Value beyond function: analyzing the perception of wheelchair innovations in Kenya

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ABSTRACT

Innovations in the field of assistive technology are usually evaluated based on practical considerations related to their ability to perform certain functions. However, social and emotional aspects play a huge role in how people with disabilities interact with assistive products and services. Over a five months period, we tested an innovative wheelchair service provision model that leverages 3D printing and Computer Aided Design to provide bespoke wheelchairs in Kenya. The study involved eight expert wheelchair users and five healthcare professionals who routinely provide wheelchair services in their community. Results from the study show that both users and providers attributed great value to both the novel service delivery model and the wheelchairs produced as part of the study. The reasons for their appreciation went far beyond the practical considerations, and were rooted in the fact that the service delivery model and the wheelchairs promoted core values of agency, empowerment and self-expression.

CCS CONCEPTS

• Human-centered computing • Accessibility • Empirical studies in accessibility

KEYWORDS

Disability, Wheelchairs, 3D printing, Emotional Design

1 Introduction

The World Health Organization (WHO) defines Assistive Technology (AT) as "*an umbrella term covering the systems and services related to the delivery of assistive products and services*" [6]. This definition highlights how AT encompasses not only the physical and digital products used by millions of persons with disabilities (PWDs) worldwide, but also the systems and services that accompany the provision of these devices [78].

Much of the research on AT conducted within HCI focuses on the use, design or development of new assistive products such as solutions for mobility, vision, hearing, communication and cognition [22, 37, 48, 62, 69]. However, global research shows that developing appropriate services and systems for the provision and delivery of ATs is crucial to ensure that people with disabilities (PWDs) receive physical and digital devices that can have a sustainable and significant impact on their lives [29, 43]. Establishing appropriate services can be particularly challenging in low-and-middle-income-countries where lack of appropriate policies, shortage of trained personnel and inconsistent supply chains can make it impossible to rely on traditional provision models [36].

Both assistive products and services are routinely evaluated based on functional and pragmatic criteria such as cost, convenience, usability and effectiveness [4, 9, 28, 75]. Although these aspects are definitely important, previous research has shown that social and emotional aspects such as identity [30], social conventions [67], embodiment [11] and biographical meaning [12] play a major role in how PWDs evaluate assistive products and services in real life.

In Emotional Design [49] Norman postulates that our interaction with the world and, our decision to love or hate everyday objects and systems, is articulated around three different and interconnected cognitive layers: visceral, behavioral and reflective [49]. Emotions modulate our responses to products and services from the first moment in which we come into contact with them, though our interactions and the reflections we have on the interaction. Our desire to use or not use a product or service is developed through a combination of our responses at these three layers and we evaluate and construct judgements about them as we progress along the layers [49].

The Emotional Design model has been used to evaluate products and services ranging from websites [54], mobile applications [51], layouts of libraries [44], to training aids for healthcare professionals [42]. Despite the crucial role attributed to emotion in the interactions between PWDs and AT products and services in most high income countries [19, 41], this model has never been used to understand how people in low-and-middle income countries (LMICs) assess the value of AT innovations.

In this paper we use the Emotional Design model to evaluate the results of a study that sought to test a novel wheelchair service provision model for LMICs. The new service leverages the use of Computer Aided Design and 3D printing technology to manufacture bespoke wheelchairs for local users. The study took place in Kenya over a 5-month period and involved 8 expert wheelchair users and 5 professionals involved in wheelchair services delivery.

The contributions of this paper include:

1. The first study combining digital and classical manufacturing techniques to produce bespoke wheelchairs in LMICs
2. An innovative way to explore participants reactions in relation to both the wheelchairs and the service provision model through the lens of the Emotional Design model
3. Reflections on the implications of our findings with respect to how both users and service providers in LMICs evaluate AT innovation in a broad sense

It is important to highlight that our work provides a unique account of how users and providers attribute value to innovative assistive products and their associated provision models. These are personal points of view which are meant to be subjective. Consequently they should be given appropriate considerations and integrated alongside objective and logistical accounts of assistive products use and the implementation of provision models.

2 Related work

The work illustrated in this paper builds on three areas of research: valuing assistive devices beyond function, emotional design and 3D printing of assistive devices in LMICs.

2.1 The value of assistive devices beyond function

Traditionally, both physical and digital assistive devices are designed to "*maintain or improve an individual's functioning and independence, thereby promoting their well-being*" [6]. Function is of paramount importance for all assistive devices, especially if we consider that PWDs invest considerable design effort to create or modify assistive devices that meet their functional needs [11, 20, 46]. However, research shows that social considerations often play a bigger role than functional ones when users make decisions concerning if and when to use an assistive device [15, 16, 66, 67].

Social interactions around assistive devices are often mediated by considerations around identity [8]. For example, early work by Shinohara & Wobbrock highlights how participants avoided using certain assistive devices that would mark out them as disabled and be associated with their personal identity [66]. Recent work paints a more nuanced picture where the form factor and the functionality of the assistive device shape both the image that PWDs have of themselves and the image that others perceive of them [67]. Similarly, work by Branham & Kane illustrates how considerations about projected ideas of ability and independence shape many of the choices around use of assistive devices made by visually impaired people in the workplace, and occasionally around the house when outsiders are involved [15, 16].

While some PWDs might feel uncomfortable about being seen through the lens of their assistive devices, others look for opportunities to attract positive attention by showcasing their creativity, personal preferences and meaningful life experiences through the modification of their assistive devices as a form of self-expression [55, 56]. In this scenario of self-expression and experimentation, the assistive device becomes part of the body of the person and new ideas of normal, identity and physical body can be explored through this *Intimate laboratory* [11]. For example, users of cochlear implants and hearing aids in the online community observed by Profita et al [55, 56] proudly showcased their unique designs which represented the image they wanted to project to the world and allowed them to take pride in their appearance.

Customization of assistive devices is not only linked to ideas of creativity and self-expression, but is connected to important themes such as control and agency. PWDs can often feel like they have reduced control over themselves and their own bodies as a result of their interactions with assistive devices and services [63]. Customizing and adapting current assistive devices or creating new solutions allows people to take back control of their own circumstances manifesting their desire for more agency in these interactions [52, 56]. It is worth noticing that, although many of these modifications might appear to be motivated only by the desire to improve the aesthetic aspect of assistive devices, they are often linked to a more profound narrative of empowerment where the value comes from the act of customization itself as the resulting adaptation [46, 56].

