From Sterile to "*Sexy*": The ModBility Smart & Modular Walking Cane System

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Abstract

For centuries, the walking cane has remained one of the most widely used assistive mobility aids globally. However, despite rapid advancements in modern manufacturing, its fundamental design has stagnated within the bounds of orthodox clinical practicality. Traditional mobility aids prioritize basic physical support while neglecting the user's psychosocial reality, often resulting in social stigma, a loss of bodily autonomy, and high rates of device abandonment. Grounded in Inclusive Design principles and participatory action research, this Major Research Project challenges the medical model of disability by reimagining the walking cane not as a static medical device, but as a dynamic, personalised lifestyle accessory.

Through generative participatory co-design ideation workshops with individuals holding lived experiences of mobility impairments, qualitative data was synthesized to uncover deep intersections between mechanical friction and social objectification. Responding to these insights, this research introduces the ModBility Modular Walking Cane System. Built upon a lightweight carbon-fiber framework featuring a universal electromechanical connector architecture, ModBility allows for absolute personalisation and interchangeability. The proof-of-concept features both active and passive modules – including an ergonomic heated grip, a programmable LED light bar, continuous telescopic height adjustment, and a flexible charms module for personalized aesthetics. By democratizing the hardware through an open-source, 3D-printable architecture, ModBility shifts the assistive technology paradigm from "***sterile***" to "***sexy***," providing users with unprecedented aesthetic agency and fundamentally bridging the gap between clinical necessity and human desirability.

Keywords: Inclusive Design, Assistive Technology, Participatory Co-Design, User Testing, Modularity, Emotional Design, Smart Cane, Modular Crutches, Open-Source Hardware, Mobility Aids.

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1 Introduction

For centuries, the walking cane has remained one of the most widely used assistive mobility aids globally, utilized by approximately 4.1% of the population with demand steadily increasing (Charette et al., 2018; "Canes and Crutches Market Size & Industry Share By 2034 — factmr.com", n.d.). Yet, despite rapid advancements in modern manufacturing, its fundamental design has barely evolved beyond orthodox clinical practicality (Spinelli et al., 2019). Modern aluminum canes are engineered strictly to keep a user upright and alive, largely ignoring the user's social reality and their human desire for dignity, dynamic comfort, and self-expression (Oro, 2025; Rogers, 2020). In response to this aesthetic and social failure, this research introduces a Modular Walking Cane System.
ModBility Modular Walking Cane System challenges the rigid, clinical paradigm of traditional assistive technology by utilizing a participatory co-design framework to transform the walking cane from a static medical device into a dynamic, personalised and customisable accessory.

Figure 1: The fully assembled ModBility prototype.

The necessity of this transformation is highlighted by a common paradox in how we perceive assistive technology. My grandmother recently turned 78; her hearing is fading, but she refuses to wear a hearing aid. If you ask her why, she will tell you: "What will people say? Everyone will think something is wrong with me." But here is the paradox: she wears another assistive tool every single day: her glasses. Yet, she feels no shame about them because her glasses are an accessory. She chose the frames; they fit her face; they add character to her personality.

In his book Design Meets Disability, Graham Pullin points out this exact contradiction (Pullin, 2009). Historically, the priority for disability design was to enable while attracting as little attention as possible. Devices were moulded in flesh-toned "pink plastic" to camouflage them against the skin. The goal wasn't to project a positive image; it was to project no image at all. Eyewear, on the other hand, embraces fashion. It makes the wearer feel good and achieved a positive image without needing to be invisible. So, why haven't we applied this same philosophy to other assistive technologies like walking canes?

Figure 2: Project's design approach, bridging the gap between sterile clinical practicality and dynamic human desirability.

1.1 Background & Context

When we treat assistive technology strictly as an exercise in medical engineering, we strip it of its humanity. The traditional "medical model" of disability prioritises keeping the user upright and alive, viewing the body as something to be fixed(Spinelli et al., 2019; Oro, 2025). However, the "social model" of disability argues that people are disabled not by their bodies, but by the physical and social barriers erected by society (Shahar & Ventura, 2023).

Ironically, the very tools that are designed to help individuals navigate physical barriers often create profound social barriers, like standard aluminum walking canes. They are engineered for orthodox practicality, completely ignoring the user's social reality, diverse needs and their human desire for dignity, self-expression, and dynamic comfort (Moumeni, 2026). During the early co-design sessions for this project, the participants described their current canes consistently as grim using words like: "*sterile*," "*ugly*," and "*non-aesthetic*."

The social consequences of this clinical design are profound. This is the true aesthetic problem of modern mobility aids: a sterile design may invite pity, othering or a feeling of angst, transforming the user from a person navigating their environment into a "patient" taking up space, ultimately contributing to what sociologists term a 'spoiled identity' (Goffman, 2009). Addressing this is not a matter of superficial vanity; it is a fundamental requirement for inclusion and dismantling social stigma (Bright & Coventry, 2013).

In response to this aesthetic and social failure, this research introduces a smart and modular walking cane system with the primary focus to bridge the historical gap between clinical engineering and personalisation. Rather than accepting the walking cane as a static medical prescription, this research explores how a modular architecture can transform a mobility device into a dynamic, customisable and emotionally personal accessory (de Gois Pinto, n.d.). To achieve this, the project aims to utilise participatory co-design framework to develop different physical modules to validate the customisability of the modular system. Ultimately, giving users the agency to continuously adapt their mobility aid to their changing environments and personal styles serves as a tool to empower the users and reduce the barriers to adoption, actively combating the high rates of device abandonment caused by static, one-size-fits-all designs (Morris et al., 2022; Zhang et al., 2024). This also redefines the public narrative surrounding assistive tools.

1.2 Research Questions

The ModBility Modular Walking Cane System project, challenges the rigid, clinical paradigm of traditional mobility canes. By harmonizing design with clinical engineering and prioritizing the lived experiences of users, this research asks:

1. "***How can a comprehensive modular walking cane system be designed to enhance user autonomy, reduce fatigue, and improve overall mobility experience for individuals with diverse mobility impairments?***"

2. "***How can different modules be designed using inclusive design methodologies to shift from a static medical device to a dynamic and customisable walking aid?***"

2 Methodology: A Participatory Approach

To successfully shift the walking cane from a sterile medical device to a more dynamic and personalised accessory, the research and design process itself had to shift from a traditional top-down engineering approach to a horizontal, participatory one. This research is grounded in the belief that users are not simply passive recipients of medical interventions, but expert co-creators of their own lived experiences.

2.1 Inclusive Design Framework

The traditional mass-manufacturing model designs the walking canes for the "mythical average," resulting in one-size-fits-all products that inherently exclude those with diverse needs. As Jutta Treviranus notes, when we design exclusively for the center of the bell curve, our designs are brittle; however, when we design with the margins, we create systems that are adaptable, resilient, and better for everyone (Treviranus, 2019a).

Assistive technologies, like the standard aluminum walking cane, frequently suffer from this "mythical average" approach by focusing only on basic physiological support while completely neglecting emotional and social variance. To counter this, this project utilised a Co-Design Framework. Following the disability rights principle of "Nothing about us without us," (Charlton, 1998) individuals with lived experiences of mobility impairments were positioned not as test subjects, but as primary design partners (Mitchell & Treviranus, 2017). By designing with the margins rather than for them (Sanders & Stappers, 2008; Treviranus, 2019b), the research aligns with core accessibility guidelines prioritizing 'flexibility in use' (Accessibility Standards Canada, 2024) uncovering aesthetic and social pain points that a purely clinical engineering approach would have missed.

2.2 The Four-Phase Research Structure

To translate these inclusive design philosophies into physical hardware, this project followed an iterative, four-phase roadmap. This structure allowed initial engineering assumptions to be challenged and reshaped by user feedback in real-time.

