It's a Much Harder Journey: Scaling Assistive Technology Innovations in Africa

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ABSTRACT

Access to Assistive Technology (AT) in Africa is severely limited, with less than 25% of those who need AT have access to it. This paper examines three cases illustrating the journey of scaling AT innovations in African markets to enhance access. Our methodology involves within-case and across-case analyses, highlighting the significant impact of contextual factors on assistive product design and service delivery. Key insights from these cases include the importance of securing standard approvals and demonstrating tangible benefits to build trust in emerging ecosystems. Modular, versatile, and customizable AT solutions proved crucial for adaptation and scalability without requiring substantial additional investments. In conclusion, this study emphasizes the profound role of context in shaping AT innovation. Addressing challenges and opportunities identified in these cases contributes to the discourse on enhancing AT innovation scalability, ultimately improving access for those in need of AT.

CCS CONCEPTS

• **Human-centered computing**; • **Accessibility**; • **Accessibility theory, concepts and paradigms**;

KEYWORDS

Assistive Technology, Innovation, Africa, Entrepreneurship

1 INTRODUCTION

In Africa, an estimated 15.6% of the population, equivalent to 60-80 million individuals, live with disabilities [52]. While Assistive Technology (AT) has demonstrated significant socioeconomic benefits in poverty reduction and enhancing social inclusion [42] of people with disabilities, a substantial access gap exists. Only 15% to 25% of those who require assistive products in Africa can access them [40]. This deficit is primarily attributed to contextual challenges, including governance issues, funding shortages, limited promotion of public-private partnerships, and a fragmented supply chain for assistive products [52]. Hence, the AT ecosystem in Africa is multifaceted, involving a diverse range of stakeholders; AT developers, users, clinicians, funders, and intermediaries, all of whom have the potential to either facilitate or hinder the spread of AT innovations. They are not a single sector like Fintech or Argritech but a fragmented sector of sectors, which complicates the dynamics within them and multiplies the challenges for entrepreneurs to be successful [20]. The ecosystem unites both tangible and intangible dimensions, encompassing a wide spectrum of stakeholders and contextual factors that collectively define the intricate environment in which AT innovations evolve and flourish. This has spurred many innovations with the goal of creating appropriate access to AT.

The entrepreneurial journey of AT innovations, emerging from the African context and tailored to the African market, is closely intertwined with these unique circumstances. Prior research in the African innovation ecosystem has attributed growth in the area to the significance of culture [1], context-specific usability demands [39], resource-efficient digital practices fostering innovation [32], and the growing economic ecosystem [53]. Our research grows this domain by analysing the journey of three African AT start-ups through in-depth interviews, using both within-case and across-case thematic analyses [23]. It aims to provide qualitative insights into how these start-ups adapt their AT innovations to African market needs. The research question guiding this study is: "How do AT innovators navigate the challenges within the African assistive technology innovation ecosystem?"

Our primary goal is to provide an overview of how innovations reach people in the African AT ecosystem, highlighting the specific challenges within this landscape and the strategies employed to address them by entrepreneurs. We discuss these findings using macro-Human-Computer Interaction (HCI) elements [43] and

the Disability Interactions (DIX) framework [19] which include building trust, nurturing empathy for stakeholders, and fulfilling responsibilities throughout the value chain to develop products and interactions. Through this, we aim to contribute to the junction of AT, HCI, and innovation communities and emphasize what it takes to scale AT innovations in Africa.

2 RELATED WORKS

2.1 Innovation in AT and HCI

As HCI becomes increasingly central in technology, there's a growing need for deeper research on innovation and design practices [43, 45], especially in disability innovation [19] as it is crucial that AT reaches people. Given 80% of people who need AT don't have access and high number of potential users live in Africa, it is important that future research and innovation seeks to ensure adoption of inventions. This entails creating not only accessible technologies but also effective strategies for delivering them to those in need. To address this, HCI research must go beyond user-system interactions and explore the broader landscape of innovation, design, and utilization.

Shneiderman's approach to HCI and technology research, combining applied and basic research [45] is integral to DIX framework [19]. DIX acknowledges disability's complexity and employs a challenge-based approach, blending applied and basic research. Unlike traditional accessibility methods, DIX focuses on addressing large-scale systems from the start and emphasizes participatory approaches across the entire technology value chain [5]. Several factors influence the adoption of AT by disabled individuals, including understanding the context and recognizing the value and usefulness of AT for users [19, 45].

These elements, which might seem beyond HCI research, are important parts of the ecosystem and can make or break the successful adoption of an AT. Chilana et al. [7] demonstrate how user-centered approach of AT development evolved to an adoption-centric approach, driven by the differences between end users and customers, that necessitated critical iterations in the product to suit its new customers. Adoption-based design aims that technology reaches end-users. Others have expressed the frustrations of translating research into product adoption. For example, Mascetti et al. faced challenges in translating research outcomes from AT mobile apps to its users with visual impairments. Challenges included navigating the fragmented market and developing sustainable financing and distribution models [26]. Hence, for an impact from AT research and development there is a need for deep understanding of the context in which they will be used by disabled individuals as well as how devices will be procured and provided to users, that HCI methods can facilitate [4].

