DESIGNING AN ALL-TERRAIN WHEELCHAIR; A CASE STUDY OF INCLUSIVE DESIGN FOR SOCIAL IMPACT IN LOW-RESOURCE SETTINGS

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ABSTRACT

Developing appropriate assistive technology to be manufactured and maintained within the local context of a low-resource setting requires alternative design principles and designerly ways to those used when designing in, or for, more resourced regions of the world. This case study offers an empirical account of the design of SafariSeat, an all-terrain wheelchair which has been designed, tested, manufactured and turned into a sustainable enterprise in East Africa. The wheelchair was developed with intentions to reduce inequality and help alleviate poverty in low-resource communities by improving users' health, wellbeing and participation in society, whilst creating and facilitating local jobs to support communities. Having developed SafariSeat with a human-centred design approach, a local mindset, and prioritisation of usability and affordability, this case study is used to reflect on the applied design principles, practices and processes whilst providing contextual insights for other designers seeking to work in a similar way. The study discusses challenges encountered whilst designing in a low-resource setting, and highlights how local collaboration and partnerships can help lead to the creation of a more sustainable solution.

Keywords: User centred design, Design engineering, Inclusive Mobility, Open source design, Social responsibility

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1 INTRODUCTION

The need for wheelchairs is rising across the world, partially due to a globally growing and aging population. The World Health Organisation (2018) recognises that over 75 million people are in need of an appropriate wheelchair, around 90% of whom do not have access to one. This is largely due to the majority of individuals in need of a wheelchair living in low-resource settings, where access to appropriate and affordable mobility interventions is significantly lacking, as is funding to cover such healthcare costs (Holloway et al., 2018). Without being independently mobile, people in low-resource settings often find themselves marginalised and struggling to participate as valued members of their community (DFID, 2018). This nature of exclusion is magnified by attributes common in such settings, including absence of state support, social stigma around disability, and limited accessible infrastructure such as pavements and ramps (particularly in rural areas with rough terrain). As a result, people in low-resource settings who are in need of a wheelchair but do not have access to one, are susceptible to falling into a disability-poverty cycle, which can lead to them being unable to financially or physically support themselves or their family (Banks et al., 2018; Polak & Warwick, 2013). Tackling and preventing this phenomenon requires long-term efforts, in which designers can play a critical role in understanding and proactively responding to help solve such deep-rooted societal challenges.

In 2015, the United Nations outlined 'inequalities for people with disabilities' and 'poverty' as two of the seventeen most significant challenges facing humanity (United Nations, 2015). Efforts have been made to provide wheelchairs to people in low-resource settings as a means to tackle these challenges. Many imported wheelchairs have been donated through charitable organisations, although these are often unsuitable for areas with rough terrain, and are generally fabricated from pre-formed components and materials that cannot be easily repaired or replaced locally when maintenance is required. Tricycles which better suit rural contexts have been designed for local repair, but they are typically too large for indoor use, forcing users to crawl inside their home whilst their tricycle is left outside. Other attempts have been made to design suitable wheelchairs for such contexts, but many of these have tended to be too expensive for locals to afford, adopt unsustainable business models, or rely upon charitable support rather than striving for long-term local sustainability. There is thus significant need for a wider range of low-cost, durable wheelchairs that can function on varied terrain, are small enough to use indoors and can be manufactured and repaired from what is available locally (Constantine et al., 2006).

2 DESIGN AIMS AND METHODOLOGY

The overarching aim of this design project was to create an all-terrain, locally manufactured and low-cost wheelchair for low-resource settings, with intentions to help alleviate poverty, improve accessibility and reduce inequality. The design aimed to meet the needs of the present and support future generations to meet their own needs, through establishing a locally-owned and self-sustaining enterprise to manufacture the design. Prior to commencing development, extensive primary and secondary research was conducted into the design and implementation of various existing or discontinued assistive technologies and business solutions in low-resource settings, to reflect on and question the heritage and current state of design in, and for such contexts. The design team spent several weeks conducting research alongside individuals who used, or were in need of, a wheelchair in Kenya, to investigate and thoroughly understand the problems they face each day, paying particular attention to how their context effected their experiences (Figure 1). This helped to frame and validate the design problem through the lenses and voices of those with lived experience, to ensure design justice (Costanza-Chock, 2020) and a human-centred perspective were maintained from the outset. This was combined with the exploration of embedded entanglements of culture, technology and environment, to distil three core design principles which were applied throughout the design process. The principles outlined below were central to the methodology of this project, helping to guide and justify design decisions, and keep it on track to solving the real root of the identified problems:

- Localised Design; work with local materials, tools, communities and networks wherever possible.
- Prioritise Usability; optimise durability, reliability, ease of manufacture and maintenance.
- Ruthless Affordability; minimise costs and production time without compromising safety.