1. **Phase 1: Participatory Design Ideation Workshop** This phase utilised structured discussions and collaborative ideation. The objective was to uncover the genuine daily friction points of mobility aids rather than presenting users with a pre-determined technical solution. This phase catalyzed a critical pivot away from the original complex mechanical suspension toward the need for aesthetic modularity and personalisation.

2. **Phase 2: Prototype Development** Based on the insights gathered in Phase 1, this phase focused on translating user desires into physical, cross-sensory prototypes. This period encompassed the engineering and aesthetic refinement of the ModBility system, ultimately resulting in the development of six distinct, interchangeable modules ranging from customisable charm attachments to integrated lighting and heated grips.

3. **Phase 3: User Testing** Participants from the initial Design Ideation sessions returned to conduct hands-on evaluations of the physical prototypes. While constraints prevented active load-bearing tests, participants rigorously

assessed the ergonomics, weight, balance, tactile comfort, and mainly the emotional resonance of the aesthetics and connecting mechanisms.

4. **Phase 4: Final Validation & Feedback Collection** To close the iterative loop, post-testing technical refinements were made to the modules. A final asynchronous review was conducted, providing participants with complete visual models of the fully integrated six-module system to validate the updates and capture their concluding insights without the pressure of a formal lab setting.

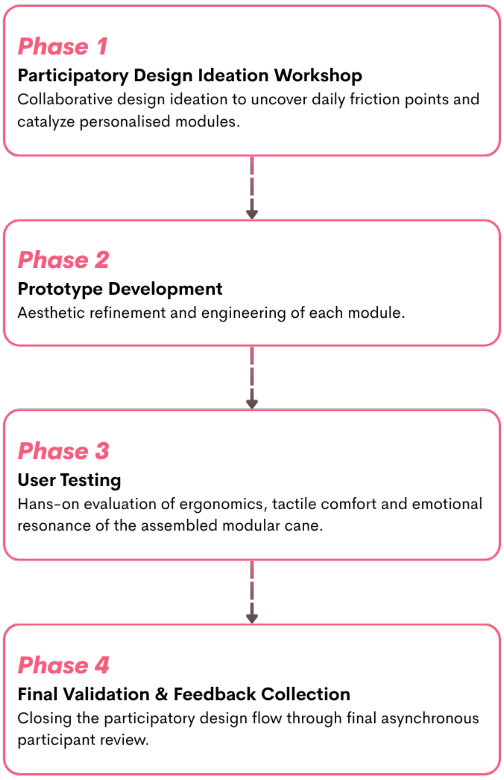


Figure 3: Flow diagram for the 4-Phase research structure.

3 Phase 1: Participatory Design Ideation Workshop

To successfully shift from the sterile "medical model" of designing walking canes, the design process had to start with the true experts: everyday cane users with lived experiences. Phase 1 served as the foundational layer of the modular cane project, utilizing a semi-structured, co-design workshop to explore the lived experiences of the participants and translate their frustrations into low-fidelity physical concepts.

3.1 Objectives

The primary objective of this phase was to gather in-depth, qualitative insights into the daily physical, social, and emotional challenges that individuals face while using the standard walking canes. The goal of this phase is to facilitate a collaborative design ideation environment where users could co-design accessory modules for a modular cane system that articulates their preferred design choices by sketching and building low-fidelity prototypes.

3.2 Approaches

3.2.1 Participant Recruitment

Following the inclusive design ideology of "Nothing about us without us," the study targeted to recruit adults (18+) residing in Greater Toronto Area who actively use walking canes. While the initial plan aimed to recruit a total of 10 to 12 participants across the entire study, a smaller cohort of 6 participants were successfully recruited out of which five highly engaged participants joined for the Phase 1 workshop. The other 1 only showed up for Phase 2. Ultimately, this intimate group size proved highly beneficial for the qualitative participatory co-design, allowing the research to reach thematic saturation. Crucially, the eligibility criteria were tiered: explicitly including even participants with weight-bearing restrictions in this seated design workshop phase to ensure diverse spectrum of physical realities are captured during ideation, while encouraging the participation of individual with no such restrictions in the next phase as well.

3.2.2 Design Ideation Workshop Protocol & Facilitation

To prevent the session from feeling like a clinical evaluation, the 120-minute workshop was intentionally structured as a tactile and generative maker-space. The session was broken into four distinct participatory activities, designed to gradually move participants from verbalising their frustrations to building physical solutions:

- **Warm-up & Cross-Sensory Icebreaker (15 mins):** Following a brief project introduction and the formal signing of consent forms, the session transitioned into a tactile space where participants were provided with modelling clay. As they introduced themselves, they were asked to physically shape the clay to their mood. This tactile icebreaker grounded the participants and set the tone for physical making as a valid form of communication.
- **Activity 1: Pain Points & The "Magic Wand" Wishlist (30 mins):** The generative phase began with an open discussion of daily friction points that the participants faced with their canes. Participants identified specific annoyances with their current canes, which were mapped as keywords on a whiteboard. After the identification of pain points, a "Magic Wand" prompt was introduced to the participants: "If you had a magic wand, what would be at least two features or more that you would add to your cane right now?" Participants were encouraged to use their imagination without feeling limited by technology, complexity, practicality, or anything else, proposing everything from basic and practical features like cup-holders to anything that might feel extravagant. These ideas were then written on sticky notes and mapped directly near the corresponding pain points generating an affinity map with *Problem : Solution* mapping.
- **Activity 2: Designing & Prototyping (50 mins):** To introduce modular architecture without requiring engineering expertise, the system was presented using a "Lego" analogy, where blocks could be attached to the top, middle, or bottom within a cane shaft made up of more such modules. Participants used everyday craft materials like pipe cleaners, popsicle sticks, modelling clay, paper, and markers, to build cross-sensory, low-fidelity prototypes of their

"Magic Wand" ideas. However, now introducing a slight understanding of practicality, still not keeping technology as a limiting factor. The facilitation explicitly removed the pressure of viability, instructing participants not to worry about whether their designs were "technologically practical" or aesthetically polished.

- **Show and tell & Wrap-Up (30 mins):** The design ideation workshop concluded with a collaborative presentation round. Each participant was given two to three minutes to explain their prototypes, wherein they shared details about: what it was, where it attached, and how it resolved their specific pain point. The session naturally transitioned into a collaborative peer-critique, providing a space for users to validate shared daily frustrations and solidify the core thematic directions required for the subsequent development phase.

3.3 Results

Following the generative workshops, the raw qualitative data (comprising of participant quotes, daily pain points, and 'Magic Wand' solutions) were systematically analyzed using session transcripts and digitized version of the physical white-board and sticky notes affinity maps. This visual synthesis method was critical for identifying overlapping friction points and translating individual grievances into actionable design themes that would dictate the physical architecture of the ModBility system.

