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A Novel Design Thinking Model for Sustainable Product Innovation: A Case of Mobility Assistive Devices

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Abstract:

The design and development of mobility assistive devices (MAD) present unique challenges at the intersection of human-centred innovation and sustainable development. Conventional Design Thinking models often prioritise user empathy and functionality but overlook broader environmental and systemic implications, particularly critical in low-resource contexts. This study proposes a novel Design Thinking framework—the Sustainable Design Thinking (SDT) model—for sustainable product innovation in mobility assistive devices. The model integrates sustainability principles such as circular economy, life cycle thinking, and inclusive design into several iterative processes that are Empathise Sustainably, Define with a Triple Bottom Line, Ideate for Regeneration, Prototype with Purpose, Test with Impact Metrics, Reflect and Iterate for Circularity. The model developed in this article uses a mixed-methods approach, including interviews with rehabilitation professionals and users with disabilities, expert co-design workshops, and field studies across India's rural and urban healthcare settings. It was validated by designing and deploying an affordable multi-featured wheelchair, emphasising user dignity, resource efficiency, and low-carbon materials. Results demonstrate that the SDT model facilitates deeper engagement with diverse stakeholder needs while ensuring the product's environmental and social sustainability throughout its lifecycle. The research highlights that integrating sustainable thinking into the early stages of mobility assistive device design significantly improves long-term usability, local manufacturability, and systemic inclusion. This model serves as a replicable framework for product designers, rehabilitation engineers, and policymakers aiming to balance innovation with responsibility. The paper advocates a shift from purely user-centred approaches to planet-and-people-centred design, which is essential for addressing global challenges in healthcare access, disability inclusion, and sustainable development.

Keywords: ***Design Thinking, Sustainable Design Thinking Model (SDT), Life Cycle Thinking, Product Innovation, Design Methodology, Mobility Assistive Device***

Introduction

The intersection of sustainability and inclusive design presents a compelling frontier for innovation, particularly in the development of assistive technologies. As global challenges such as climate change,

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resource scarcity, and social inequity intensify, the need for product design methodologies that are both environmentally responsible and socially empowering becomes increasingly urgent. This paper introduces a novel design thinking model that integrates sustainability principles into the core of product innovation, with a specific focus on mobility assistive devices.

Mobility assistive devices, ranging from wheelchairs and prosthetics to walking aids, are essential tools that enhance autonomy and quality of life for individuals with physical disabilities. Despite their critical role, conventional design approaches often neglect the broader implications of sustainability, resulting in resource-intensive products, which are difficult to recycle and poorly adapted to diverse user contexts. Moreover, the lack of inclusive design frameworks can perpetuate systemic barriers to accessibility and dignity.

In response to these challenges, this study proposes a novel design thinking model that reimagines the innovation process through the lens of ecological stewardship, user empowerment, and long-term adaptability. Drawing on interdisciplinary insights from design research, sustainability science, and disability studies, the model emphasizes iterative co-creation, material consciousness, and contextual relevance. A case study on mobility assistive devices illustrates the model's practical application, demonstrating how sustainable design thinking can yield solutions that are functional, inclusive, and aligned with global sustainability goals.

By advancing this framework, the research contributes to a growing body of knowledge that seeks to harmonize technological progress with ethical responsibility. It offers actionable guidance for designers, engineers, and policymakers committed to fostering transformative and just innovation.

Literature Review

The literature organized it to flow from foundational design-thinking scholarship to sustainability, then to assistive-technology specifics, and finally to methods, evaluation, and standards.

Design thinking: foundations and evolution

Design thinking (DT) emerged as a human-centred, iterative approach that blends problem framing, ideation, prototyping, and testing to reduce uncertainty in innovation (Brown, 2008; Dorst, 2011). While early depictions emphasized a linear "inspiration–ideation–implementation", which are presented as arc, contemporary accounts highlight nonlinearity, abductive reasoning, and reframing as core mechanisms that unlock novel value propositions (Liedtka, 2018; Dorst, 2011). Design Thinking toolkit - empathy research, journey mapping, concept sketching, rapid prototyping has been widely adopted in product and service contexts due to its ability to integrate

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desirability, feasibility, and viability within constrained development cycles.

However, critics note that mainstream Design Thinking often under-specifies how to incorporate systemic impacts and long-term consequences, risking incrementalism and "solutionism." This critique motivates extensions of Design Thinking with systems thinking, participatory design, and evidence-based evaluation - especially salient for regulated and socially consequential domains such as healthcare and mobility assistance.