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The project aimed to create a highly durable wheelchair without compromising usability, performance or cost, thus leaving appearance and form as secondary considerations to both function and affordability. A rural region of Kenya was selected as the context for undertaking this design project due to being characterised by particularly rugged terrain and harsh environmental conditions, as well as being a low-resource setting in terms of healthcare, materials, and financial resources. The following sections of this paper document the methods for designing, developing and implementing the wheelchair, as well as key considerations and decisions made at each stage of the design process.

Figure 1. Framing and validating the project by spending time with locals who require a wheelchair, whilst becoming familiar with the rough terrain in a rural region of Kenya.

3 DESIGNING IN A LOW-RESOURCE SETTING

Having become familiar with the nature of the rugged context the wheelchair would be used in, the first stage of the design focused on developing a mechanism to maintain constant ground contact with all wheels whilst traversing over such uneven terrain. Optimising the durability and functionality of the suspension mechanism and frame was deemed to be the most fundamental aspect for prioritising usability of the wheelchair in a low-resource and rural setting. This stage of the design (conducted as an undergraduate student design project) resulted in the creation of a lever-propelled wheelchair prototype, demonstrating a novel articulated chassis (Figure 2). Despite being far from viable, feasible or desirable to use or to manufacture, this prototype acted as the foundations for designing, developing, testing, manufacturing and implementing the all-terrain wheelchair concept in context.

Having investigated, framed and validated the design problem, the next priority for designing in a low-resource setting centred on the principle of localised design. Local materials, tools, and manufacturing methods for the design were identified and adopted from the region of rural Kenya where the development of the wheelchair took place. The local ways of life, environment, terrain and weather conditions were all taken into consideration in the creation of the design specification. Materials such as metal tubing for the frame and standard bicycle components were sourced nearby to ensure manufacture and maintenance could be carried out locally. An example of adapting the design for local manufacture was using plastic irrigation tubing inside the articulated chassis mechanism, to minimise friction of moving parts; this type of tubing is available in most areas where agriculture occurs, which happens to be the main industry in rural low-resource settings (Gulliver et al., 2001). An example of adapting the design for local ways of life was incorporating storage platforms with tie-

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down points in the design of the frame, to allow users to transport luggage such as baskets of food or containers of water, whilst keeping their hands free to control the wheelchair when moving along.

Figure 2. User testing the first lever-propelled wheelchair prototype with an articulated chassis acting as a suspension mechanism over uneven terrain.

4 USER TESTING AND OUTREACH

At the start of the project, several weeks were spent with people who required a wheelchair, to thoroughly understand how they live and to observe the hurdles they face as a result of their mobility impairments. A local Outreach Scout was recruited to help identify and compile information about prospective users, to form a group of enthusiastic user testers. Over thirty different wheelchair prototypes were put through rigorous usability testing with this group, to collect both quantitative and qualitative data. The group consisted of a diverse range of users to ensure representation from a variety of individuals in terms of their disability, age, physical strength, employment status and housing situation. User requirements and usability of the wheelchair design were iteratively refined through a combination of ethnographic observations and feedback from users after testing each prototype. For example, the first wheelchair prototype used a lever-propelling mechanism to move along, however, results from user testing concluded this was not a viable solution due to some users finding it difficult to manoeuvre, biomechanically inefficient, uncomfortable to propel in hot weather, and requiring considerable upper body strength to move up hills or over very rough terrain. As a result, the levers were replaced by rotating hand pedals (Figure 3) with a gear ratio optimised to ensure a pleasant user experience. Readily available bicycle pedal cranks were re-purposed to mount these two rotating handles either side of the seat, and simple fixed gears were used to eliminate the need for separate brakes when turning tightly or stopping. User feedback also informed design decisions such as slightly increasing the track width for better stability, using a dark coloured durable seat fabric to minimise visibility of dust and wear, adding adjustable foot plates and increasing the seat cushion thickness, all of which were incorporated into the final design.

With over 60 different languages spoken across Kenya, user testing was streamlined by the Outreach Scout acting as a translator to pre-arrange user testing visits and accompany the design team on visits to assist with communication. Activities involving local props and minimal verbal communication were devised to make user testing an enjoyable experience for the users and their families without needing to understand the design team word for word. For example, local objects such as coconut

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shells were spaced out evenly over a measured distance to create a simple obstacle course for the user to practice manoeuvring through (Figure 4); the same course was measured out for different prototypes with different users to record and quantify improvements in their manoeuvrability, accuracy and speed from start to finish, which helped to inform various aspects of usability.