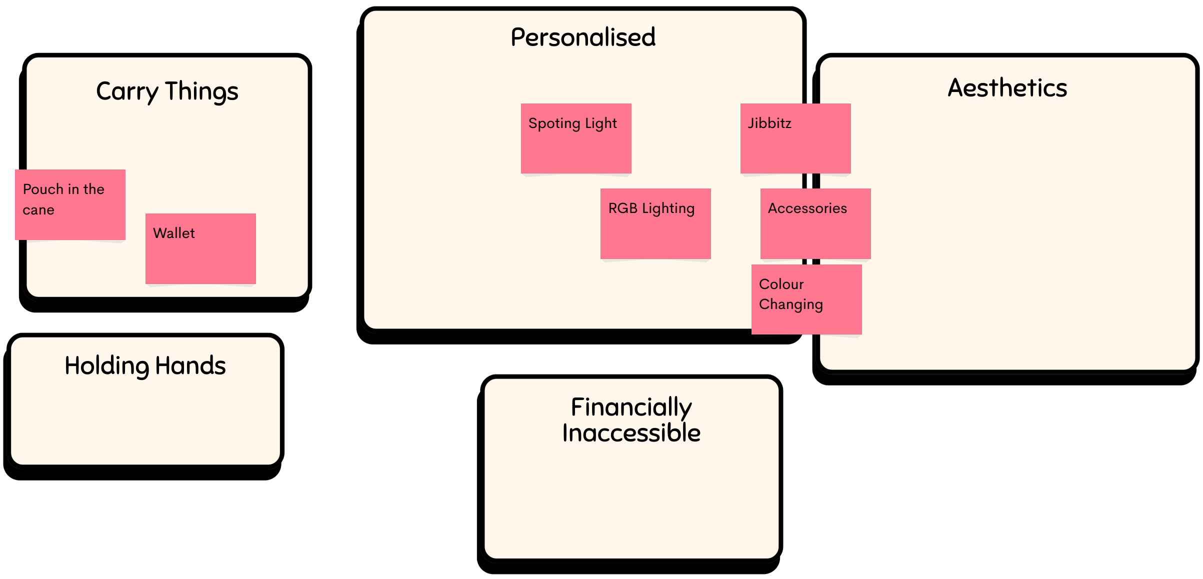


Figure 4: Digitized affinity map from the Group 1 ideation workshop, highlighting themes of personalization, carrying capacity, and financial accessibility.

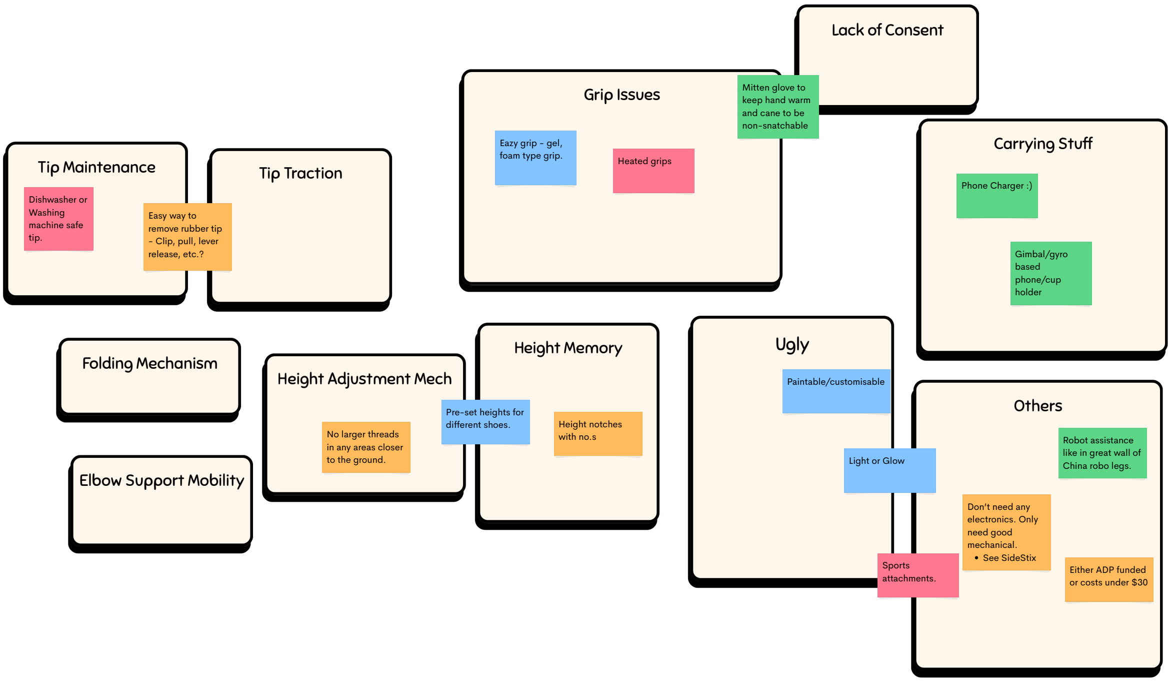


Figure 5: Digitized affinity map from the Group 2 ideation workshop, detailing mechanical frustrations, aesthetic concerns, and diverse user-generated solutions.

The mapping revealed a profound intersection between functional failure and social stigma, demonstrating that the aesthetic presentation of mobility aids directly dictates public interaction, which in turn significantly impacts the users' emotional well-being. This thematic analysis yielded three core themes:

3.3.1 Aesthetic Dismay Resulting in Social Objectification

The most visceral frustrations shared across all the participants was the clinical and sterile nature of the standard mobility aids. In the affinity mapping, both Group 1 and Group 2 explicitly clustered solution ideas like "*Accessories*", "*Paintable/customisable colour*" and "*Light or Glow*" categorised under the "**Ugly**" label. Participant 1A described their standard aluminium cane as: "*it looks very sad*" and too much like "*hospital equipment*," it leads them to zip-tie a decorative garland to the shaft just to make it "*look like something that belongs to me*." Participant 1G echoed this aesthetic dissonance, "*The canes are ugly!*," noting the deep frustration of putting together and wearing "*the cutest outfit*" only to have it ruined by a visually unappealing cane.

The participants linked this sterile aesthetic directly to a loss of social agency and bodily autonomy. Because of the purely medical aesthetic, the public often assumes temporary injury or feels entitled to intrude with questions like "*When do you have to stop using that?*", "*When are you getting free from that thing?*". Group 2 further mapped the "*Lack of Consent*" as a major problem statement, when 1B shared "*Sometimes people on TTC will grab the cane and displace it without your consent*." As 1C powerfully summarised, "*This lack of consent makes disabled people feel like objects*," to which everyone else shared a common frustration, prompting ideas for protective covers with spikes to "*keep strangers away*." To which, 1B further points out "*This is also because all of our equipment is so sterile and so medical looking, people think they are entitled to know why it is there, and move it around for you without your consent*." Participants hypothesized that extensive and colourful customisations would make it personal, as 1C describes how it would signal to the public "*the cane belongs to the person*" rather than a communal medical artifact.

3.3.2 Everyday Functional Frictions

Beyond social reality and aesthetics, the affinity maps and discussions highlighted significant daily mechanical struggles that traditional medical engineering has failed to resolve. 1A from Group 1 heavily emphasised the inability to "*carry things*," mapping the need for a "*Pouch on the cane*" to solve the hazard of balancing items like coffee cups while walking, which they noted is "especially dangerous on icy or slippery surfaces."

Group 2's mapping revealed deep frustrations with hardware maintenance. They clustered issues under "***Tip Maintenance***," requesting an "*Easy way to remove rubber tip*," as replacing worn rubber becomes increasingly difficult over time.

Existing height adjustment mechanisms were also heavily criticised by the participants; the traditional spring-loaded push-buttons frequently pinch fingers, behave unpredictably, and become "*even harder to adjust with sand, snow, etc. getting stuck inside the holes*," (Participant 1G reflects). Participants 1C and 1F further pointed out a lack of visual markers required to remember specific settings for varying shoe heights. To combat environmental friction, Participants 1B and 1F emphasized the need for heated, ergonomic soft grips to maintain hand dexterity during harsh winter weather.