2.2 Disability and AT in Africa

In Africa, an estimated 15.6% of the population, equivalent to 60-80 million individuals, live with disabilities [54]. It's essential to dispel the misconception that African culture is uniform; instead, it comprises diverse and unique cultures and traditions specific to each country and community. Disability is a known, intersectional issue in Africa. It intersects with various dimensions, such as gender, age, culture, and socioeconomic status [49, 52] affecting the experiences and rights of disabled individuals. Disability prevalence is disproportionately higher among women [55], often due to cultural practices favoring men for earning potential [28]. Women with disabilities face limited access to education, healthcare, employment, and assistive technologies, highlighting the need for gender-specific support to promote inclusivity [33]. Insufficient care during pregnancy and childbirth also contributes to disability prevalence. Disability stigma, negative attitudes, misconceptions, and discrimination create barriers to technological solutions [11, 56]. Socioeconomic status significantly impacts well-being, access to education, employment, and healthcare. Approximately 60% of disabled people in Africa live in poverty due to additional costs of living and poor education and employability opportunities [57], reinforcing the connection between disability and poverty [2, 29, 36]. These intersectionalities add complexity to the disability and accessibility challenge, making it a "wicked" problem.

The ecosystem for AT in Africa faces several challenges that impede its growth and integration. These challenges include a fragmented landscape marked by limited coordination and collaboration, often resulting in duplicated efforts and restricted knowledge sharing [40, 52]. Additionally, resource constraints, inadequate infrastructure, and a lack of comprehensive policies and regulations hinder the research, development, and production of AT [40]. Furthermore, there is a pervasive lack of awareness among the general public, policymakers, and healthcare professionals regarding the potential benefits and applications of AT [34, 41]. The high costs of AT, their limited availability, and the absence of healthcare insurance coverage make it difficult for those in need to access essential AT devices [2, 30]. Lastly, there is a lack of comprehensive funding and standards that govern the development, importation, and distribution of AT [31]. The high level of fragmentation results in a wasteful sector which means that funding is not effectively used to improve the supply and access to AT [27].

Efforts to improve the landscape of AT involve various stakeholders, including governmental agencies, non-profits, and international collaborations [48]. International partnerships are essential, offering support through capacity-building, knowledge sharing, and financial aid [47]. Moreover, the focus on affordable and locally sourced AT is growing [6], with mobile technology playing a transformative role. Mobile-based AT applications and services cater to individuals with disabilities [3, 4, 13, 26, 49, 58, 59], taking advantage of increasing smartphone adoption in Africa. African innovators are also developing cost-effective, context-specific AT solutions, empowering local communities and addressing unique needs of the context [47, 48]. It is driven by the social and cultural requirements and is often necessitated by the limited access to traditional AT. For example, DIY practices to create individualized AT [15, 16] have been explored to establish pathways for disability innovation research in HCI. Many other projects pertaining to education of disabled children in inclusive settings also demonstrate the value and impact of creating access to AT [50].

As the number of innovations increase there have been attempts to make sense of this growing landscape. For example, The AT Info Map application identifies AT service providers and suppliers to improve accessibility and user's awareness of the AT that is available in the African region [49]. Groups have also developed to

Table 1: Startup, their country of focus and the participant's role

Start-up	Country in Focus	Number of Participants	Their Roles
Modular upper limb prosthesis	Sierra Leone	1 (P1)	Head of Global Access
Smartphone app designed for hearing screening	South Africa	2 (P2, P3)	Director and Product Manager
AI-based wearable device crafted for obstacle detection and avoidance	Kenya	1 (P4)	Founder

share knowledge such as the African community of on AT (ACAT) that is an active virtual network that exchanges grey literature, practice guidance and troubleshoots sustainable product design and deployment [22]. The repair ecosystem can also begin to grow as the skills developed in the many micro and small enterprises have been argued to be critical for the repair of AT [35]. However, we reiterate that these developments do not operate as a sector but a fragmented juxtaposition of uncoordinated parts [28]. In this study, we seek to understand how innovators have been navigating this fragmented context to make access to AT possible for people in Africa.

3 METHODS

This study employed a multiple case study approach with an embedded methodology [46] to investigate the entrepreneurial journeys of ventures entering the African markets. The embedded approach facilitated a comprehensive exploration of each individual case while enabling an across-case analysis to uncover common themes and patterns that emerged across these diverse entrepreneurial journeys. Each case study consisted of semi-structured interview with key individuals within the three ventures chosen as they narrated a rich picture of their entrepreneurial journey to take AT to users.