Figure 3. User's family watches as they test a new hand pedal wheelchair prototype.

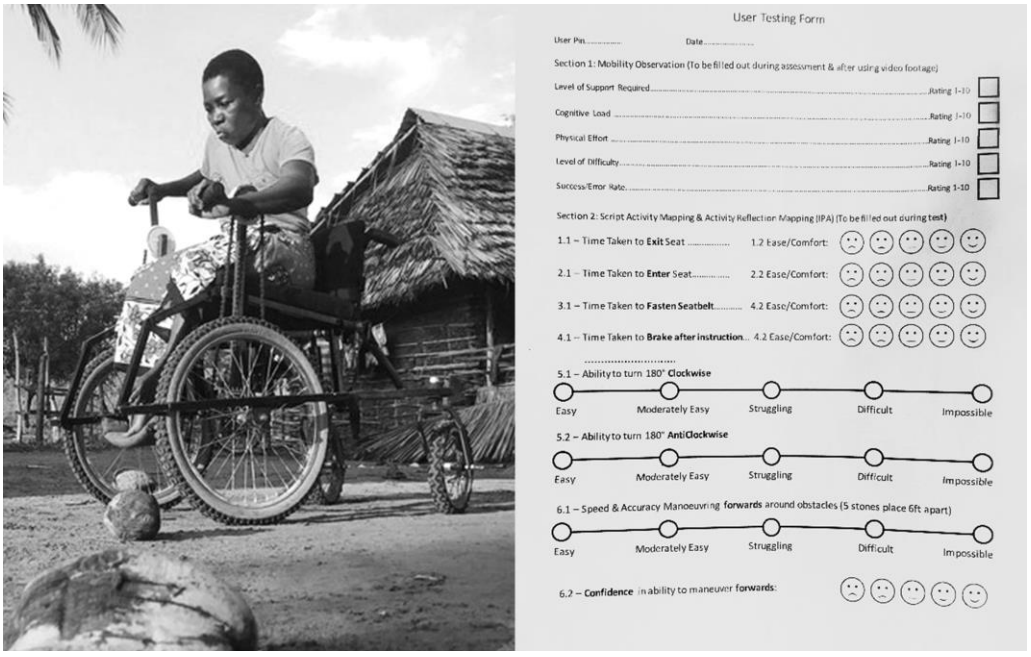

Figure 4. User manoeuvring the wheelchair around an obstacle course. An excerpt from one of the user testing forms used to record qualitative and quantitative data during the test.

User testing forms were printed out and taken along to each usability visit as a guideline for the designers to use when recording their observations of activities, whilst also acting as a prompt to remind the designers how to document or score each element of the visit. Immediately after completing test activities, users were asked to qualitatively reflect on their experience of using the prototype. Interpretative Phenomenological Analysis was used alongside a quantitative activity-reflection scale, to capture each user's personal perception and account of the experience (as opposed to solely capturing the designer's objective account of the experience). The users' verbal descriptions

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of their experiences were translated real-time by the Outreach Scout and recorded by a video camera, which also captured the users' body language, expressions and gestures when describing their experiences. All of this information was reviewed and evaluated by the designers to inform subsequent prototyping.

With potential language and literacy barriers in mind, a user manual was designed to be understood through images and symbols alongside simple text (Figure 5). All necessary steps for maintenance were included in the manual, and were demonstrated during product handover alongside basic training in wheelchair use and health issues. All users taking part in long-term usability trials were also provided with a maintenance pack containing spanners and oil to take care of their wheelchair. Long-term durability testing in the local area led to a growth in awareness of the project and thus an increase in individuals and organisations contacting the workshop with requests. The power of word-of-mouth quickly became apparent, and subsequently became a core method for identifying prospective users.