3.3.3 Financial Inaccessibility

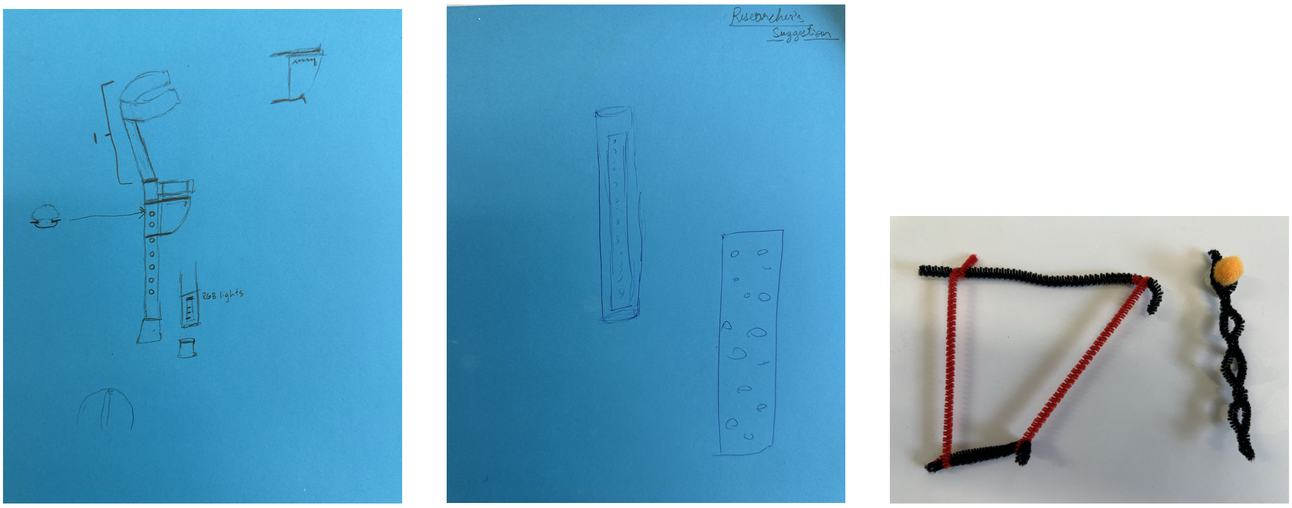
A recurring baseline across both groups was that while personalised aesthetically pleasing alternatives do exist, they are heavily gatekept by cost and import fee. Both groups mapped "*Financially inaccessible*" as a core dependent problem statement, noting that companies offering custom designs are often too expensive and mostly available in select countries. Participants emphasised that the new modular solutions must be affordable to ensure equitable access – ideally through integration with funding programs like ADP (Assistive Device Program) or by maintaining a price point that is manageable for out-of-pocket purchases.

3.4 Proposed Prototypes

Following the discussion of pain points and mapping the proposed ideas on the whiteboard, the participants transitioned into the "Design & Make" activity. The participants translated their affinity-mapped concepts into sketches and cross-sensory, low-fidelity physical prototypes using the provided craft materials, including modeling clay, pipe cleaners, and popsicle sticks. This exercise empowered users to actively dictate the physical architecture of the modular features that they wanted:

3.4.1 Participant 1A

1A developed two distinct modules: a conceptual cane bag module to address the "**Carry Things**" pain point, and a Crocs' "Jibbitz" style charms module to allow for rapid, interchangeable personalisation.



(a) Participant 1A's initial sketch of their proposed modules.

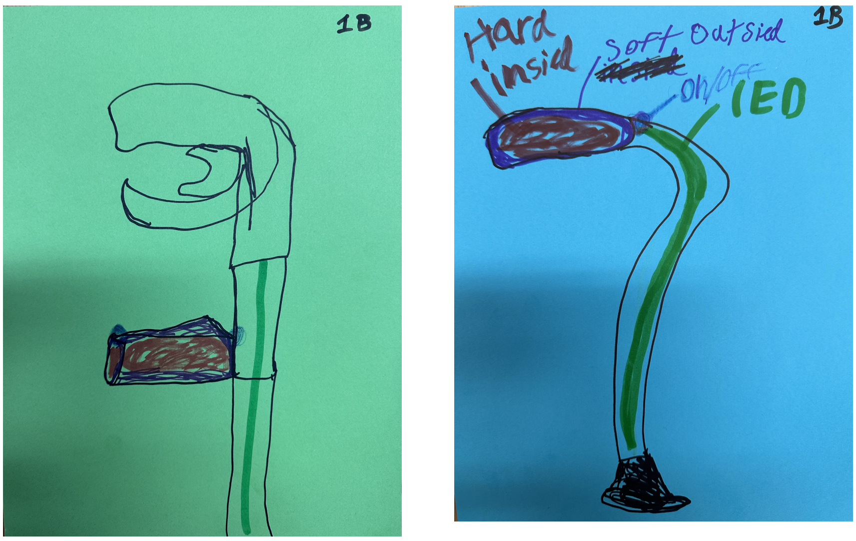
(b) Collaborative sketch refining the attachment mechanisms.

(c) Low-fidelity pipe cleaner prototypes of the concepts.

Figure 6: Participant 1A's low-fidelity physical prototypes translated from the 'Magic Wand' ideation phase.

3.4.2 Participant 1B

1B focused on tactile and visual affordances, prototyping a heated grip with a soft exterior for comfort, alongside an LED light module for both visibility and aesthetic expression.



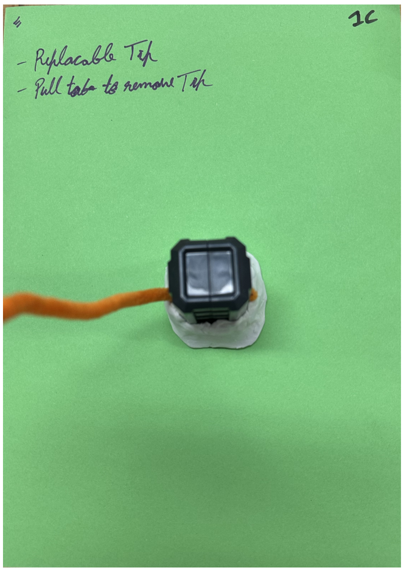
(a) Participant 1B's initial concept sketch

(b) Detailed sketch of the heated grip module with tactile controls

Figure 7: Participant 1B's ideation sketches focusing on ergonomic improvements and the integration of a heated handle module

3.4.3 Participant 1C

1C addressed the mechanical frustration of tip maintenance by designing an easily replaceable cane tip featuring a pull-tab release mechanism, physically modeling how to eliminate the struggle of changing worn rubber.



(a) Participant 1C's low-fidelity prototype alongside their written ideation notes.

(b) Alternative angle showing the structural details of the prototype.

Figure 8: Participant 1C's ideation process, demonstrating the translation from written design requirements into a physical low-fidelity prototype.

3.4.4 Participant 1F

1F penned-down points to tackle environmental and cognitive friction by explicitly mapping out cold-weather pain points to propose both heated hand grip (to maintain dexterity during winters) and a pre-set height adjustment mechanism to solve height memory issues.

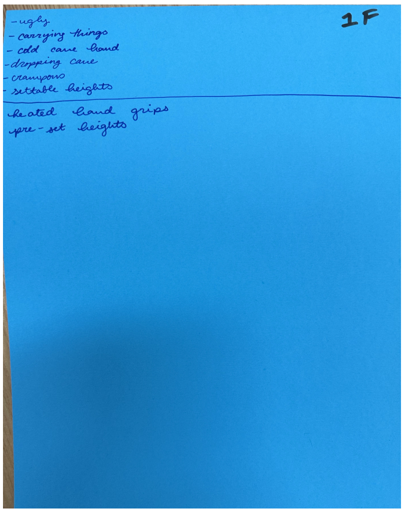
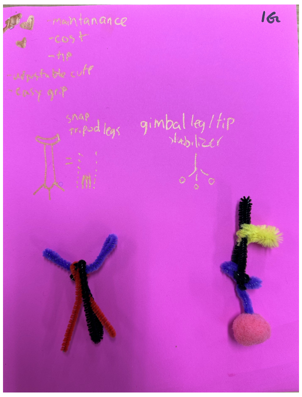


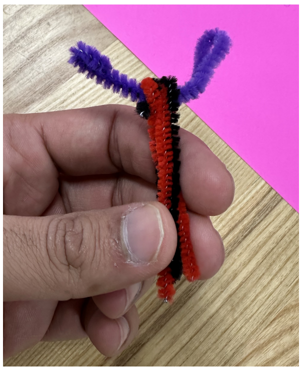
Figure 9: Participant 1F's handwritten documentation of their daily pain points and functional frustrations with standard walking canes.

