://doi.org/10.2147/CCID.S502119

Mundeli, S. P., Onguti, A. G., Mirembe, S. K., Mulyowa, G. K., & O'Brien, T. (2025). Prevalence of vitiligo among patients attending the skin clinic at Mbarara Regional Referral Hospital, southwestern Uganda: A retrospective review. JAAD International, 19, 45–52. https://doi.org/10.1016/j.jdin.2025.01.010

Nair, P. A., & Badri, T. (2023). Psoriasis. StatPearls. StatPearls Publishing.
Namaganda, G., Oketcho, V., Maniple, E., & Viadro, C. (2015). Making the transition to workload-based staffing: Using the Workload Indicators of Staffing Need method in Uganda. Human Resources for Health, 13(1), Article 89. https://doi.org/10.1186/s12960-015-0089-6

Namyalo, S. (2015). Language situation and endangerment in Uganda: Facts and perspectives https://talks.cam.ac.uk/talk/index/58684/

Odokonyero, T., Mwesigye, F., & Adong, A. (2017). Regional disparities in healthcare access and infrastructure in Uganda EPRC Research Series No. 138.

Peters, N., & Peters, S. (2019). Clinical presentation and management of atopic dermatitis across diverse patient populations. Journal of Clinical and Aesthetic Dermatology, 12(4), 22–28.

Piaggio, D., Castaldo, R., Cinelli, M., Cinelli, S., Maccaro, A., & Pecchia, L. (2021). A framework for designing medical devices resilient to low-resource settings. Globalization and Health, 17(1), Article 64. https://doi.org/10.1186/s12992-021-00717-3

Radjou, N., Prabhu, J., & Ahuja, S. (2012). Jugaad innovation: Think frugal, be flexible, generate breakthrough growth. Jossey-Bass.

Rahix. (2026). Functional 3D printing design guidelines for mechanical enclosures and snap-fit assemblies. Open Engineering Repository.

SCARLETRED Holding GmbH. (n.d.). Scarletred Vision: Digital skin imaging and tele-dermatology platform.

Stappers, P. J., & Giaccardi, E. (2017). Research through design. The encyclopedia of human-computer interaction (2nd ed.). Interaction Design Foundation.

Ting, H. C. (1984). Dermatitis cruris pustulosa et atrophicans: Case reports. Medical Journal of Malaysia, 39(1), 74–77.

Tran, V.-T., & Ravaud, P. (2016). Frugal innovation in medicine for low resource settings. BMC Medicine, 14(1), Article 102. https://doi.org/10.1186/s12916-016-0651-y

Udrea, A., Mitra, G. D., Costea, D. A., & Noels, E. C. (2020). Accuracy of a smartphone application (SkinVision) in detecting skin cancer in primary care. Journal of Medical Internet Research, 22(11), e20422. https://doi.org/10.2196/20422

Waveshare Electronics. (n.d.). E-Paper displays. Waveshare. Retrieved October 20, 2026, from https://www.waveshare.com/display/e-paper.htm

WebMD. (2026, February 16). How eczema affects darker skin tones. https://www.webmd.com/skin-problems-and-treatments/eczema/eczema-darker-skin-tones

World Bank. (2022). Rural population (% of total population) - Uganda. World Development Indicators.

World Bank Group, Climate Change Knowledge Portal. (2024). Climate data: Uganda country profile.

World Health Organization. (2022). Compendium of innovative health technologies for low-resource settings. World Health Organization.

World Health Organization. (2025). Global report on skin diseases and neglected tropical diseases. World Health Organization.

Zimmerman, J., Forlizzi, J., & Evenson, S. (2007). Research through design as a method for interaction design research in HCI. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 493–502). ACM. https://doi.org/10.1145/1240624.1240704

Appendix

USABILITY QUESTIONNAIRE

Participant ID:_____ Session Order: ☐ Prototype A First ☐ Prototype B First

Healthcare Facility: _____

Section 1: Participant Profile

What is your age? : ____ years

What is your current role in this facility? : _____

☐ Medical Doctor

☐ Nurse

☐ Clinical Officer

☐ Other: _____

How many years of healthcare experience do you have? : ____ years

What kind of dermatological training have you had? *(select all that apply)*:

☐ Formal Medical/Nursing

☐ Short Workshops

☐ On-the-job

☐ Self-taught

☐ None

☐ Other: _____

Section 2: Diagnostic Devices Background

What Dermatological Diagnostic Devices do you use?

☐ Magnifying Glasses

☐ Dermatoscope

☐ Skin Scraping Kits

☐ None

☐ Other: _____

How often do you use these diagnostic devices?

☐ Daily ☐ Weekly ☐ Monthly ☐ Other: _____

How did you learn to use these diagnostic devices? *(Select all that apply)*

☐ Formal training

☐ Peer training

☐ Self-taught

☐ User manuals / reference materials

☐ Other: _____

What are the most useful aspects of these diagnostic devices?

_____

_____

_____

What challenges do you encounter with these diagnostic devices?

_____

_____

_____

What cleaning procedures do you follow for these diagnostic devices?:

_____

_____

_____

Section 3: Prototype First Impression

These are two prototypes for a diagnostic device for skin conditions such as DCPA and eczema. They are designed to aid accurate diagnosis of similar looking conditions. Because it is a prototype to test they currently have an extra box attached. This is normally not there.

What prototype do you prefer by initial appearance?:

☐ Prototype A ☐ Prototype B ☐ No preference

Why do you have this preference?:

_____

_____

Section 4

Now, we ask you if you can perform a task with these prototypes. We will start with prototype x and after we will do the same with prototype x.

Can you start by turning on the device

Perform the task one by one.