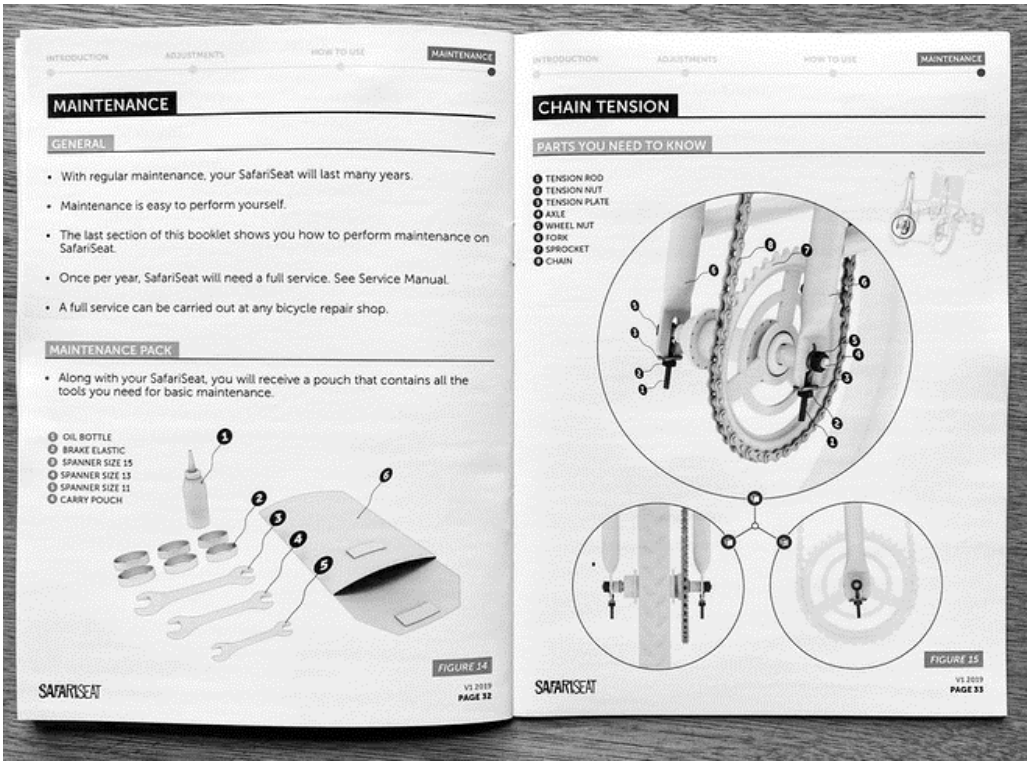

Figure 5. A page from the user manual using visuals to convey maintenance information.

5 MOVING FROM PROTOTYPE TO PRODUCTION LINE

Iterations of the design were prototyped in a metal workshop belonging to a local charity who manufactured tricycles. Extra attention to precision was required due to the condition and accuracy of tools in the workshop, and like many places in the region, frequent power cuts were encountered which often halted prototyping. Despite this, the workshop was equipped with all the essentials required for prototyping and allowed the wheelchair designers to work alongside a knowledgeable team of local engineers. As the wheelchair design team geared up to increase the scale of production, a larger and more permanent workspace was required, and despite the tight project budget, the decision was made to set up an independent workshop. A local disused abattoir was identified and plans were carried out to convert it into a new workshop, ready for production of the wheelchair to commence (Figure 6).

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Figure 6. Kitting out the new workshop and setting up the wheelchair production line ready for manufacture (before and after).

Three months were spent tweaking the design to maximise the efficiency of production which substantially reduced how long it took to manufacture and assemble a small batch of the wheelchair design, in the quest for ruthless affordability. The component count of the wheelchair frame was reduced by over 30% from the first prototype and its weight and cost both dropped correspondingly. A production line was set up to streamline manufacturing processes and minimise human error. This required the creation of new workflows and processing stations, component organisation using naming conventions, and improved assembly techniques such as the creation of various jigs to accurately position components for welding (Figure 7). Task books were created to detail the entire manufacturing process in the style of step-by-step instruction manuals, and small batch production runs were conducted to identify bottlenecks, further optimise the design, improve quality control and boost productivity.

Where equipment was too expensive to buy on the limited project budget, the efficiency of manufacture was compromised by adapting processes to work with less expensive tools or techniques, whilst still achieving a high quality finish. For example using a heat gun to melt and cure powder paint rather than purchasing a large oven. To minimise long-term costs, almost all processing facilities were built in the workshop. Where processes or equipment could not be set up in-house, partnerships were formed with specialised local enterprises to use or borrow their equipment. When it came to standards testing, the project budget could not sustain outsourcing the process to ISO standard facilities, so the design was instead tested using established simplified methods in-house (Mhatre et al., 2017; Whirlwind International, 2011). Once the design was finalised, more rigorous and accurate test facilities were built to conduct KEBS testing in the wheelchair workshop.

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Figure 7. Using a jig to accurately position frame components in preparation for welding.