3.4.5 Participant 1G

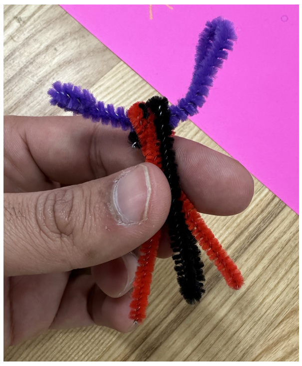
1G prototyped solutions for dynamic balance and stability, utilizing pipe cleaners to model snap-out tripod legs that allow the cane to stand independently when needed, as well as a gyro-stabilised tip to assist with navigation over uneven surfaces.



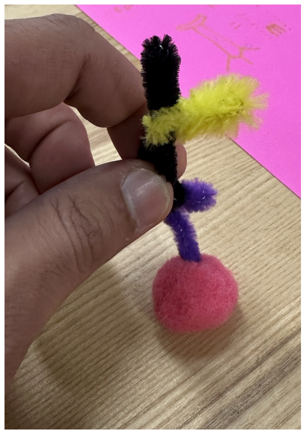
(a) Participant 1G's initial design sketch alongside their corresponding low-fidelity physical prototypes.



(b) Participant 1G's first physical prototype, showing tripod legs closed.



(c) Participant 1G's first prototype, showing tripod legs extended open.



(d) Participant 1G's second prototype, showing gimbal style cane stabliser.

Figure 10: Participant 1G's comprehensive ideation and prototyping process, showcasing the development of multiple modular concepts, from initial sketching to multi-angle physical models.

4 Phase 2: Prototype Development

Transitioning from the generative design ideation of Phase 1 to the physical engineering of Phase 2 required synthesizing the participants' proposed low-fidelity prototype concepts into a functional, manufacturable system and engineer prototype modules that form an exemplary foundation of a unified modular cane system. This aims to prove that inclusive aesthetics and clinical utility could coexist within a single, modular architecture.

4.1 Objectives

The primary objective of this phase was to develop a high-fidelity, working proof-of-concept for the modular cane system. This involved designing a universal attachment mechanism that would allow individual modules to connect seamlessly, creating a baseline structure that was both physically robust and visually distinct from the traditional "non-aesthetic" medical model. A secondary objective was to ensure the resulting modules provided diverse, cross-sensory affordances, catering not just to physical support, but to personal expression and tactile comfort.

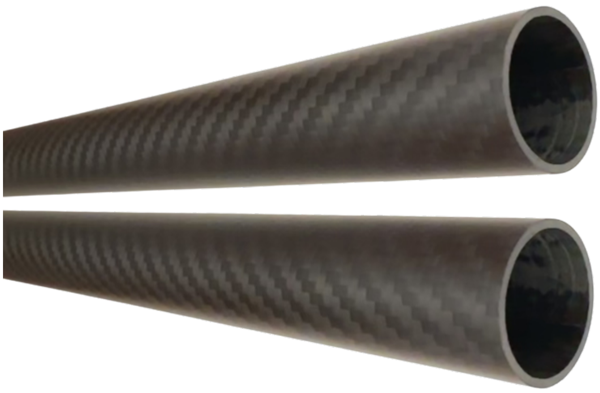
4.2 Approaches

While the design ideation workshop yielded multiple potential features, translating these into physical hardware required a realistic filtering process. Through a collaborative review with the participants, the proposed concepts were evaluated against three strict criteria: technical feasibility, priority of the user's needs & wants, and the time limitations of the current research scope. After deciding the modules, building high-fidelity, load-bearing system required solving two distinct engineering challenges: developing a universal connector architecture to allow infinite modularity, and fabricating the individual smart modules themselves.

4.2.1 Core System Architecture & Connector Design

The foundational requirement of the modular cane system is absolute interchangeability. Theoretically, any module must be able to connect anywhere on the cane – before or after any other module, while maintaining load-bearing strength, continuous power and data transmission. To achieve this, the architecture was categorised into two module types: Active (electronically controlled, requiring power and/or data lines) and Passive (mechanical or analog components).

- **Materiality & Mechanics:** To maintain a lightweight yet robust structure, the main body of each module forming the core shaft of the cane was constructed using two sizes of carbon fiber (CF) tubes (fig: 11a) : 20x22mm and 22x25mm (InnerxOuter Diameter), aligning with average walking cane dimensions. For the physical connections, standard aluminum screw connectors designed specifically for CF tubes were utilised to create a secure male-female threaded joint (fig: 11b), ensuring safety, rigidity, and ease of assembly.

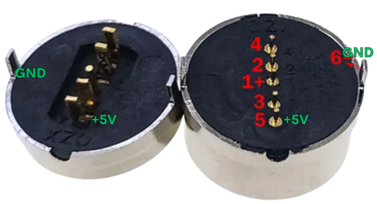


(a) Hollow carbon fiber tubes with woven twill pattern, selected for the primary structural sections.

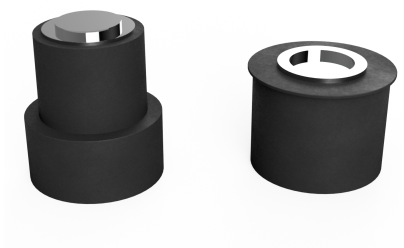
(b) Carbon fiber tubes fitted with threaded aluminum connectors, demonstrating the male and female joining mechanism.

Figure 11: Structural materials and joint mechanisms of the modular system.

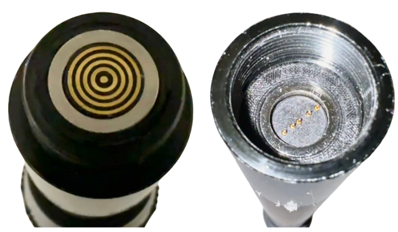
- **Electronic Integration:** To pass power and data seamlessly through the mechanical joints, 6-pin 360° pogo-pin connectors were integrated inside both the male and female aluminum screw connectors. Flexible TPU adapters were 3D printed with a high infill density to hold the pogo pins securely in place while allowing just enough flex for a tight fit.



(a) 6-pin 360° pogo-pin connectors detailing the power, data, and ground pin configurations.



(b) 3D renderings of the flexible TPU adapters used to house the electronic components.



(c) The final assembly showing both male & female pogo pin connectors recessed within the threaded aluminum screw connectors.

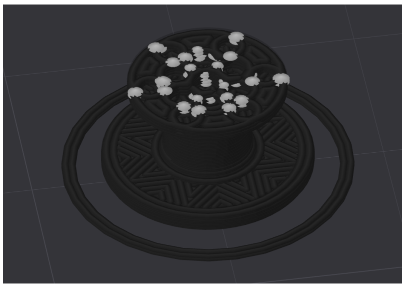
Figure 12: Electronic integration components for the modular joints.

- **Communication Protocol:** Internal wiring utilised flat ribbon bands. While the overarching design intends to use a UART protocol with an additional address select line (occupying 5 of the 6 pins including power and ground) leaving an additional pin for auxiliary use, time constraints for this initial proof-of-concept meant only the primary power lines were actively utilised. The remaining four pins currently act as auxiliary lines, leaving the architecture fully open for future data communication upgrades.