3.1 Participants

The research focused on three distinct cases of AT innovations. The selection of these cases was guided by a strategic sampling approach [25], ensuring diversity across three distinct types of AT innovations, each with the goal of expanding and scaling within different geographical regions—specifically, East Africa, West Africa, and Southern Africa. The first case study was presented by P1, who spearheaded the efforts to provide affordable upper limb prosthetics in Sierra Leone. P1's involvement extended to expanding access to upper limb prosthetics humanitarian contexts. In the second case, the discussion was led by both the director (P2) and the product manager (P3). P2, a university professor and one of the technology's inventors, played a crucial role in the start-up. P3 was responsible for overseeing the product and service delivery, collaborating with local partners, and ensuring the success of the initiative aimed at simplifying and enhancing hearing impairment screening via a smartphone app. The third case study was shared by P4, the founder of a start-up based in Kenya. This start-up has expanded its presence to multiple countries across Africa, Europe, and Australia, reflecting its remarkable growth and impact. All the participants volunteered to share their journeys without any incentives.

3.2 Data Collection

Semi-structured interviews were audio recorded and transcribed. Ethical clearance was obtained from the university ethics review committee, and all interview data was anonymized to safeguard the privacy of the participants.

The interview guide comprised a series of questions to delve into various aspects of the entrepreneurial process. These questions covered key topics, including the motivations driving the initiation of their ventures, the early stages of their entrepreneurial journeys, the challenges encountered and victories achieved when entering the market, the strategic approaches adopted, the identification of significant partners or stakeholders, the factors contributing to their scaling-up efforts, the current challenges impeding their progress, and the invaluable lessons derived from their entrepreneurial experiences.

Each interview consistently covered these questions to maintain coherence and facilitate comparative analysis across cases. They lasted 60 to 90 minutes, allowing for an in-depth exploration of entrepreneurial journeys. With the analysis of this data, we attempt to explore the challenges characterizing the landscape of AT innovation in Africa and pathways to scale.

3.3 Analysis

The qualitative data were subjected to hybrid reflexive thematic analysis [12] approach in two steps, encompassing within-case and across-case analyses [23]. The within-case analysis involved an inductive thematic analysis approach [13], where data from each case were examined individually to understand their unique characteristics. In this process, initial coding was performed independently for each case, highlighting, and categorizing recurring concepts and patterns that emerged within that specific case. An iterative refinement process was then employed, involving the consolidation of similar codes drawn from different data points. To enhance the reliability of the findings, a summary of these initial findings was shared with the respective participants, inviting their validation and accordingly, the insights were refined.

Next, a deductive across-case analysis [13] was conducted to compare the coded data and themes from all three cases to uncover overarching patterns and relationships. The objective was to uncover overarching patterns and relationships that transcended the individual experiences of the cases. Cross-cutting codes across cases were clustered into new thematic patterns, highlighting common challenges and strategies. This approach sought to generate higher-level insights that extend beyond the specific cases, thereby offering a more comprehensive understanding of the factors influencing innovation within the contexts under study.
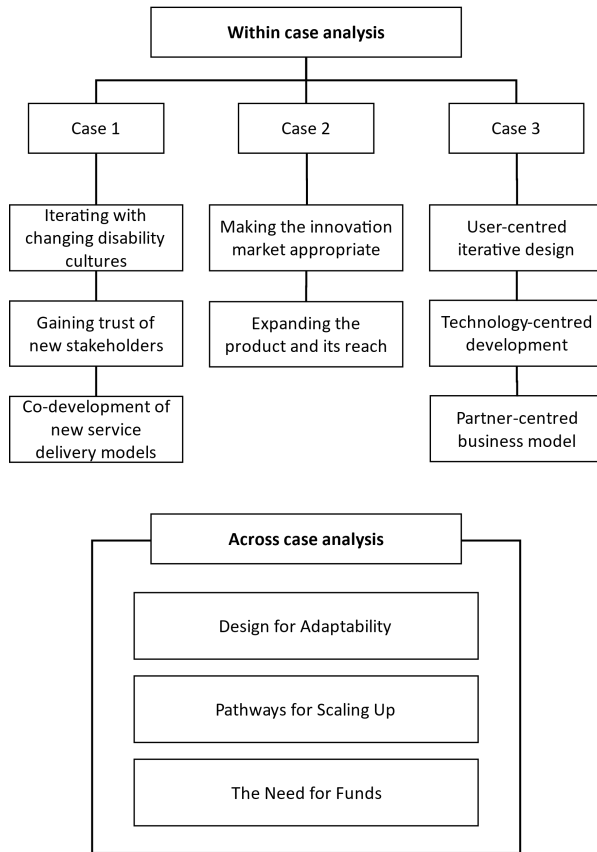
Figure 1: Thematic analysis - within and across case studies

Given the small sample of participants, by employing this two-step analytical process (Figure 1), our research aimed to achieve both depth and breadth in understanding the intricate dynamics and influences that shape the innovation processes within the African AT ecosystem. We adopted this hybrid approach to not only identify unique elements that define individual journeys within their respective ecosystems, but also to gain insights that enable us to discuss common themes across cases, contributing to existing frameworks.