Finally, the participatory work carried out by Bennett et al [12] shows that PWDs develop deep emotional connections with their assistive devices not only through successful interactions, but also through failed ones.

Like any other design process, the adaptation of existing devices or the creation of new ones highlighted the transition between failed and successful interactions and provided a testament to the creativity of PWDs and their ability to make things work for themselves [12].

2.2 Emotional Design

The Emotional Design model [49] developed by Norman is a three-level model exploring how we interact with different products, process information and elaborate judgements on them based on our reflections and emotions. These judgements reflect our opinions on a product, how attached we are or could be to it, and therefore have serious implications on how we engage with it. These three levels of interaction are: Visceral Design, Behavioral Design and Reflective Design.

Visceral Design. Largely rooted in the senses of the individual and related to the physical characteristics of objects (such as look, feel or sound), emotions at the visceral level are quick to arise. Initial sensory information is processed by the brain and produces simple emotional responses such as like, dislike, attraction, excitement, and fear [49]. These impressions can be illogical but are still very powerful and can determine the willingness of PWDs to engage with assistive devices [21]. Emotions at the visceral level often occur before the person has actually interacted with the product in any meaningful way, but they can determine how much a person is willing to "forgive" in terms of usability, cost and other practical considerations [39]. Interestingly, studies have shown that visceral responses linked to aesthetic considerations of assistive devices such as wheelchairs seem to be more important in collectivist societies, such as Kenya, compared to individualist societies which are typical of Western countries [5].

Behavioral Design. The most practical of the three levels, the behavioral level of interaction is still governed by emotions. However these emotions are related to the use and the performance of a product. Instead of the appearance and the reflective implications attached to a certain object , what really matters at this level is how well the product achieves the desired function, how easy it is to use, and how seamlessly it performs operations [49]. As function has always been attributed the highest value in the development of novel assistive devices, behavioral aspects, especially usability and functionality, have traditionally been the most studied in the field of AT [3, 70].

Reflective Design. Emotions processed at the Reflective level are the most complex ones generated as a result of interaction with external objects. Reflective design is concerned about the meaning that we attribute to different products and how it reflects on us as individuals and as part of a group or a society. Reflective design is often about processing our interactions with a product after the interaction, examining it in light of the situation, our personal preferences and cultural outlook and making judgements as a result of these reflections [49]. Considerations about value of assistive devices and other aspects such as identity [66], visibility [30], self-expression [11], and control [56] illustrated in the previous section are all generated primarily at the reflective level.

Although the three level Emotional Design model [49] was primarily developed to understand the interaction between people and products, it has also been applied to services and experiences [10, 73]. Service delivery processes often involve multiple interactions between providers and users, creating a number of touch points that can be opportunities for Emotional Design [10]. We argue that users will interact and process their reactions to new service models based on the three layers of Emotional Design, just as they do with products. Visceral responses such as excitement, fear, skepticism and dislike are triggered when the person first hears about a new service model. Behavioral considerations are generated depending on the effectiveness and efficiency of the service. Finally, after completing their journey through the service, people attribute meaning to their experience at the reflective level based on their personal and societal values.

2.3 3D printing of assistive devices in LMICs

The field of digital manufacturing and 3D printing have grown exponentially in the last decade [13]. The possibility of generating, modifying and manufacturing bespoke design in a relatively short time frame is particularly attractive for the production of assistive devices as many people have unique needs that might not be fulfilled by conventional mainstream devices [45, 46, 68]. Although 3D printing is more commonly accessible in high–resource settings, the technology is spreading to LMICs. Local makers, designers and researchers have started investigating the potential of 3D printing to produce solutions addressing issues in various domains ranging from healthcare [61] to construction [2].

In the last few years, the number of projects leveraging 3D printing for the production of assistive devices in LMICs have started to flourish but full research accounts of them are still rare [26, 27, 47, 72]. Driven by the pioneering e-NABLE hand (http://enablingthefuture.org/), the large majority of these projects focus on the production of prosthetics and orthotics devices for both upper and lower limbs [64].

For example, authors in [47] described the development and fabrication of a lower limb prosthetic socket. Rather than designing the socket from scratch using a CAD software, the shape of the socket is closely matched to the shape of the stump of the person which is captured through a 3D scanner. After the socket was manufactured and the whole prosthesis assembled, two amputees briefly evaluated it and gave positive reviews of the comfort, fit and weight of the prosthesis. On the other hand, Stelt et al [72] evaluated the feasibility of using 3D printing to fabricate upper limb prosthetics, upper limb splints and lower limbs braces in rural Sierra Leone. Devices were provided to local PWDs by clinicians and user satisfaction with device function was monitored after a 3-4 week follow up period. In a different study, Cuppens et al [27] compared functional outcomes such as joint angles and walking speed and users' satisfaction between conventional and 3D printed orthoses and found that 3D printed orthoses performed on average as well as conventional ones. All these studies collected quantitative feedback from users on the 3D printed devices they received but no qualitative opinions on the devices or the service delivery model was collected from users.

Finally, deploying service delivery models for assistive products in LMICs based on 3D printing technology requires commitment and effort from the local healthcare workforce. Previous studies by Meissner et al [46] and McDonald et al [45] show that significant effort is needed from novices to be able to use 3D printing technology for the fabrication of assistive devices. This could act as a deterrent for many clinicians in LMICs who are often already dealing with high patient loads and staff shortages [1, 36]. Furthermore, results from a study with occupational therapists carried out by Slegers et al [68] show that clinicians have high performance expectancy towards 3D printing technologies and might feel underwhelmed about the potential impact on their work after trailing them.

Furthermore, collaboration in this field between makers and clinicians has proven challenging due to the tensions between the clinical philosophy of 'do no harm' and the desire of makers to get assistive devices to all [34]. Ultimately, understanding the opinions of local staff on the technology, the implications for the service delivery model from a clinical point of view and on the devices produced with the aid of 3D printing technology is crucial to implementing innovations that are appropriate for the context and more likely to have a sustainable impact.