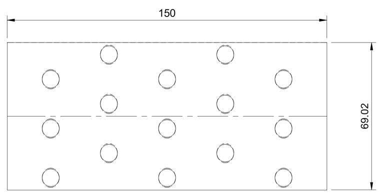
4.2.2 Module Fabrication Process

With the universal bus established, the specific modules were fabricated using a blend of 3D printing, off-the-shelf electronics, and custom mechanical fabrication:

1. **Decorative Charms Module:** Initial testing with off-the-shelf Crocs "Jibbitz" revealed a material inversion problem: Jibbitz connectors use hard plastic because they plug into soft and flexible foam shoes. Because the cane's CF tube is entirely rigid, the connectors needed to be flexible instead. To solve this, an open-source connector design was slightly modified and 3D printed in flexible TPU. The original hard plastic backings of the charms were sliced off, and the new TPU connectors were securely super-glued in their place. Meanwhile, for this passive module a 2D projection of the module was mapped in Fusion 360 to create a wrap-around template, allowing for precise grid drilling into the CF tube.



(a) 3D print slicing of the custom connector insert designed to anchor the charms.

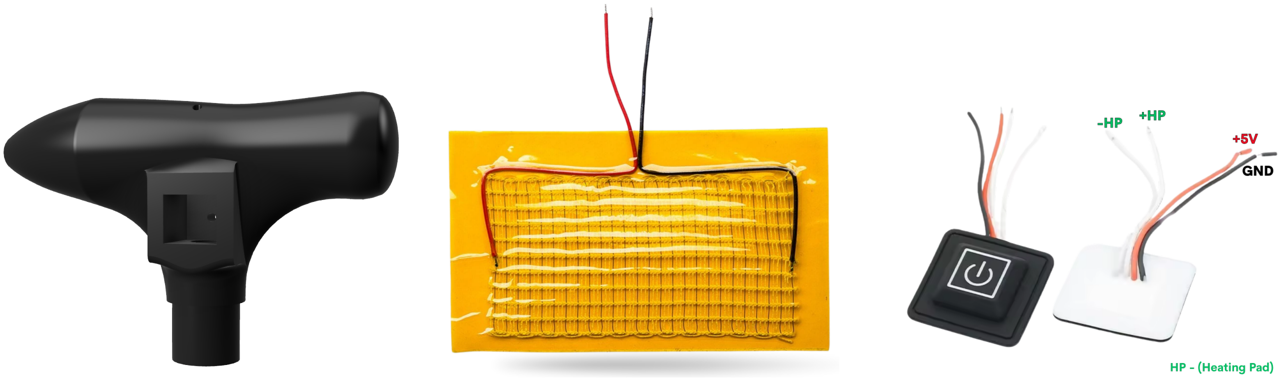


(b) 2D flat-pattern schematic detailing the staggered 8mm hole dimensions (150mm x 69.02mm) mapped to the circumference of the tube.

(c) 3D render of the modified carbon fiber shaft displaying the final machined hole pattern.

Figure 13: Design and fabrication components for the Decorative Charms module.

2. **Heated Grip Module:** This active module utilised an off-the-shelf electric heating pad woven with stainless steel fibers and wrapped in polyamide insulation, which was then connected to a wearable heating jacket controller with 3 level heat adjustment. A custom handle was 3D modeled to house the button controller and cleanly route the wiring for the heating element, which was then encapsulated using a clean wrap of Gaff tape for tactile comfort.



(a) 3D CAD model rendering of the ergonomic cane handle featuring a custom recessed cavity to securely house the thermal controller.

(b) The flexible, low-voltage heating pad designed to wrap around the handle beneath the fabric grip.

(c) The push-button thermal controller detailing the wiring configuration for the 5V power supply and heating pad connections.

Figure 14: Components and integration design for the Heated Grip module.

3. **Battery Bank Module:** To power the active components and provide external battery supply, a single-cell 18500 battery was initially paired with a Battery Management System (BMS) and a boost converter charging module intended to deliver 5 Volts and 1 Ampere to the system. This setup was designed to route power to an external USB hub, effectively allowing the module to serve as a portable power bank built directly into the cane. A custom TPU adapter was 3D printed to securely house the battery inside the CF tube, featuring an integrated hook on one end to allow for easy ingress and egress of the cell. However, during system integration, this module experienced a critical functional failure. The physical capacity of the 18500 battery proved too small, and the selected boost converter failed to supply the actual amperage it claimed. Consequently, while the concept was structurally sound, the module was unable to meet the high current demands of power-hungry components like the Heated Grips and the Light Bar, ultimately necessitating the use of a makeshift external power source for the subsequent user testing phase.

(a) The 18500 lithium-ion battery cell used in the initial proof-of-concept.

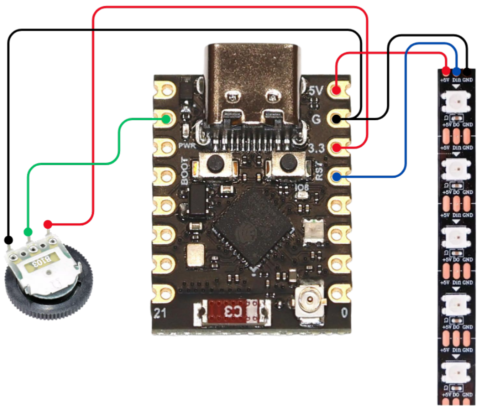
(b) 3D CAD render of the custom TPU battery housing adapter.

Figure 15: Internal components of the initial Battery Bank Module inside the structural shaft.

4. **Telescopic Height Adjustment Module:** This passive module utilised two CF tubes cut to equal lengths, allowing the smaller diameter tube to slide inside the larger one. A CF-specific telescopic twist-lock secured the height. To maintain the system's electronic continuity through a telescoping joint, the internal ribbon wires were designed to fold in an accordion style, passively bypassing the mechanical lock while allowing for vertical expansion.

Figure 16: Twist-lock telescopic adapters used for the cane's continuous height adjustment mechanism.

5. **Light Bar Module:** This active module used a NeoPixel LED strip controlled by an ESP-32 S3 Mini microcontroller, deliberately chosen to allow for future wireless capabilities. A scroll-knob potentiometer was wired to the controller for manual brightness and color adjustments. A long PLA outer sleeve was 3D printed to slide over the CF tube and house the components, with a precise slit cut into the carbon fiber to route the wires between the sleeve and the inner shaft.



(a) Wiring diagram of the Light Bar Module's internal electronics, featuring an ESP32-C3 SuperMini, potentiometer dial, and LED strip.

(b) 3D CAD render of the custom sleeve designed to house the microcontroller, potentiometer and LED strip along the cane's carbon fiber shaft.

Figure 17: Hardware and structural design of the Light Bar Module, illustrating the electronic circuit prototype alongside its corresponding 3D-printed housing sleeve.

6. **Pull-Tab Release Tip:** This passive module aimed to hack an off-the-shelf cane tip. Two steel wires were attached to the CF shaft, looped through the bottom of the rubber tip, and left open on the other end to act as a mechanical pull-tab release. (Note: During rapid prototyping, this specific mechanism proved fragile, with the steel wires breaking under the pressure of the cane. This is an insightful failure that highlights the extreme mechanical stress placed on the lowest points of mobility aids).

4.3 Results

Phase 2 concluded with the development of the modular cane system proof-of-concept. These six modules together build a custom cane that allows interchangeability. Each module was designed to directly solve a specific physical or social challenge identified by participants in Phase 1:

1. **Decorative Charms Module:** To combat social stigma and allow for easy personalisation, this module featured a standardised grid where users can snap in Crocs' "Jibbitz" style decorative charms. This gave users the creative control to quickly change the visual character of their cane to match their clothing, eliminating the need to purchase multiple mobility aids.

Figure 18: The Decorative Charms module, designed to reduce clinical stigma by allowing users to personalize their cane with standard plug-in accessories.