4 WITHIN-CASE ANALYSIS

4.1 Case 1: Introducing a Modular Upper Limb Prosthetic in Sierra Leone

The venture was founded in 2020 on the back of a successful university project in which the founder, then a student, as part of their work with a user who was dissatisfied with the available upper limb prosthesis. The abandonment rate of upper limb prosthetics is high globally, while traditional prosthetics are heavy and require skill and craftsmanship to create. Furthermore, too few trained personnel exist to fit devices globally. The project explored using textiles and fabrics to make an upper limb prosthetic that is soft, light, and comfortable. After multiple iterative designs, with the technical goal to simplify the design, the prosthetic device finally features a simple Velcro-based sleeve that can comfortably and snugly fit

around the arm and has modular attachments that can be changed to perform different tasks. The non-bespoke design of the prosthetic arm made it affordable, mass manufacturable and scalable so that the same device can be to a user in a high-income setting and a low-income setting. There is a definitive need for upper limb prosthetics in low-resource settings. Many users who may need it and can benefit from it do not have access to AT. However, when expanding to Africa, the founders had little understanding of the contextual barriers that make access to AT challenging within this context.

4.1.1 Iterating with changing disability cultures. The first exploration in a low-resource context was in a West African country. The first 20 users expressed pleasure after wearing the prosthetic, citing that it was comfortable and light, but also remarked that they would never wear it because it didn't look like what they wanted. The users in the country wanted to blend in with society and would prefer a prosthetic that looked like a normal arm – a cosmesis rather than a functional prosthetic device, not wanting to show their limb difference. This was a significant shift in disability culture for the company as the ethos of the design, embedded in the social model of disability, encourages people to be confident about their difference and be comfortable with their identity as a person with a disability [10].

> "The way that I would want to look it you know, I kind of want to almost blend in. I don't really want to stick out and show the fact that I've got limb difference and that was a bit difficult for us to sort of must think, put some thought into that, cause that [the start-up] would kind of very much don't want people to feel like that." – P1

In this new context, stigma was more prevalent, possibly due to how most people had attained their limb difference (many by forced amputation), and therefore, the company had to redesign the end effector (hand part) of the arm and provide a cosmetic solution. Here, the modular design of the prosthetic system enabled rapid iterative development according to the new user-centric requirements.

In innovation research, context variation by design, a process that provides a scaffolding to design for diverse context so that designs are not specific to the use context [21]. In this approach, insights from different contexts are combined to the design. Indecently, this variation due to the context due to the design of the device. Such confronting insights can also reveal new solution directions that may be useful for other contexts. This case presents an example of design that can work in diverse contexts without expensive iterations.

> "So, it's the same product. We don't you know we don't offer different quality of product for anywhere. It's the same thing whether it's the US or you know a country in sub-Saharan Africa or Asia or wherever." – P1

4.1.2 Gaining trust of new stakeholders. The innovation introduced by this company represents a fundamental departure from the traditional design of upper limb prosthetics. In the eyes of traditional prosthetists, the primary concerns have traditionally revolved

around factors such as functionality, durability, and reliability—specifically, the ability of the prosthetic device to support everyday activities, including tasks like lifting heavy weights and managing household chores like laundry. To establish trust and credibility within the structures and organizations that could potentially adopt their solution, the company recognized the need to demonstrate traditional outcome measures, particularly in relation to the socket's functionality and its usability by the end-users.

> "Prosthetists who of course are experts in the field about, you know, will this stay on the arm? Will it be able to lift, you know, heavier objects can people do various tasks? Cause I don't really trust it because it's a soft socket. … We absolutely looked at traditional like outcome measures and functional tests and these sorts of things that prosthetist and occupational therapists would use for." – P1

However, within the new context of this low-resource setting, there has been a fundamental shift in the user experience, driven by the incorporation of different modular attachments and the evolving goals and needs of the users. Consequently, the activities and tasks that people in this context aspire to perform with the prosthetic device differ significantly from those in high-income settings. Therefore, it has become evident that new and more context-relevant outcome measures are necessary to effectively evaluate the functionality and usability of the prosthetic device within this unique user environment.

> "And you know, but it can also be more traditional things if somebody wants to, you know, eat with cutlery and actually they struggle with that at the moment or hold a glass of water or whatever, that's also included. But really the key measure of success for us in terms of functional outcomes is. Okay, what did you want to do with this and can you?" - P1

This recognition underscores the importance of tailoring both the design and evaluation processes to align with the specific needs, goals, and cultural contexts of the users. It also highlights the need for a flexible and adaptive approach to innovation, particularly when introducing transformative solutions that challenge conventional norms and practices.