3 Methods

3.1 The InnovATe wheelchair manufacturing model

The concept for the InnovATe bespoke wheelchair manufacturing model was developed by Motivation UK, a NGO with over 28 years of experience in designing and providing wheelchairs to PWDs. The development of the InnovATe model originated from the desire to leverage novel technologies to address some of the pressing challenges affecting wheelchair provision in LMICs.

Current provision systems largely rely on mass importation of flat packed or pre-assembled wheelchairs usually from China or the US. Shipping, and custom charges drive up the cost of the wheelchair and rehabilitation centers struggle to provide users with wheelchairs that match their needs [36]. Kenya produces wheelchairs locally, but the quality of the products is inconsistent and the range of wheelchairs produced fails to meet the demand of users [58]. As a result, many PWDs in Kenya do not have access to wheelchairs and, if they manage to access one, it is often an inappropriate device that does not allow them to participate in work, family and community life [32].

The aim of the InnovATe model is to leverage digital manufacturing technology to enable local providers to produce bespoke wheelchairs of consistent quality locally, using available materials and components. The wheelchairs fabricated with this innovative model incorporate 3D printed joints connected by metal tubing. At the core of this innovation is a parametric CAD model that can be modified according to the measurements, the user's environment and their preferences.

Clinicians can record the user's measurements using an assessment tool called "Wheelchair simulator". The wheelchair simulator is an adjustable modular seating unit that allow the user and the clinician to find the ideal sitting position. Measurements are then taken by the clinician from previously selected points on the simulator rather than the user's body; reducing errors and imprecisions [76]. As the parameters inputted by the clinician change, the model digitally alters the shapes of the joints and tubes, creating appropriate files to then produce components locally, specific for each user. An example of how users' measurements and preferences affect the configuration of the wheelchair is shown in Figure 1.

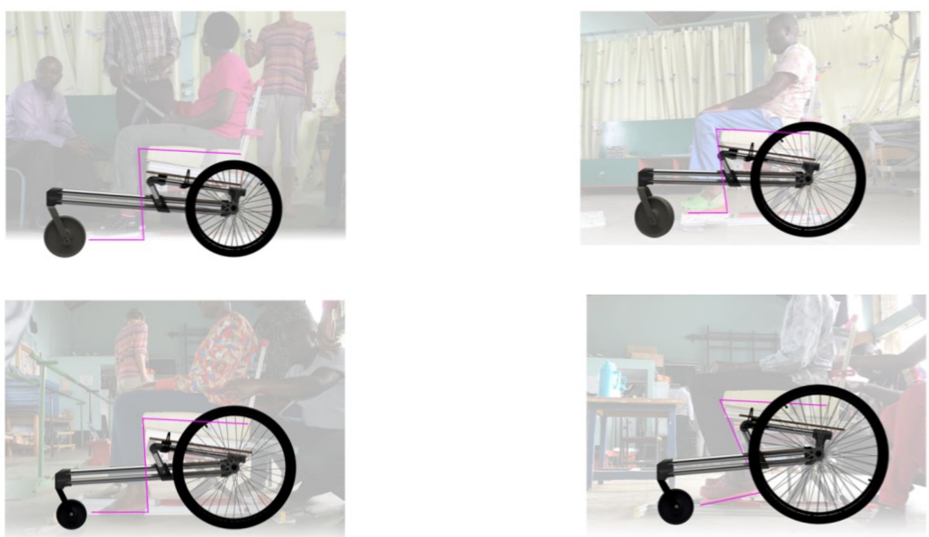

Figure 1 Four examples of different wheelchair configurations created based on the measurements, postural requirements and personal preferences of four different users

The wheelchairs feature a removable seating unit with a folding backrest. The backrest is also made-to-measure, with a custom contour that matches the shape of the user's back. Reference points on the user's back are located using a device called Dimensional Information Measurement System (DIMS) that allows the clinician to measure 3D points in space by using a pen connected to 3 potentiometers via non-elastic cables. The potentiometers are fixed on a base that is attached to the seat of the simulator. Data from this portable device are fed to the parametric model that creates the custom shape for the backrest and generates the files for the 3D printers. Figure 2 shows both the Wheelchair simulator and the DIMS.

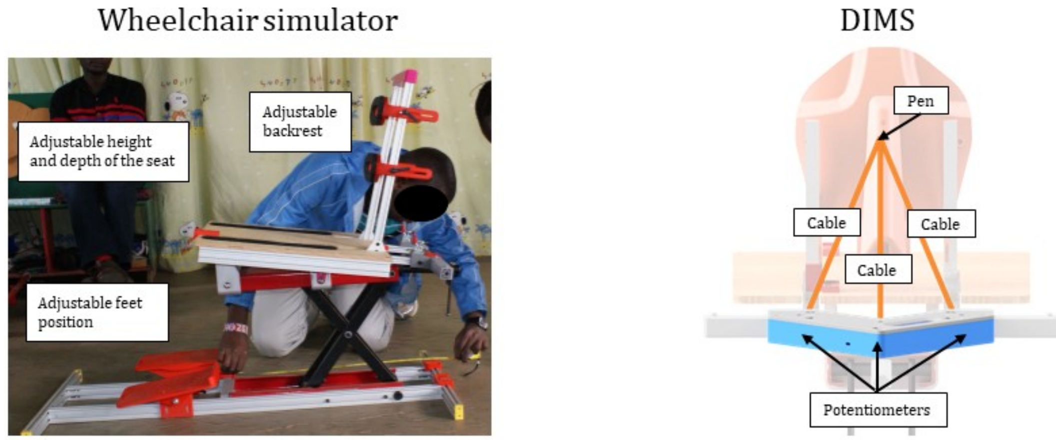

Figure 2 One of the trainers in the study showing local members of staff how to take measurements for the contour backrest using the Wheelchair simulator and the DIMS

After assessing the clients and taking appropriate measurements for both the wheelchair's chassis and the contour backrest. The local provider can simply 3D print the appropriate files for the wheelchair joints, cut the tubes to the appropriate length and fasten the components using blind rivets. The system currently only supports the production of three wheeled wheelchairs which are commonly provided in many LMICs, as they offer considerable advantages when navigating rough terrain [40, 53].