2. **Heated Grips Module:** To address the loss of hand mobility in cold weather, this module features an integrated heating element to keep hands warm, making winter travel much more comfortable and helping to maintain the user's dexterity.

Figure 19: The Heated Grip module, featuring a fabric-wrapped ergonomic handle and an integrated central power button for thermal control.

3. **Battery Bank Module:** This central module was designed to power the system's electronic features and route power to an external USB hub, effectively serving as a portable power bank built directly into the cane. However, during system integration, this module experienced a critical functional failure. The physical capacity of the chosen 18500 battery proved too small, and the boost converter failed to supply the amperage it claimed. Consequently, the module was unable to meet the high energy demands of components like the Heated Grips and the Light Bar, ultimately necessitating the use of a makeshift external power source for the subsequent user testing phase.

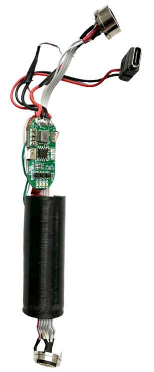


Figure 20: The unsuccessful prototype of the Battery Bank module, highlighting the wiring and exposed circuitry that failed and needed to be disassembled out of the carbon fiber shaft.

4. **Telescopic Height Adjustment Module (Twist-Lock):** Because traditional push-buttons often pinch fingers and get jammed with dirt or snow, this module replaces them with a smooth twist-lock mechanism. This design choice makes adjusting the cane's height much easier, safer, and more precise.

Figure 21: The Height Adjustment module, utilizing a twist-lock telescopic mechanism to accommodate diverse user heights and ergonomic needs.

5. **Colour Changing RGB Light Bar Module:** This module embeds LED lighting directly into the shaft to assist with both environmental safety and self-expression. Users can activate a bright light to navigate dark spaces, or change the color to match their mood or the outfit, transforming the cane into a highly visible, personalised accessory rather than a sterile medical tool.

Figure 22: The Light Bar module, integrating a vertical RGB LED strip to improve user visibility and environmental illumination in low-light conditions.

6. **Pull-Tab Release Removable Tip:** To solve the difficult task of removing worn-out rubber traction, this module introduces a mechanical pull-tab release. This mechanism allows users to easily pop off and replace the base without needing strong hand grip strength or secondary tools.

Figure 23: The Tip module, terminating the cane structure with a durable, flared rubber base for optimal ground traction and stability.

Together, these six modules theoretically create a unified system. Because the modular cane architecture is open and adaptable, it is not limited to just these initial features. Instead, it serves as a foundation where new modules can be continuously designed, attached, and swapped to adapt to user's changing needs based on different socio-cultural or environmental factors.

5 Phase 3: User Testing

With the modular cane proof-of-concept fabricated, the research moved from the workbench back to the users. This phase was critical for validating whether the engineered modules actually resolved the physical and social frictions identified in Phase 1, and whether the universal connector architecture was truly accessible.

5.1 Objectives

The primary objective of Phase 3 was to conduct qualitative and hands-on evaluations of the physical prototypes. However, because an Occupational Therapist (OT) was unable to be present for the sessions, active load-bearing tests were suspended for participant safety. Consequently, the testing objectives strictly focused on evaluating the ergonomics (comfort, weight, balance, and grip), the mechanical usability of the connecting mechanisms, and the emotional/aesthetic resonance of the system.

5.2 Approaches

The testing session utilised a dual-group approach. The initial research design aimed to have a 50/50 split of returning co-designers and fresh users. Due to recruitment time constraints, the final testing cohort consisted of three returning participants from Phase 1 (1A, 1B, and 1G) and one entirely new participant (2A). This specific mix proved highly effective: the returning participants provided continuity, evaluating how well their initial "magic wand" ideas had been translated, while Participant 2A offered fresh perspectives unburdened by previous conceptual fixations.

The user testing was structured around a tactile, four-step protocol:

1. **Show and Tell:** A visual walkthrough of the final six modules, explaining the fabrication results and acknowledging technical failures (such as the battery and pull-tab tip).
2. **Q&A:** An open floor for initial technical queries regarding each module.
3. **Hold, Play, and Feel:** A hands-on evaluation where participants actively tested the weight, connected and disconnected the modules, and engaged with the final cross-sensory module prototypes.
4. **Feedback Sharing:** A collaborative group discussion to synthesize reactions and propose future iterations.

5.3 Results

The user testing session validated the core hypothesis of the ModBility modular cane project: granting users with aesthetic agency and modular flexibility fundamentally shifts their relationship with the assistive device from one of clinical reluctance to enthusiastic play.

5.3.1 The Universal Architecture & Connector Validation

The most celebrated aspect of the prototype was the sheer freedom of its architecture. When Participant 1B asked if modules could only connect in a specific order (e.g., only after the charms module), the revelation that any module could theoretically connect anywhere on the cane was met with unanimous appreciation.

The physical aluminum screw connectors were a mechanical success. Participants were deeply impressed by how smooth and reliable the joints felt. Addressing the critical metric of accessibility, Participant 1B noted, "*I could even connect or disconnect the modules even when I am having dexterity issues*." This ease of use sparked imaginative discussions about scale, with Participant 1G laughingly wondering "*how weird people can make their canes just for fun, how long can they keep adding modules to build a mega-cane*." Furthermore, 1B and 1G discussed how the modular nature means users could eventually accumulate enough parts to build multiple distinct canes with different feature sets.

5.3.2 Aesthetic Agency, Play, and Emotional Durability

The introduction of the Decorative Charms module confirmed that mobility aids can be emotionally durable. Participant 1A enthusiastically declared, "*I want all modules to be Jibbitz!*" The group leaned heavily into the idea of using the cane as an expressive, humorous extension of identity. Participant 1G noted that "*disabled people can have a really funny sense of humour*," and suggested that attaching an ironic Jibbitz that says "I love running" would be a hilarious way to reclaim the narrative around their mobility.

This sense of play extended into the tactile affordances of the device. Participant 1A found the physical act of pressing the button on the Heated Grip highly satisfying, leading Participant 2A to compare the interaction to a "*fidget toy*." Participant 1B subsequently suggested that future iterations should include a dedicated fidget module or fidget Jibbitz.

5.3.3 Ergonomics, Friction, and Rapid Ideation

While the light-weight and well-balanced nature of the modules were highly praised, the tactile testing session also generated immediate, collaborative problem-solving regarding real-world environments:

- **Twist-Lock Dexterity:** While the Twist-Lock Height Adjustment module was appreciated over traditional push-buttons, participants expressed concern that extreme dexterity loss might prevent a user from locking it completely tight. A collaborative solution was ideated: providing a small leverage tool to assist with twisting. Participants 1B, 1G, and 2A expanded on this, noting that this key shouldn't be loose, but should slot directly into a custom storage module or the hollow of the cane to ensure it is never lost.

- **The Failed Tip Mechanism:** Because the mechanical pull-tab release failed during fabrication, an alternative pneumatic "plunger/pump" concept was verbally pitched to the group. The idea of using air pressure to shoot the worn cane tip off the bottom was highly appreciated by the participants, though they noted it would require physical prototyping to fully validate.

- **Lighting and Weatherproofing:** The Light Bar was praised as a major safety upgrade. Participant 1G validated its necessity, explaining their current hack: "*This would be very handy because I currently use my phone and somehow hang it from my shirt with the flashlight on if I am supposed to navigate a dark environment*." When 1G asked about the weatherproofing of the overall system, it was noted that the open holes of the Charms module present a vulnerability. Participant 1B immediately ideated a solution, suggesting the creation of physical "*plugs*" to seal the holes for the unused holes.