4.1.3   Co-development of new service delivery models. The non-bespoke design opened the door to scalable and decentralized service delivery models, which are well-suited for areas with limited specialists and remote regions lacking affordable transportation options. This concept led to the idea of a "clinic in a bag" as it doesn't rely on complex infrastructure for deployment. However, implementing such a model in these contexts comes with challenges. One major hurdle is the lack of familiarity with local healthcare systems and limited knowledge of the potential beneficiaries in the target country. Building a user base under these circumstances is challenging. Hence, effective collaboration with larger non-governmental organizations (NGOs) and Ministries of Health becomes crucial to scale both the product and service system. These organizations often have established global infrastructure and resources, but their support requires concrete evidence of the innovation's success and impact. This is where outcome measures play a vital role. By

demonstrating the device and service's effectiveness in a specific low-resource setting, the venture can not only establish its value but also adapt the service delivery model to address various low-resource contexts effectively.

> "The size of some of these big international organisations means that, you know, we can get some pretty good commitments from them to work with us, to really scale this up. So, I think it is a really good way of for a smaller organisation like us to start scaling up our provision around the world." – P1

This approach creates the necessary evidence base for larger organizations to become consumers of the innovation and potentially introduce it through their established service delivery systems. While this may not represent the most sustainable long-term delivery model, it serves as a vital steppingstone until the venture reaches a size and maturity level that can support its own independent supply chain and services across various regions. In essence, collaboration with established organizations and demonstrating success in specific contexts is a strategic approach to ensure that the innovation can reach and benefit the intended users across a spectrum of low-resource settings.

4.2   Case 2: A Smartphone Application for Screening of Hearing Impairments in South Africa

The product was a hearing screening test application designed for mobile phones, utilizing calibrated headphones for school-based hearing screening tests. This tool was designed to be inclusive and user-friendly, requiring minimal to no training to operate. The overarching goal was to democratize the screening and diagnosis of hearing impairments, shifting the process from traditional healthcare settings to the hands of community health workers, primary healthcare clinics, and schools. To realize this vision, leveraging mobile technology was a logical choice, aligning with principles of inclusive design and the broader goal of advancing digital inclusion. The design underwent rigorous quality control measures to ensure accuracy, even when used by non-professionals. To scale the system effectively, all collected data was managed and integrated into a cloud-based data management system which not only facilitated remote surveillance and monitoring but also enhanced the overall efficiency and effectiveness of the solution.

4.2.1   Making the innovation market appropriate. While the technology behind this tool had its origins in research setting and had been validated through experiments that are published, transitioning it into a healthcare device for use in the market required navigating the complex landscape of medical regulations requirements and clearances. For a small start-up, this regulatory process can be particularly challenging, but it is an essential step to ensure that the technology is not only validated but also appropriate and usable by healthcare professionals.

> "You must get through the regulatory bodies to approve it. So, the CE authorities and FDA authorities, so we eventually had to go through the whole process of becoming an ISO1345 medical device, which for a

for a small start-up, is a super expensive and intensive process." – P2

In the field, the utilization of the smartphone app by non-professionals, including in schools, community health clinics, and early childhood development centers, has yielded positive results. Even individuals with limited digital literacy have been able to use the app for hearing screening without the need for extensive training or guidance.

However, scaling the technology to new contexts within low and middle-income countries, presents its own unique set of challenges. The venture must continually innovate and iterating on existing ones to accommodate the evolving requirements encountered in different field settings. Each context is distinct, and this diversity can disrupt existing service delivery models, necessitating flexibility and adaptability in the approach. While the journey from research to market-ready healthcare technology involves numerous hurdles and complexities, the ability to provide valuable and accessible healthcare solutions to a wide range of users makes it a worthwhile endeavor. The key lies in embracing innovation, staying responsive to the unique needs of each context, and remaining committed to the goal of improving healthcare accessibility and outcomes.

> "In a new context, there are all kinds of barriers that you didn't even know of." – P3

4.2.2 Expanding the product and its reach. Over time, the product has undergone significant expansion in terms of its range of technologies. It initially began as a screening application but has since evolved to include diagnostic tools capable of quantifying hearing loss. Additionally, the venture has introduced a partner product for vision screening. This expanded offering enhances the utility for end-users who may wish to independently screen and diagnose both hearing and vision impairments without the need for professional on-site support.

> "We've also expanded our platform to include vision testing. So, we have a partner product that that do vision screening. This is because when we do screening for years the question is always what about the eyes?" – P2

Through strategic partnerships with larger international non-governmental organizations (NGOs), the solution's reach has extended through a business-to-business (B2B) model. For instance, the application is now employed as a tool for screening hearing impairments in large-scale population health surveys. In contrast, in higher-income countries with established insurance service networks, the venture has adopted a direct-to-consumer model, enabling the provision of hearing aids directly to users.

> "So, the technology has been utilized, I think probably now close to 50 countries around the over the globe, and I think the number of lives kind of touched is like two million." – P2

Expanding to new markets necessitates several critical steps. First, the company must establish new on-the-ground partnerships in the target country. Second, it must navigate and comply with the regulatory requirements specific to that country. Third, innovation remains essential to adapt to the unique needs of each market. Lastly, securing the necessary funding is crucial to establish a presence

and effectively operate in new contexts. In summary, the venture's evolution from a screening application to a comprehensive suite of diagnostic tools and its diverse business models demonstrate its commitment to making hearing and vision healthcare more accessible and efficient. The ability to tailor its approach to different markets underscores its adaptability.