Both the wheelchair simulator and the DIMS, are assessment tools developed for the InnovATe manufacturing model. Neither tool requires expensive components which might be unavailable in low resource settings. Furthermore, the wheelchair simulator can be built using different materials, depending on what is available in the country. However, their dimensions and correct assembly are crucial to the successful integration with the parametric CAD model, so accurate documentation on how to build both tools has been created as part of the project. Similar training manuals for local staff on how to correctly use the wheelchair simulator and the DIMS alongside documentation on how to use the 3D printers and assemble the InnovATe wheelchairs have been created for the project.

3.2 Study design & data collection

The study was carried out in the Bethany Kids rehabilitation centre and special needs 'school in Joytown (Kenya) for a period of five months between July and November 2019. The project received ethics approval from UCL research ethics committee and the University of Nairobi internal review board. The project was divided into two phases. The first phase, which took place for the first 10 weeks, focused on training local staff at the rehabilitation centre and carry out supervised wheelchair production. The second phase, on the other hand focused on the independent implementation of service delivery from local staff. Eight wheelchair produced throughout the study, two during Phase 1 and six during Phase 2, were evaluated by local expert users

3.2.1 Phase 1: Training

Training for local staff was divided into modules which covered: user assessment to integrate the new wheelchair simulator and DIMS in the wheelchair assessment process; data entry to allow clinicians to modify wheelchair requirements according to data gathered during the interview with the client; set up and maintenance for electronic equipment to ensure appropriate levels of stock according to production requirements; 3D printing and tube cutting to manufacture required parts for the wheelchair; wheelchair assembly to ensure correct and safe preparation before client fitting. Training featured both theoretical and practical sections to allow local staff to gain a solid understanding of processes, tools and techniques involved in this novel approach to wheelchair provision. Knowledge and understanding was practically assessed through the manufacturing of 6 bespoke wheelchairs. The first four test wheelchairs were fabricated based on mock-up specifications and measurements local staff collected from each other. Following this, an additional two wheelchairs were manufactured under supervision for two local expert wheelchair users who were invited to take part in the study.

Data collection: Independent assessors conducted structured observations of the training. This was complemented with focus groups with the 5 members of local staff at the end of each module to understand barriers and facilitators encountered during training

3.2.2 Phase 2: Independent delivery

Throughout this phase local staff had to manage the complete service delivery process using the new technologies and techniques learned during training. Six bespoke wheelchairs for 6 expert wheelchair users who volunteered to take part in the study were manufactured during this phase. A local member of the research team was available for immediate support if needed and the design team from Motivation UK was available remotely for technical support.

Data collection: Semi-structured interviews were carried out with the five of local staff at the end of the project to reflect more broadly on their experiences throughout the study, discuss impressions concerning the wheelchairs and the service delivery model trialed, and examine the practical implications for future implementations.

3.2.3 Wheelchair testing

The eight expert wheelchair users who had been invited to take part in the study, during both phases, were asked to functionally test the wheelchair across a different range of activities including navigating slopes, rough terrain, obstacles and steps. The activities and scenario chosen for the functional testing of the wheelchair was completed using the Wheelchair Skills Test 5.0, a clinical tool routinely used to assess how users use the wheelchair in different situations [38]. To ensure safety of the users, all testing was carried out under the supervision of local staff and inside the grounds of the rehabilitation centre. Comprehensive results of these test go beyond the scope of this paper and they are reported in another publication [31].

Data collection: Semi-structured interviews were carried out with the eight users immediately after they trialed the wheelchair to gather first impressions of both the device and their experience interacting with the service delivery system. At the end of the project, all users took part in a focus group where more general reflections concerning both the use of the wheelchair in real life and the practical implications of this new model of service delivery for users were discussed.

3.2.4 Mitigation of bias

We were aware that participants', both the wheelchair users and local staff, could be positively biased towards the NGO that developed the InnovATe wheelchair provision system, which in turn could produce more favorable responses. To mitigate this, interviews and observations throughout both phases were carried out by a member of the local branch of the NGO who was not involved in the development of the InnovATe system. Furthermore, the final semi-structured interviews with local staff and the final focus group with wheelchair users were carried out by the first author, a UK based researcher, who was not a member of the NGO. Finally, throughout all interviews and focus groups we explained clearly to participants that critical feedback was most useful to facilitate further developments of the InnovATe system.

3.3 Data Analysis

All data from observations, focus groups and semi-structured interviews were analyzed using reflexive thematic analysis [17, 18] through the lens of Emotional Design [49]. The approach we used was hybrid with an initial deductive phase where the Emotional Design model provided the theoretical framework we used to establish initial broad categories. Within each level of the Emotional Design model, visceral, behavioral and reflective, we used an inductive approach to develop themes describing the factors that shaped people's experiences. Due to the nature of our research question we focused the analysis on semantic reporting for behavioral responses, latent interpretation for reflexive responses and a mixture of the two for visceral responses.

3.4 Participants

Five member of staff at [name of the rehabilitation centre] who are routinely involved in providing wheelchairs to students at the school and members of the communities. Three of them were clinicians, 2 female physiotherapists (C1 & C2) and 1 male occupational therapist (C3), and two were male wheelchair technicians (T1 & T2). All members of local staff had previously received training in wheelchair assessment and provision according to WHO standard guidelines, but none of them had any experience with 3D printing.

The project also involved 8 experienced manual wheelchair users, who had at least 2 years of experience using their wheelchairs on a daily basis and who lived in the community. Table 1 shows a brief overview of their characteristics.

Table 1 Summary of wheelchair users' characteristics

Participant code	Gender	Age	Type of wheelchair used
U1	F	33	Rigid frame four wheels wheelchair
U2	F	30	Rigid frame four wheels wheelchair
U3	F	29	Rigid frame four wheels wheelchair
U4	F	34	Foldable frame four wheels wheelchair
U5	F	35	Foldable frame four wheels wheelchair
U6	M	26	Rigid frame three wheels wheelchair
U7	M	43	Rigid frame three wheels wheelchair
U8	M	39	Rigid frame three wheels wheelchair

4 Findings

The findings presented in this section are organized according to the three layers of the Emotional Design model. Themes that have been conceptualized based on participant's interaction with the wheelchair are separate from the ones referring to the interaction with the service delivery model. Finally, wheelchair users' responses have been separated from the responses gathered from the local staff, as their roles and experiences throughout the study were considerably different.