Proposed Task:

1. *Turn on the device.*
2. *Position the device at the marked target*
3. *Capture an image.*
4. *Follow the information shown by the device and take any additional action you think is necessary.*
5. *Review the result.*
6. *Turn off the device.*

Section 5: Immediate Rating

Prototype A / B

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
It was easy to perform the task with this prototype	☐	☐	☐	☐	☐
It was comfortable to hold and position this device	☐	☐	☐	☐	☐
It felt stable when positioning the device	☐	☐	☐	☐	☐
The instructions on the display were clear	☐	☐	☐	☐	☐
It was easy to understand the result	☐	☐	☐	☐	☐

What, if anything, did you find difficult or confusing about using the prototype?

_____

_____

_____

Prototype A / B

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
It was easy to perform the task with this prototype	☐	☐	☐	☐	☐
It was comfortable to hold and position this device	☐	☐	☐	☐	☐
It felt stable when positioning the device	☐	☐	☐	☐	☐
The instructions on the display were clear	☐	☐	☐	☐	☐
It was easy to understand the result	☐	☐	☐	☐	☐

What, if anything, did you find difficult or confusing about using the prototype?

Section 6: Prototype Comparison

PROTOTYPE COMPARISON

Aspect	Prototype A	About the Same	Prototype B
More comfortable to hold and use	☐	☐	☐
More stable while taking an image	☐	☐	☐
Easier to know how to perform the task	☐	☐	☐
Clearer presentation of the result	☐	☐	☐
Better fit with my usual workflow	☐	☐	☐

What prototype do you prefer after performing the task?

☐ Prototype A ☐ Prototype B ☐ No preference

Why do you have this preference?:

_____

_____

_____

_____

Section 7: Implementation Feedback

Likelihood of using such a diagnostic device in my clinical practice

Very Unlikely	Unlikely	Unsure	Likely	Very Likely
☐	☐	☐	☐	☐

What is the reason for this?

_____

_____

_____

When would you use this device for work?

_____

_____

_____

What needs to be changed/improved about the device to better fit into your workflow?

_____

_____

_____

Is there enough information given on the screens to feel confident with a diagnosis?

Why/ why not?

_____

_____

_____

What is your view on the device touching the patients skin?

_____

_____

_____

Do you have any additional comments or suggestions?

FACILITY CAPABILITY QUESTIONNAIRE (RESEARCHER SHEET)

Section 1: Facility Profile

Facility Name:_____

Location/District: _____

Contact Person:_____

Facility Type: ☐ Makerspace ☐ Commercial Print Shop ☐ Electronics Repair

☐ University Lab ☐ Other: _____

Section 2: Enclosure Fabrication

[Show physical prototype models]

Can you 3D print this enclosure model on your machines? ☐ Yes ☐ No

If yes: On which 3D printer: _____

If no: Possibility of Fabricating in another way:_____

What Filament/ Material would you use?: ☐ PLA ☐ PETG ☐ ABS

☐ Other:_____

Why would you use this specific material?:

_____

_____

What print settings would you use to print this with a smooth surface?

_____

_____

This CAD model has a maximum of 45 ° overhang. Would you prefer to print this with or without supports?

☐ With support ☐ Without support

Why would you prefer this?

_____

_____

Section 3: Electronics Integration

[Show Google Coral Board]

Do you have Fine-Tip Soldering Tools in this facility?: ☐ Yes ☐ No

Do you have experience with wiring SMT/Micro Components:

☐ High ☐ Moderate ☐ None / Inexperienced

Insights on Electronics Tools & Assembly Challenges:

_____
_____
_____
_____
_____
_____
_____

Section 4: Local Repair & Service Feasibility

Can your team repair/replace broken casings, loose wires, or failed displays on-site?

☐ Yes, fully capable ☐ Partial (casing only / electronics only) ☐ No

Repair Workflow & Spare Parts Strategy:

_____
_____
_____
_____
_____
_____
_____

Section 5: Technical & Material Specs

What other 3D Printers are Available at this facility?:

Types: _____

Advantages / disadvantages of these 3D printers:

_____

_____

_____

_____

What Nozzle Sizes do you use?:

☐ 0.4mm (standard ☐ 0.2mm (Fine detail) ☐ 0.6mm+ (Fast print)

☐ Standard delivered with printer

What CAD Software do you use?:

☐ SolidWorks ☐ Fusion 360 ☐ Blender ☐ Rhino ☐ Shapr3D ☐ SelfCAD

☐ Other: _____

If multiple: what is the most used software and why?:

_____

_____

Do you keep microcontrollers, tactile buttons, LEDs, or displays in stock?

☐ Yes, kept in stock ☐ No, bought per project / order as needed

If in stock, specify items:

_____

_____

_____

_____

_____

_____

_____

Section 6: Facility & Infrastructure Context

Material Supply Sourcing:

Where are filaments & electronics bought?

_____

_____

What are the average delivery times?

_____

_____

_____

_____

Power Reliability:

What is the impact of power outages/fluctuations on long prints & electronics work?

_____

_____

_____

_____

Do you have any available backup power?:

☐ Generator ☐ UPS/Battery ☐ Solar ☐ None (Outages disrupt operations)

General Tools / Power Capabilities Available:

_____

_____

_____

_____

_____

CORE CAPABILITY CHECKSHEET (For Easy Cross-Facility Comparison)

Fill this out immediately after leaving to compare facilities directly in your final report:

Specific Requirement	**Capability Confirmed?**	**Notes / Constraints**
Print a smooth 3D enclosure	☐ Yes ☐ No	Filament suggested: _____
Fine-pitch electronic soldering (Coral + display)	☐ Yes ☐ No	Tool quality: _____
Local repair/component replacement	☐ Yes ☐ No	Spare parts stocked?: _____
Power stability for long jobs	☐ High ☐ Low	Generator/UPS present?: _____