4.3 Case 3: A Wearable Obstacle Detection System from Kenya

In unstructured environments, especially in low-resourced contexts, achieving independent mobility can be an immense challenge for people with visual impairments. Many individuals rely on white canes, which can be unreliable in detecting all obstacles in their path, especially those that are overhanging. Consequently, people often require the assistance of friends or family for even simple journeys. This start-up initially created a device that operates on the principle of echolocation, emitting sound waves that bounce off obstacles so that when an obstacle is detected, the device triggers a vibration in the cane to alert the user. It has achieved significant success in a range of African markets. However, it became evident that this single product did not provide complete independence to individuals with severe visual impairments. Consequently, the company embarked on the exploration of a wearable device concept.

> "So, it's there's sort of this learning curve with the development and I think dividing them into their sensing and feedback technology, I think those will be the two main technical challenges that we're trying to solve." – P4

The development of this wearable device presented several technical challenges. One crucial aspect was the integration of affordable, suitable, cost-effective, and accurate sensors into the product while ensuring that the final price remained accessible to those who could benefit the most. The second challenge centred on maximizing the effectiveness of haptic feedback, ensuring that it delivered consistent and meaningful information to the user's body. Lastly, there was the task of understanding and translating a new haptic language. In pursuit of addressing these challenges, the venture attracted engineers from a global network of professionals who could contribute to the development efforts. This collaborative approach has significantly expanded the project's scope and potential, ultimately leading to a broader launch of the product in multiple countries, extending beyond the African continent.

4.3.1 User-centered iterative design. The exploration of wearable haptics introduced a novel research dimension to the venture. To effectively communicate with users, a new language of feedback, primarily through vibrations and navigation, had to be developed. In a strategic move, the start-up partnered with a charitable organization that provides support to individuals with visual impairments. This collaboration allowed the start-up to engage in a continuous evaluation of design improvements and ideas. Weekly interactions with the target consumer group proved invaluable in refining the technology and establishing this new feedback language.

> "When it comes to the feedback side, we must work very closely the visually impaired people. So right now, we have a direct partnership with a charity that

supports visual impaired people where we get a pool of maybe 1000 people that we go to." – P4

User journey maps and scenarios were recreated within a controlled lab environment to optimize both sensing capabilities and the quality of feedback. This iterative process proved instrumental in simplifying the product, streamlining its features, and enhancing its overall usability. However, finalizing the product presented a delicate balancing act between introducing innovative new experiences and retaining elements of familiarity for users accustomed to existing assistive technologies. The integration of wearable haptics represented a significant advancement for the start-up, necessitating the development of a new communication language through vibrations.

4.3.2 Technological-centered development. By incorporating smartphone control into the technology, the start-up transformed its product into a lifestyle-oriented offering. This integration allowed users to seamlessly incorporate the technology into their daily activities and technology usage, moving away from the potential stigma often associated with specialised devices. Moreover, the shift from an audio-based analogue signal to a camera-based system supported by computer vision and AI significantly enhanced the device's capability to detect obstacles and objects. Embracing these new technologies not only expanded the product's potential user base but also contributed to cost reduction efforts. The core technology is designed as a platform, ensuring that it can continue to evolve and grow its global user base, keeping the product competitive for years to come.

> "Once you move to that direction, you find that users become very interested very quickly because just switching the kind of technology you use immediately can offer like five times more value than a smart cane with the basic features." – P4

4.3.3 Partner-centered business model. The start-up has adopted a partnership distribution model, leveraging established distribution channels that are already in direct contact with their target consumer base. This approach capitalizes on pre-existing trust and relationships within these distribution networks, recognizing the importance of specialized distributors in providing essential training for the successful use of their assistive products. Furthermore, the start-up has forged partnerships with existing manufacturers to produce the devices. In this role, the start-up envisions itself as the driving force that coordinates and facilitates collaboration among this diverse set of partners. Their aim is to create, build, and disseminate the necessary assistive products to individuals who can benefit from them. In essence, this partnership distribution model relies on the strengths and expertise of various stakeholders in the ecosystem, from specialized distributors to manufacturers, with the start-up assuming the role of orchestrator and facilitator to ensure the effective delivery of assistive products to the intended users.

> "We don't plan to sell it directly to the users. We'll use distributors to do that. Distributors worked with visual impaired people for a long time, and they gain

their trust. Also, we are working with product development partners who are experienced with manufacturing and the whole end to end supply chain." – P4

The approach, coordinating and combining user-centred design, technological innovation, and strategic partnerships, enabled the start-up to create solutions that enhance the independence and mobility of individuals with visual impairments across diverse contexts.