4.1 The wheelchair

4.1.1 Visceral design

4.1.1.1 Users

The initial reactions users had when first seeing the wheelchair were generally positive. The wheelchair was described by some users as "Sexy" (U8), "Cute" (U3), and "Pleasing to the eye" (U7). Almost all the women in the users group said that they felt disappointed when they were initially told that the wheelchair made for them, as part of the trial, was a three wheeler. Female participants told us that the presence of the central beam combined to a large castor wheel normally prevents them from being able to wear a dress, making three wheelers very unpopular among women despite the practical advantages they offer on rough terrain. However, the smaller castor used for the InnovATe wheelchairs combined with the use of two lower profile beams made of light grey aluminum gave the wheelchairs a more elegant look that strongly appealed to our female participants.

"*When I hear it was a three wheeler I was scared because a three wheelers I have seen it before and I hate a three wheeler. But the moment I saw it [InnovATe wheelchair], I liked it."* (U2 – Final focus group)

Overall, participants were struck by how the InnovATe wheelchair (see Figure 3) looked different from an ordinary wheelchair. The bright and colorful appearance, the curved shape of the backrest and the light low-profile chassis were extensively praised. Participants immediately perceived the novelty of the design and were mostly excited by it. However, the novel look was almost too strong for some users who were perplexed rather than excited.

"I thought that the design was crazy. You see… I have never seen a wheelchair like it, with all those joints and nodes and stuff" (U7 – Final focus group)

Figure 3 Picture showing one of the InnovATe wheelchairs manufactured as part of the study

4.1.1.2 Local staff

Staff's visceral reactions were generally similar to those of the users. The wheelchair was described as "Attractive" (T1), "Perfect" (C3) and "Nice and presentable" (C2).

Similarly to what was stated by users, the presence of 3D printed joints somehow divided opinions of local staff. One clinician felt that the 3D printed joints made the wheelchair look "Innovative" (C1) drawing attention to how novel technologies played such an important part in the manufacturing process. At the same time, another clinician felt that the presence of the joints highlighted the composite nature of the frame, making it look more fragile than a conventional wheelchair.

"You could just see all the different parts that made the wheelchair and it made me afraid it could more easily break" (C2 – Independent delivery phase, final interview).

4.1.2 Behavioral design

4.1.2.1 Users

As soon as they sat on the wheelchair, users were struck by the high level of comfort provided by a combination of the bespoke frame and backrest. Users were particularly pleased with how the backrest was shaped according to the curve of their own back and how the elongated sides increased the feeling of support in a way that felt natural and comfortable.

"It doesn't squeeze you and it aligns your back. Especially my back, it aligned my back really well so I can sit straight and I don't have anything you know, no objects or stuff that maybe can pierce me or push me or anything" (U7 – Interview after wheelchair testing).

Although the level of comfort was generally high, half of the wheelchair users (U2, U6, U3, U8) thought that increased padding, covering both the front and the top of the backrest, would be beneficial. They reported that the backrest could feel too hard, while they were moving around the compound performing different wheelchair skills.

The basic functionality was generally rated quite highly and the InnovATe wheelchair was described as easy to propel and maneuver. Participants who were not used to three wheeled wheelchairs had more difficulty with maneuvering the wheelchair and they found balancing on the rear wheels more challenging due to the different weight distribution. On the other hand, participants who were used to three wheelers described the wheelchair as extremely light, and easy to use both indoor and outdoor.

The biggest functional concerns around the InnovATe wheelchair were related to safety, stability and robustness. The absence of sideguards made the users feel that they did not have sufficient support, causing concerns during the performance of more challenging skills. Similarly, some users found that the footplate did not provide sufficient stability, especially when participants were having issues due to spasticity in the lower limbs. Additionally, four users stated that the wheelchair felt like it was "pulling on one side" (U4) due to the front castor losing alignment under load. Participants also reported that the brakes provided were too weak, creating problems on steeper terrains. Finally, several participants had concerns about the robustness and durability of the plastic nodes on the chassis of the wheelchair. U5 reported that when she transferred on the wheelchair the plastic joints were unable to support her weight properly, making the wheelchair unusable. Although this was an extreme case, the uncertainty about robustness was shared by all participants, including the ones that did not experience any functional issue.

"I am worried about the joints. The joints they give me a little of fear since it's a ball of plastic and it can crack. Because outside here is hard. So maybe it should be given consideration when it goes into production" (U8 – Interview after wheelchair testing)

4.1.2.2 Local staff

Behavioral responses to the wheelchair from the local staff were similar to those of the users. The comfort of the seating unit was generally praised but C1 mentioned that the backrest could almost feel too tight for certain users, especially at the beginning as they might not be used to the feeling.

Functionality and maneuverability were highly praised by all members of the local team and the low weight of the InnovATe wheelchair was considered one of the biggest advantages in comparison to other wheelchairs traditionally provided to local users. The possibility to quickly remove the wheels and the seat was seen as a particularly useful feature as many people with disabilities in Kenya had to deal with limited living spaces.

Concerns expressed by local staff were also similar to those voiced by users. Primarily, both clinicians and technicians were worried about the safety and the stability of the wheelchair. Clinicians were clear in stating that the brakes should be made stronger, especially considering that completely flat surfaces where wheelchair users can afford not to use brakes when stationary are rare. Clinicians also lamented the lack of side guards which reduced the lateral stability of the user, although they acknowledged the more wrap-around design of the backrest partially made up for it. Almost all members of staff expressed concerns about the robustness of the frame for heavier clients, especially considering the issues encountered by U5. However, T1 stated that the InnovATe wheelchair had the potential to be more safe and durable than standard wheelchairs provided, as it would be less likely to rust or experience brittle failures which were typical of welded metal frames.

Finally, both technicians were apprehensive about the fact that, once manufactured, the frame of the InnovATe wheelchair could not be modified. This could prevent them from being able to make adjustments that the user might request after a period of use.

"*We should also have another alternative on - if [...] the user decides the wheelchair is too low although we had taken all measurements accurately but they want it different. Because now if we change the caster wheel or to change some tubes it would not work properly anymore*" (T2 – Training phase, interview after wheelchair assembly module).