5.3.4 Market Desirability and Open-Source Impact

The ultimate validation of the ModBility modular cane system was the cohort's unanimous desire for commercialisation. The group emphatically agreed that they wanted to see the project hit the market so they could physically purchase it. However, the project's commitment to accessibility extends beyond commercial retail; Participant 2A actively celebrated the research's goal to publish the designs as open-source. By making the architecture freely available, users are empowered to bypass the traditional medical market entirely, replicating, improving, and 3D printing their own custom modules to fit their specific bodies and lives (Hurst & Tobias, 2011).

5.3.5 Project Identity: Coining "ModBility"

The participatory nature of this research extended beyond the physical hardware and directly into the overarching identity of the project itself. During the final feedback discussions, as the group celebrated the intersection of modularity and personal agency, Participant 1G spontaneously suggested the name "*ModBility*" – a clever wordplay of 'modular' and 'mobility'.

6 Phase 4: Final Validation & Feedback Collection

The final phase of the participatory framework was designed to close the iterative design loop. It provided an opportunity to transparently share the final technical resolutions with the co-designers, ensuring they had the final word on the ModBility system's proof-of-concept.

6.1 Objectives

Following the technical hiccups experienced during Phase 3, specifically the power failure that prevented the Light Bar from operating, the primary objective of Phase 4 was to present the repaired and resolved system to the participants. This phase aimed to allow users to validate the final physical refinements and offer concluding thoughts outside the time constraints and pressure of a formal lab environment.

6.2 Approaches

To ensure accessibility and minimize participant fatigue, this final validation was conducted asynchronously. An email was distributed to the testing cohort. The communication provided a point-wise summary of the Phase 3 testing findings and detailed the post-testing design refinements.

Crucially, the email included comprehensive visual documentation: close-up photographs of the finalised 6-module architecture, detailed shots of the universal connectors, and a visual simulation of the repaired Light Bar module glowing to demonstrate its intended effect. To remove the friction of filling out formal surveys, participants were simply invited to reply directly to the email with their thoughts on the updates, any final suggestions, or additional sketches.

6.3 Results

The asynchronous feedback collection yielded a formal, written response only from Participant 1G. In their reply, 1G positively validated the final design updates, confirming that the visual and technical refinements aligned with the cohort's initial goals.

Furthermore, 1G utilised the open-ended feedback opportunity with a recorded video to advocate for the continued expansion of the system's architecture. They specifically suggested that for further development, the priority should be a return to their original Phase 1 "magic wand" concept: a cane tip module featuring snap-out, retractable tripod legs to allow the cane to stand independently when needed.

This concluding feedback perfectly encapsulates the intent of the ModBility architecture. By validating the current proof-of-concept while immediately demanding new modular additions, the participant demonstrated that the system successfully shifted the walking cane from a static, finalised medical product into a dynamic, evolving platform.

7 Limitations

While the ModBility project successfully validated the conceptual framework of a highly personalised, modular mobility aid, the research and physical proof-of-concept are bound by several limitations:

- **Absence of Clinical Load-Bearing Testing:** The most significant limitation of Phase 3 was the inability to perform active, dynamic load-bearing tests due to the absence of an Occupational Therapist (OT). Consequently, while the carbon fiber and aluminum screw connectors proved structurally rigid during seated and stationary handling, the system also lacks formal clinical validation regarding its safety under the continuous, high-impact stress of daily walking.
- **Sample Size and Recruitment Constraints:** Due to the time limitations of the research scope, the participant cohort was relatively small (five participants in Phase 1, and four in Phase 3). While this intimate group size allowed for deep qualitative engagement and thematic saturation within the context of participatory design, it does not represent the full spectrum of mobility impairments, cognitive diversity, or anthropometric realities.
- **Technical and Material Failures:** The current proof-of-concept experienced notable hardware limitations. The pull-tab tip mechanism that relied on steel wires, failed under pressure, highlighting the extreme mechanical stress placed on the bottom of a cane. Additionally, the Battery Bank module suffered a critical failure when the 18500 cell and boost converter could not supply the necessary amperage for the Heated Grips and Light Bar.
- **Electronic Integration:** While the physical pogo-pin connectors were successfully implemented, the internal wiring presents a scalability issue. The current ribbon wires possess a relatively high internal resistance. While this voltage drop is negligible when testing two or three modules, it becomes increasingly noticeable and problematic as the architecture scales and more modules are connected in series. Furthermore, the planned UART communication protocol was not fully coded due to time constraints, leaving the four auxiliary pins awaiting programming for true smart-data communication.

8 Future Scope

The ModBility system was fundamentally designed not as a finished product, but as an open-ended platform. The immediate future scope of this research involves resolving the technical limitations of the current hardware, followed by community expansion:

- **Resolving Issues with Current Modules:** The most immediate hardware priority is re-engineering the existing modules to resolve the identified technical failures. The Battery Bank module requires a larger, higher-capacity cell/s and a more robust boost converter to ensure it can independently power the system's high current drawing components. The failed pull-tab tip will be reimagined using the pneumatically driven "plunger/pump" concept proposed during Phase 3, utilizing air pressure to eject worn rubber tips. Finally, the internal ribbon cables across the entire architecture will be upgraded to lower-resistance wiring to eliminate voltage drops across extended, multi-module configurations.
- **Developing Participant-Requested Modules:** Future development will also focus on the specific module requests generated in the final feedback loops. This includes prototyping the proposed retractable tripod-leg tip for independent standing, an ice-pick extension for winter safety, and a dedicated "*fidget*" module for tactile stimulation.

Practical additions, such as weatherproofing plugs for the Charms module and an integrated storage slot for a Twist-Lock leverage tool, will also be designed.

- **UART Data Communication:** To fully realize the "smart" capabilities of the cane, the next iteration will implement the UART communication protocol across the 6-pin bus. This will allow active modules to talk to one another seamlessly across the architecture.
- **Open-Source Publishing & Instructional Planning:** The ultimate goal of this project is to democratize assistive technology. The next step after fixing the functional issues is to prepare a comprehensive, step-by-step instructional plan to be published open-source alongside the complete system architecture. By releasing the CAD files, 3D printing parameters, electronic schematics, and microcontroller code, the project ensures that users are not locked into a closed medical ecosystem. Instead, the community is empowered to bypass traditional gatekeepers to download, hack, and build their own highly personalised "*mega-canes*."

9 Conclusions

For decades, the design of assistive mobility aids has been trapped within a rigid medical paradigm, treating the walking cane as a purely clinical tool meant to keep a patient upright. This research began by examining the aesthetic paradox of assistive devices: while eyeglasses have evolved into celebrated fashion accessories that project identity, walking canes have remained sterile, inducing pity, inviting non-consensual physical touch, and making users feel, in their own words, "*like objects*."

The ModBility Modular Walking Cane System proves that it does not have to be this way. By shifting the design methodology from a top-down engineering approach to a horizontal, participatory co-design framework, this project successfully centered the lived experiences of actual users. The resulting proof-of-concept demonstrates that modular architecture can harmonise clinical utility with deep emotional and social realities.

The integration of cross-sensory affordances, such as the aesthetic agency of the Decorative Charms, the tactile comfort of the Heated Grips, and the environmental visibility of the Light Bar can fundamentally changes the user's relationship with their device. The user testing phase clearly illustrated this shift: participants moved from expressing frustration and aesthetic dismay to expressing joy, humor, and an active desire to play with their hardware.

Addressing the aesthetic presentation of a mobility aid is not an exercise in superficial vanity. As this research demonstrates, giving users the power to customise, adapt, and claim ownership over their assistive tools is a fundamental requirement for dismantling social stigma and abelism. The ModBility system succeeds not just because of its carbon fiber and custom electronics, but because it recognizes the user as a whole person, transforming the walking cane from a symbol of medical limitation into a dynamic, emotionally resonant accessory of human capability.

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