5 ACROSS-CASE ANALYSIS

5.1 Design for Adaptability

Disability intersects with various aspects of society, including social, economic, political, and cultural dimensions [54]. Consequently, AT solutions must adapt to these complex contextual characteristics, which vary significantly. Identifying and accommodating these requirements is an evolving process that unfolds through immersive field practices, making it impossible to fully anticipate at the design's outset.

In the three case studies, it was evident that changing the context where the product is used and provisioned changes the product offering and the service delivery concept around the product. In the first case, the core design ethos of breaking down the labels of disability and celebrating individual identity was challenged by the collectivist perception of users in a different context, where being considered as a part of the group was significantly more important than being functional and independent. In the second case, it was necessary to get the regulatory approvals to be able to scale, while establishing new on the ground partnerships to be able to bring the solutions to people and constantly innovating the solution to make it contextually appropriate. The third case showcases how global expertise is utilized to design and develop the product, so it's made with the latest advances of technology, building excitement in both low-income and high-income contexts, but its provision is still dependent on people who have established relationships with users.

However, there is an opportunity to design for adaptability by considering modularization, thus transforming the product's disability interactions and services to align with the specific context and disability culture. This raises the fundamental question: "How can we design AT that is adaptable and affordable?"

In the first case, adaptability was addressed through product modularity, enabling non-bespoke mass-manufactured designs to fit various individuals. Modular units could be attached and scaled to assist with different context-specific tasks. In the second case, a platform technology was employed, allowing similar operation across smartphones while personalizing the service through a cloud database, making it non-bespoke at the production level. The third case, still in development, used context-specific requirements to create a new haptic language that adapts to user preferences by learning their behaviours and context. Through these modular product and service designs, these ventures could adapt and scale into new markets, an important criterion for research evaluation. Future efforts will explore this design attribute further, using cultural dimensions [17] to develop brainstorming cards and evaluation criteria to ensure that designs prioritize adaptability.

5.2 Pathways for Scaling Up

The adoption of innovation hinges on various ecosystem factors, including market maturity, customer readiness, team capabilities, and timing [9]. Critically, in contrast to high-income context where users have direct access to and choice of assistive technology, the provision in low resource context is mediated by established service provision systems that are directed by the government or international NGOs. The cases highlight a critical dependency of innovations on the existing service provider ecosystem that has established links to users in low-resource contexts. Their existing engagement with users becomes a crucial mediating bridge between the start-up and the user in a new context. Hence, beyond the adaption of the product to meet the requirements of users in the new context, it is critical to understand how the on-the-ground service can adopt the innovation provided and facilitate this adoption through context-specific, iterative innovations to the products and services.

Therefore, while user-centered innovation is crucial for attracting early customers the AT market often relies on social businesses, NGOs, and governments to be customers, innovations need to align with the needs of these organizations in a B2B model. Hence, a modular product architecture, which can accommodate context-specific design requirements to a common platform and a modular service delivery model that can be plugged into existing service delivery frameworks, will be more easily scalable.

Despite the diversity, there are some commonalities that start-ups need to have irrespective of the market, product-service solutions and existing healthcare and provisioning systems. The first is certifications - having the necessary regulation that any high-income context requires (i.e., CE mark, FDA approval etc.) would enable existing service providers to trust the product and function in the commercial market at scale. It also is an ultimate validation of its function. However, it is often not feasible – there is a need for testing facilities in Africa provided at an affordable cost to innovators to make this more achievable.

Second, the product must have shown evidence of significant impact in one geography. Achieving impact in one region not just increases the credibility of the product, but also demonstrates learning and growth through iterative user research and technical development. Having success in one place and demonstrating adaptability and adoption in another geography encourages service partners and NGOs to adopt the innovation more easily. It becomes easier to do so when the product and the services are modular.

5.3 The Need for Funds

Despite their adaptability and evidence for impact, the three cases emphasized funding as a major driver to adapt to new markets. In the domain of doing good for society, there are many 'well-wishers' who can create connections, plug people into the network and facilitate innovation. However, to penetrate a market, grow and become established, funding, or financial capital is perhaps as important as the network in the ecosystem and knowledge of the ecosystem.

The cost of developing the adapted product, changing the service delivery model, and developing the infrastructure required to provide in a new context and scale must be borne by some organizations as users will not be able to pay for the assistive technologies. It allows ventures to gather evidence of success and impact in the new region, building trust and credibility among potential users, service providers, and partners. Additionally, financial capital supports the scientific measurement of impact, which is vital for demonstrating solution effectiveness and attracting support from governmental and non-governmental organizations, investors, and philanthropic institutions.

In the AT sector, development can be more challenging than mainstream AT, and early-stage ideas require investment to reach readiness levels and demonstrate impact. While more funds may be available for scaling solutions, there's a need for increased funding for early-stage research and development in low-resource contexts, necessitating strategic targeted missions. Hence, AT accelerator programs must focus on supporting the ventures with funds to gather evidence of success through developing a knowledge and network capital in the region along with scientific measures of impact and potential for adoption.