4.1.3 Reflective design

4.1.3.1 Users

The reflective aspects of the design were important to all wheelchair users involved in the study. The bright and elegant appearance of the InnovATe wheelchair made users feel proud to be associated to it. Some participants felt that because of its design the wheelchair removed the stigma associated with disability, making them look more capable (U5, U7). Others were pleased that the wheelchair looked cool and interesting to their non-disabled peers making it a universal object of desire (U2, U8). Finally, two participants felt that the design of the InnovATe wheelchair was so unobtrusive that it allowed them to be more visible as a result.

> *"For me I liked it. It's simple and light. And also when I sit in it, people are able to see me. Not the wheelchair. They are able to focus on me and not the wheelchair. Because this one (points at her own wheelchair), first of all you have to see me before you see the wheelchair. But that one (points at the new wheelchair) I feel like I am seen*" (U4 – Final focus group)

One of the most valuable aspects of the InnovATe wheelchair for most participants was that it was not just a customized product but a personalized one. The obvious implication of this was that wheelchair would be able to fit the body of the user enhancing physical attributes that the person was proud to show off.

> *"I would love that! Because the wheelchair would be… I am a tall person, I am a tall girl you know and the wheelchair that way would be to my liking, to my height*" (U2 – Final focus group)

At the same time a wheelchair shaped according to one's body could also emphasize aspects that the person did not necessarily want to highlight. U1 is a young woman of relatively short stature. This caused her wheelchair to be smaller than an average adult wheelchair and she felt that this would reflect poorly on her, making her look like a child.

4.1.3.2 Local staff

The reflective appeal of the wheelchair was also really strong for all the members of local staff. Overall, staff felt happy and excited about the InnovATe wheelchair because their clients were happy and excited about it. The other element that gave the InnovATe wheelchairs a special meaning, was that local staff felt that they actively contributed to making them. This feeling was particularly strong for the two technicians, who felt increased pride in their own work and more committed to produce quality wheelchairs.

> *"I remember that first time we finished one of the first two users, when we took the very first photo, I was very proud. Actually, posted in somewhere that was made in Kenya and I specified it was here in [name of the rehabilitation centre]. So it something which is good and I am proud of having made it*" (T1 – Independent delivery phase, final interview)

At the same time, the increased impact of their work made the local staff feel more responsible for potential failures and increased feelings of disappointment when things did not go according to plan, as was the case when the wheelchair was unable to sustain the weight of U5.

4.2 The service delivery model

4.2.1 Visceral design

4.2.1.1 Users

Users' visceral responses when first interacting with the new service delivery model were overwhelmingly positive. From the beginning users were excited when they heard about the model proposed as part of the project. People felt attracted by the technological aspect and by the chance of seeing 3D printing technology in action. The other element that users felt excited about was the fact that they could be part of a process used to make customized wheelchairs, as this was also a completely novel experience for all of them.

As they were going through the steps of the provision process, users continued to have positive visceral experiences. Most of these positive experiences were because, for the first time during a wheelchair provision process, they felt listened to. The user centered approach combined with the support offered by the local staff enabled the user to feel in control throughout the process, without getting overwhelmed by the decision making, creating a sense of safety and self-confidence.

> *"They didn't just did things you know, when they were looking at my hips and considering for the wheelchair they asked first about my opinion and if I was happy with one thing or if I preferred another. But they also helped me with explanations and helped me to make good choices"* (U6 - Interview after wheelchair testing).

4.2.1.2 Local staff

Staff's responses at the visceral level after initial interactions with the service delivery model were shaped by a mixture of excitement and apprehension. Similarly to the users, both clinicians and technicians were curious about the use of novel technologies, especially 3D printing. Both CAD and 3D printing were technologies that most members of staff had heard of, but never had the opportunity to interact with.

This excitement mingled with a certain dose of worry for most members of staff. In particular, C2 and T1 were concerned that this new model of wheelchair provision would involve too many unfamiliar concepts for them, completely changing the way in which clients were assessed and fitted with new wheelchairs. C3 felt apprehensive about the introduction of computers to record information during assessment as he considered his digital literacy level was low and he was concerned about the potential implications of any mistakes. Finally, C1 was concerned that by having wheelchair technicians more involved during the assessment stage and clinicians more active during wheelchair assembly and fitting, professional boundaries and responsibilities would be blurred, generating confusion and making errors and contrast more likely.

4.2.2 Behavioral design

4.2.2.1 Users

Users' behavioral impressions concerning the practicalities of the service delivery system were generally positive but some concerns were raised in relation to specific aspects. Because the wheelchair is specifically manufactured for each individual after all appropriate information has been collected, users were required to come to the clinic on two separate occasions. Although participants found that the overall process was quick and the waiting time lower than expected, four users (U4, U5, U7 and U8) encountered some challenges in making both appointments. To limit these difficulties they suggested having a more widespread network of clinics where the assessments were carried out with one of the appointments to reduce the burden.

Users were extremely satisfied with the professional interactions they had with the local team during both visits as they felt that the staff was both skilled and respectful. Users were happy about both the procedures and the tools used during assessment and fitting but they had mixed feelings about the simulator. Although they found the simulator comfortable and they liked the fact that the seat could be adjusted to their preferred position, they found transferring to and from it difficult, wished it could feel more stable and thought it could be more useful if it was more similar to their prospective wheelchair.

4.2.2.2 Local staff

The behavioral experiences of staff as they became more familiar with the service delivery model helped to allay some of the worries that were initially expressed. For example, both clinicians and technicians felt that, although this novel approach involved learning new concepts and procedures, a large part of these built on knowledge that they already had from their professional experience, allowing them to quickly gain confidence in their skills (T1, T2, C1, C3). Secondly, clinicians noted that by producing wheelchairs on demand they eliminated the need for ordering, also reducing dead times in which clients would be waiting for a wheelchair who fit their measurements. Technicians, on the other hand, found that the new manufacturing process reduced the chances for errors and the need to make repeated and time consuming modifications to ensure appropriate fitting.