6 FUNDING AND FINDING A LOCAL TEAM

The wheelchair design project was led by a small group of designers from the United Kingdom, who set out to turn it into a sustainable enterprise to be adopted and managed by locals in Kenya. In order to reach this goal, the team first needed to secure funding to design, prototype, test, and set up facilities. Crowdfunding was chosen as a suitable means of funding the project due to the ability to share a story and vision with a global online community at the same time as publicising the product idea, sharing project progress, and requesting further support from the supporting crowd if needed at a later date. It was decided from the outset that all founders would work entirely voluntarily on a full-time basis to allow as much budget and time for the research, design and development of the wheelchair as possible. Over $90k was raised through the crowdfunding campaign, which lasted up until the implementation stage, two years later. By this point, the design was finalised, long-term user trials had been successfully completed and the design was ready to be manufactured.

Figure 8. The design and manufacture team in the new Kenyan wheelchair workshop.

An enthusiastic and diligent local was trained up to become the new workshop manager alongside a group of reliable technicians who either joined the team from the tricycle workshop, or were recommended by trusted locals (Figure 8). Finding a local team to take over from the founders marked

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the beginning of the design being adopted by the community and allowed the founders to take a step back. The first batches of wheelchairs produced in the workshop were donated to individuals through funds raised in the original crowdfunding campaign, however, it was realised that despite its low production and sale costs, an unconventional business model was required for the longer term to make the wheelchair accessible to low-income users and achieve self-sustainability (Polak & Warwick, 2013). A social business development expert was brought on board to help devise a suitable business model involving microfinancing, to make the wheelchair design accessible to those most in need, and to guide the transition to total sustainability.

7 DISTRIBUTING DESIGN VALUE AND IMPACT

Upholding the founding design principle of locality, the plan to scale-up production centred on partnering with existing workshops across Kenya and beyond, to become local hubs for manufacture and distribution through a decentralised approach. Earlier research in the project illustrated how this style of distributed manufacturing approach can be beneficial to both those in need of a wheelchair as well as their local communities due to the creation of new work opportunities and support networks. In parallel to scaling up production, the original workshop began to receive increasing demand for wheelchairs and started to expand its capacity by purchasing more machinery and establishing more formal distribution channels. Packaging is sourced locally to transport batches of the wheelchairs to distribution partners such as healthcare providers, whilst a motorcycle with sidecar is used for delivering to individuals in rural off-road locations (Figure 9). With the intention of extending accessibility, the wheelchair design blueprints were made available in the form of an open-source 'DIY' manual, to guide those with the necessary funds, tools and skills, to manufacture their own version of the wheelchair design. The DIY manual intends to convey a high level of information regarding the required materials, tools, manufacturing processes, and safety considerations, in a coherent, succinct and understandable manner. This was communicated through a standalone document which maximised the use of detailed visuals and minimised the use of written language (in a similar style to the user manual in Figure 5).

Figure 9. Transporting a wheelchair by motorcycle sidecar for delivery to an off-road village.

To further increase the impact of the design, secondary research and development projects have been established to design a range of compatible wheelchair 'add-on' products to facilitate work opportunities and support the intended users in generating income. The range includes add-ons such as an accessible trailer to facilitate transporting and selling produce, and a portable workspace to facilitate the handling of

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merchandise, money, and hand tools for doing crafts or vending produce from the wheelchair. Such job opportunities require minimal training, meaning the intended users of these add-on products have a greater chance of quickly generating income to improve their living conditions, and thus reduce their likelihood of falling into prolonged poverty.

8 CONCLUSION AND FUTURE RESEARCH

The case study presented in this paper offers a reflective account of the design methodology applied through the development of an all-terrain wheelchair designed in a rural Kenyan context, including the principles, practices and processes used. This paper highlights the need to utilise local materials, tools, and manufacturing methods when designing in a low-resource setting, as well as the value of having a local person to assist with user testing and outreach. The study describes how the design team approached manufacturing on a small budget and the importance of minimising long-term costs when moving from prototype to production line. The study also offers a brief account of using crowdfunding to finance research and development, and gives pointers with regards to finding a local team to take over such a project. The design principles, practices and processes documented through this paper provide empirical contextual insights which are intended to be of use to others who seek to develop products or services using a similar approach or in a similar setting, as well as to design educators seeking to enrich teaching around this subject.

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It took ‘a village’ to create the ‘SafariSeat’ wheelchair described in this paper; from end users, families, craftspeople, manufacturers and wheelchair designers, to business advisors, journalists, investors and an international community of supporters. The author would like to thank everyone who has supported and shown an interest in SafariSeat along the way.

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