> "It's much harder than developing a mass market product because it's harder to fundraise. The users are very limited and it's hard to find them. It's a much harder journey than developing just a mainstream product. So sometimes people just join this journey and go yeah, I think it's going to be easy, but it's really not. And then after a few difficulties most people give up. So just understanding the commitment at the beginning really helps so that you have the patience to build the product. But it's I think it's an amazing journey. So, who wants to start, don't build the product in isolation as well. Once you start engaging the users, you realise that the kind of value you can deliver the product and then from the just gives you a purpose."
> – P4

6 DISCUSSION

This paper presented findings from interviews with three AT start-ups in Africa. Thematic analysis, within and across cases, provided insights to answer the research question: 'How do AT innovators navigate the challenges within the African assistive technology innovation ecosystem?'

Our research diverges from classic HCI, that is focused on user understanding, enhancing user experiences, and employing established UX methods in technology design. This perspective may appear unconventional to traditional HCI researchers and practitioners [38]. The growth of accessibility research has been significant in recent years [24], with frameworks like Ability-Based Design and Inclusive Design [8, 37, 51] improving developmental practices. While user-centred design addresses user needs well, it is limited to the interaction and experience design to support the user's immediate needs rather the wider adoption and implementation of technology by the masses [14] to develop practical solutions that can be integrated into the lives of people with disabilities. Recent HCI research emphasizes the need to move beyond lab-based research prototypes and advocate for in-depth immersion into the real-life context of technology use, which require

innovative research methods. Hence, our work provides a small snapshot that bridges innovation, business, and developmental studies, considering technology as a crucial component of a broader system aimed at making a meaningful impact on people's lives. We hope the HCI community sees the relevance to the wider scope of this work in understanding the adoption-centric approaches taken by entrepreneurs, and the broader perspective helps frame future research challenges within the HCI community.

Our findings demonstrate that the innovation journey required the start-ups to be adaptable to the changing contexts of AT users and the wider ecosystem when scaling AT innovations across the African markets. The first case study revealed context-specific user requirements, and the second case highlighted the importance of regulatory approvals and scaling. The third case showcased global technical development with local stakeholder engagement, emphasizing the importance of creative facilitation of stakeholders for meaningful impact. Although the three cases are diverse, our findings showed key stakeholders that lie beyond AT users, play vital roles in creating access to AT that should be included in the design process. It also alludes to processes that assess the impact of AT wherein HCI research can expand to include the broader ecosystem of stakeholders, infrastructures, and value chains across policy, social science, design, and technology domains. They also highlight the importance of adaptability of the AT and AT innovation business, not only to the context of use but the wider ecosystem that may impact how the AT solution is developed, tested, marketed, and scaled.

The findings support and contribute to the DIX framework which calls for a combined applied and basic research approach (Schniderman's ABC approach [44]) to understanding and addressing the challenge of disability inclusion and AT as a "wicked" problem [18]. Through this research, we encourage HCI researchers to cast a wider look at complexities and practical challenges that may influence the effectiveness and adoption of AT and address the complex, systems-level problems that impact user ability and well-being, increase co-creation with diverse stakeholders beyond users, and promote open innovation processes across the ecosystem. To this end, we must develop new and innovative ways to develop and assess the impact of ATs in real-world conditions and move beyond laboratory settings.

6.1 Limitations and Future Work

The perceptions of AT and the availability of AT services vary across Africa, shaped by intricate political, environmental, and sociocultural factors. One limitation of our study is the small sample size of our case studies. While we acknowledge that this limited sample doesn't provide a comprehensive overview of AT innovation in Africa, our goal was to spotlight challenges for AT innovators in the African ecosystem using substantial examples from established practitioners in the continent. Additionally, our study underscores the importance of understanding the broader AT ecosystem beyond just AT users. This includes examining the cultural, socioeconomic, and policy context and the roles of governmental, nongovernmental, and community stakeholders in both supporting and impeding AT innovation. While we provide some insights from AT innovators' experiences, a more comprehensive understanding of

the wider AT ecosystem is needed. Future studies should broaden their focus to include other stakeholders, such as government and non-government organizations.

7 CONCLUSION

In conclusion, our paper offers insights into the experiences of AT innovators as they navigate the challenges of scaling their innovations in Africa. Through an analysis of three distinct cases from different regions of the continent and an across-case analysis, we sought to answer the question of how AT innovators navigate the complexities of the African AT innovation ecosystem. Our findings underscore the critical role of diverse local and global stakeholders in supporting and endorsing innovation efforts. Additionally, the research highlights the significance of tailoring solutions to specific markets and the necessity for ongoing iterations beyond achieving a product-user fit. These considerations are pivotal when designing AT solutions with the goal of making a tangible impact on people's lives. While frameworks like Context Variation by Design, Macro-HCI, and DIX have begun to explore the convergence of design, HCI, and AT innovation, our study suggests that more attention and further research in this area are essential to creatively identify ways of reducing the fragmentation and coalescing a strong sector within the continent that ensures that people can access the AT they need to do what they want to do.

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