Although more linear, the novel service delivery model was also described as more tightfitting, with a high level of interdependence between the various steps. Small mistakes during the initial assessment could snowball and cause issues that could considerably affect the quality and fit of the InnovATe wheelchairs. Preventing errors required better planning and teamwork between clinicians and technicians to ensure that all the different elements of the process slotted together seamlessly.

Clinicians found that the assessment was considerably longer and more convoluted than with traditional wheelchair provision. Especially the interview with user became a much more crucial step as details about lifestyle and preferences could have a huge influence on the characteristics of the wheelchair. This increased dialogue with the user was generally appreciated as it helped to build a more cooperative relationship. However, clinicians also found it occasionally challenging to negotiate between the options that were preferred by the clients and the ones that they thought were more appropriate for clinical reasons.

"There are some things that we need to maybe compromise – whereby you see a client says I want this and you know as the clinical person there that it is not good so in –now convincing a user and why do we need to do this is difficult" (C1 – Training phase, interview after wheelchair assessment practice)

4.2.3 Reflective design

4.2.3.1 Users

The most important value that all the users felt could be provided by this service delivery model was to firmly place wheelchair users at the centre. Although, according to both national and international guidelines, user involvement should be at the core of all wheelchair provision models, participants reported that this was rarely the case in their experience. On the other hand, a model built around the idea of providing customized wheelchairs, will by default be centered on the user as their physical characteristics, lifestyle and goals will drive design and development of the device.

"This is the best process for me. When we get wheelchairs from other donors you are not involved in the process of choosing and your measurements being taken. You are just given a wheelchair. They don't see the purpose of a wheelchair, they just give you a wheelchair and assume that it will serve the purpose, they don't know where you are coming from, where you live. But here they want to know about it so they could make the right wheelchair" (U8 – Final focus group)

In order to be able to direct the design process in their own best interest, users also recognized the need for further training to better understand how different choices will influence the performance of the chair in everyday life. Within the context of the study, wheelchair users were happy to have received sufficient support and information from the local staff. However, if this service provision model was to be rolled out in clinical practice, several users (U1, U4, U6, U7, U8) felt that they would want to have better knowledge about the implications of different wheelchair setups.

4.2.3.2 Local staff

One of the most commonly cited reflective values of the InnovATe service provision model was the fact that it enabled local production of wheelchairs. On the one hand, this was seen as a positive aspect by all clinicians and technicians as it enabled them to have more control and ownership of the whole provision process from client's assessment to wheelchair's fitting. Additionally, C1, C2 and T1 believed that local manufacturing will significantly reduce the elevated shipping and importation costs, potentially reducing the price of wheelchairs overtime. However, C2 also mentioned that implementing this new localized wheelchair provision system would require significant initial investment in order to ensure adequate material and human resources are in place.

The ability to repair the wheelchairs locally was seen as a crucial advantage. To help with reparability and decrease time and cost of manufacturing new wheelchairs, both technicians thought that streamlining some aspects of production, such as building a stock of printed nodes which were the same across all wheelchairs, would be an effective solution. T1 also suggested that recycling 3D printed nodes might help to reduce the waste of material overtime, especially in case of breakages or if wheelchairs were provided to children who would require more frequent adaptations as they grew. When considering future implications of the technology, some members of staff (T1,T2 and C2) also envisioned that the current manufacturing techniques could be used to provide more kinds of assistive technologies such as crutches and walkers to increase both the scale and the impact of the service delivery model.

> *"There are opportunities to make these other assistive devices, crutches, the walkers and the walking frames such things. Because day in day out we meet different people and their needs are different. So having done this bit about the wheelchairs I really in a position to do other assistive devices, and even for those, I know it can happen quite easily"* (T1 – Independent delivery phase, final interview)

Although local manufacturing was mostly seen as a positive aspect, some members of local staff (C2, C3 and T1) mentioned that it could also lead to significant challenges. Manufacturing wheelchairs using digital technology would require space, a reliable supply of power and internet connection which were seen as potentially difficult to access.

Finally, another major advantage of the novel service delivery system was that local staff felt it enabled them to properly meet the needs and expectations of the client. All clinicians felt that this would not only made their job feel more worthwhile, but it would also help them to prevent secondary injuries that might compromise the health of the client overtime.

> *"The new method with customized wheelchairs is better because a good wheelchair will help eliminate some deformities that will need the attention of the rehab team in the future. So I think this will be really good for the patient in the future as well, not just now"* (C2 – Independent delivery phase, final interview)

5 Discussion

Numerous studies in HCI and design have shown that the ability of products or services to evoke positive emotions in the user is likely to determine its success much more than the practical advantages they might offer [24, 49, 79]. In the last decade, researchers have started to investigate the same phenomena in relation to assistive and inclusive devices used by PWDs and discovered that social and emotional aspects play a crucial role in how PWDs choose to interact with assistive devices and the feelings that arise as a result of these interactions [12, 30, 56, 66, 67].

The InnovATe wheelchairs introduced as part of the current trial were not free of practical issues, including brakes, chassis and the seating unit. Yet, they received overwhelmingly positive reviews from both users and local staff due to their visceral and reflective appeal. For a device which is as functionally crucial for a PWD as a wheelchair, this can seem counter intuitive; however the relationship between the person and the wheelchair is an incredibly complex one that cannot be simply reduced to its practical components [23, 71, 77]. Furthermore, it is worth remembering that, although functional challenges for PWDs are bigger in LMICs, so it is stigma around disability which makes self-presentation even more important [60]. The visceral and reflective responses of participants to the InnovATe wheelchair highlighted how the personal image of the user and the wheelchairs reflect and influence each other in a unique way. Ultimately, the coupling between the person and the wheelchair becomes so strong that the wheelchair is effectively an extension of the self as defined by Clark and Chalmers [25]. This external coupling is built through an extension of the body that incorporates the device as seen in the tales of prosthetic users collected by Bennett et al [11], but it is also built overtime as the interactions between the person and the device shapes the biographical meaning of the object. This relationship requires careful consideration in design as the wheelchair should be a clear lens that allows the user to be seen and enhanced not a filtered one that hides and distort their true self.

From the responses we collected from participants, it is easy to see that the aesthetic attractiveness of the InnovATe wheelchairs were definitely a major factor in their success [74]. Further, the implications of gender preferences and concepts such as masculinity or femininity are rarely considered in the field of AT. Yet, these aspects are important to users affecting opinions on prosthetic arms [57] or leading people to decide how to customize their hearing aids [55, 56]. Despite the fact that the variations introduced by the new design did not significantly alter the basic form factor of a three wheeled wheelchair, they were sufficient to shift the perception of female users towards a device they held negative opinions of. Gender identity, weather binary or not, is hugely important for PWDs, yet it's rarely discussed in the field of AT [12, 65]. Findings from our study point out at the need to better understand the impact that the design of assistive devices can have on empowering PWDs to express important concepts such as femininity, masculinity and queerness.

Although it could be argued that participants in our study did not have the time to form any meaningful attachment to the InnovATe wheelchair, they nonetheless did so through the processes that led to the creation of the wheelchairs themselves. For local staff the wheelchair became a signifier of their own efforts, learning and skills, this is very similar to sense of empowerment, pride and ownership generally associated with novice, and experienced makers, both within the context of AT and beyond [46, 59]. Although users played no part in the manufacturing process of the InnovATe wheelchairs, they still perceive them as a personalized object that they had the opportunity to shape according to their bodies and personal preferences.

As observed in the digital community of hearing aid and cochlear implant users described by Profita et al [55, 56], personalizing devices is also a way to exert control over one's circumstances and appearances. Wheelchair users in our study valued the opportunity for personalization that was offered by the InnovATe service delivery model but they were conscious of the fact that with that opportunity also came a level of responsibility to make the "right decisions" for themselves and their assistive devices. Within the context of the research users were happy to be advised by clinicians and technicians that they trusted, but their aspiration was to increase their own knowledge so that they could make better decision for themselves. This is in line with the observation of mobile technology use of visually impaired people in Kenyan informal settlements described by Barbareschi et al [7], where participants reported being happy to be supported in their interactions with technologies but they were not always comfortable having to fully trust others.

Aspects of agency and control were also important for local clinicians and technicians who felt that the InnovATe model gave them a chance to provide a quality wheelchair service to their clients without having to rely on unknown manufacturers and suppliers. However, the increased sense of agency also made local staff more worried about the impact that any mistake they made could have, especially as modifying the InnovATe wheelchairs after production could be extremely challenging due to the interdependent nature of the parametric design. This resonates with the testimonies collected by Hoffman et al [33] who found that clinicians were reluctant to be involved in the design of open source assistive devices as they were worried about moral, and potentially legal, implications of failure.

The production of customized wheelchairs requires a deep knowledge not just of users' physical needs, but also of their lifestyle, living environment and personal preferences. The InnovATe service delivery model pushed local staff to better engage and communicate with their clients. Overall, clinicians were glad to be able to involve users more in the assessment and fitting process. However, they also experienced challenges when having to negotiate between their clinical opinions and the conflicting desires of the users. As observed by Berry et al [14], developing new technologies that promote concordance between patients and clinician is a worthy but complex goal for designers and HCI professionals. Developing technologies and services that enable patients to share their values, as it is the case with the InnovATe model, is the first step for success but challenges can always arise when the patient's priorities are completely at odds with the clinician's goals [14].

In Disability Interaction: A manifesto [35] Holloway asks "How do we develop design practices that result in products and services that support the inclusion of disabled people in all aspects of life?". Findings collated from our study show that this is only possible if we understand the emotional aspects that govern the way in which users and providers attribute value to AT products and services. Leveraging novel technologies in a new service and producing aesthetically pleasing devices can trigger attraction and imagination at a visceral level. Behavioral aspects such as the efficiency of a service and the functionality of a wheelchair can determine how useful and applicable AT innovations are perceived to be. However, AT products and services can only support inclusion if they are able to evoke positive reflective responses, such as the sense of agency that users experienced as they made decisions that defined the characteristics of their customized wheelchairs, or the pride felt by providers when seeing a client enthusiastic about a device that they had created because of their new skills.

The findings presented in this paper represent the subjective experiences and opinions that are shaped by the emotional responses of participants, not an objective evaluation of the InnovaTe system. We acknowledge that, as some of the interviews and focus groups took place at the end of the study, some of the participants' responses could display recollection bias and pleasant memories of their experiences might overshadow negative ones which are more likely to fade, as highlighted by Norman [50]. Participants opinions greatly emphasised the importance of visceral and reflective aspects of wheelchairs and their associated service provision models, but this does not negate the value of evaluating behavioral aspects such as robustness and safety when developing assistive technology. Wheelchairs and associated services play a crucial part in the life of people with disabilities and they need to be functional, safe and effective. Nonetheless, we emphasise that behavioral aspects are far from sufficient and, as highlighted by our participants, values such as self-presentation, agency, and personalization are equally important. Finally, as the wheelchairs had not yet received ISO certification, users were only able to test the wheelchairs for short periods of time within the compound under the supervision of a clinician. This may have led to them highlighting visceral and reflective aspects more when compared to behavioral aspects, which might come to the fore as the wheelchair is used for longer periods. Future work will expand on independent wheelchair testing and include significant comparisons between people's current wheelchairs and the InnovATe ones to gain additional insights on how the users' relationship with their wheelchair evolves over time.

6 Conclusion

AT innovations that leverage novel technologies must focus not only on the assistive devices themselves, but also on the service delivery models that accompany them. This is particularly true in LMICs where the systemic failure of these systems is often what prevents people from accessing the devices that they need. In this paper we presented the results of a five month study in which we introduced InnovATe, a novel model to manufacture bespoke wheelchairs in LMICs leveraging CAD and 3D printing technology. Throughout the study we trained five local wheelchair providers in the tools and techniques necessary to deliver the service in practice and manufactured eight wheelchairs that had been evaluated by expert manual wheelchair users. Results from the study showed that although conscious of certain functional limitations of both the wheelchairs and the service delivery model, which would have to be addressed before practical implementation, users and providers attributed great value to the innovation. The user centric approach to customized wheelchair production led to the manufacturing of wheelchairs that felt to the users like an empowering and meaningful form of self-expression that allowed them to present an image of themselves that they could be proud of. At the same time, the localized production model made service providers feel like they had more control over the quality of the wheelchairs they were able to provide, ensuring that their clients could have the access to devices that truly met their needs.

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