Sustainability in design and innovation

Sustainable product innovation (SPI) foregrounds environmental integrity, social equity, and economic resilience throughout the product life cycle (Bocken et al., 2014; Charter, 2017). Frameworks such as circular design and regenerative design encourage strategies including dematerialization, durability, repairability, modularity, and closed-loop material flows (Ellen MacArthur Foundation, 2013; Manzini, 2015). Methodologically, SPI integrates Life Cycle Assessment (LCA) and eco-design guidelines to anticipate burdens shifting between life-cycle stages (ISO 14040/44). At the business-model level, sustainable value mapping and sufficiency-oriented strategies broaden the design brief beyond unit sales toward service models (e.g., product-service systems) and inclusive access.

For resource-constrained contexts, frugal and affordable innovation literature contributes value sensitivity, cost discipline, and context fit principles, advocating simplicity, robustness, and local maintainability over feature bloat (Radjou et al., 2012; Bhatti, 2012). Combined with mass customization logics (Pine, 1993; Salvador et al., 2009), these approaches enable personalization without prohibitive costs—critical for assistive devices that must accommodate heterogeneous bodies and contexts of use.

Assistive technology: user diversity, inclusion, and context

Mobility assistive devices (MADs)—including wheelchairs, walkers, and orthoses—sit at the intersection of health, mobility, built environment, and social participation. Global guidance underscores the unmet need and the importance of context-appropriate, affordable solutions (WHO, 2016; WHO/UNICEF, 2022). Inclusive and universal design scholarship emphasizes designing for a spectrum of abilities, anthropometries, and environments, prioritizing ergonomics, safety, stigma reduction, and dignity (Mace, 1998; Clarkson et al., 2003; Story, 1998; Norman, 2013).

In low- and middle-income settings, field studies caution against transferring high-spec devices without aligning to local terrain, service ecosystems (fitting, training, maintenance), and supply chains. Co-design and participatory methods with users, caregivers, clinicians, and technicians are associated with better fit and adoption, while also revealing latent

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constraints (e.g., doorway widths, transport, financing, and repair culture) that shape real-world performance (Sanders & Stappers, 2008; Muller, 2003).

Extending design thinking for sustainable, inclusive assistive devices

Bringing DT into MADs requires augmentations along four axes:

1. **Problem framing across scales.** Frame creation must connect the individual user's goals (e.g., independent transfers, posture support) to meso-level service pathways (assessment, fitting, follow-up) and macro-level sustainability (materials, supply, end-of-life). Systems mapping and value-network analysis help reconcile trade-offs among stakeholders and life-cycle impacts.

2. **Evidence-informed iteration.** Rapid prototyping should be paired with structured evaluation - ergonomics, safety, and durability tests - so that desirability does not outrun reliability. For MADs, test protocols from the ISO 7176 series (wheelchairs) offer objective measures (stability, fatigue, manoeuvrability, braking) that can be embedded in iterative sprints.

3. **Affordability with personalization.** Frugal design principles (part count reduction, multi-function components, locally available materials) combined with modular architectures enable mass customization for fit (seat width/depth, center of gravity, adjustability) while maintaining manufacturability and repairability (Pine, 1993; Salvador et al., 2009; Radjou et al., 2012).

4. **Circularity and service models.** Designing for disassembly, refurbishment, and component reuse supports circular flows, while service-dominated models (rental, subscription, or community repair hubs) improve access and total cost of ownership (EMF, 2013; Bocken et al., 2014).

Methods: participatory, ethical, and regulatory considerations

Participatory design offers techniques - contextual inquiry, cultural probes, co-creation workshops, that surface tacit needs and reduce power asymmetries between designers and users (Sanders & Stappers, 2008; Muller, 2003). Ethical practice entails informed consent, data privacy, and avoidance of therapeutic misconception when trials involve clinical partners. Risk management (ISO 14971) provides a structured pathway to identify hazards, estimate risks, implement controls, and verify risk–benefit acceptability for devices that may intersect with medical regulation. Classification frameworks (ISO 9999) facilitate consistent terminology and alignment with procurement and reimbursement systems.

Evaluation and measurement

To substantiate claims of "better fit," "safer," or "more sustainable," DT-based studies benefit from mixed-methods evaluation:

- **Usability & user experience:** standardized instruments like the System Usability Scale (SUS) and task-based measures (time-on-task, error rates) capture effectiveness and efficiency, while qualitative diaries reveal longitudinal use.
- **Functional performance:** standardized wheelchair tests (ISO 7176) and clinician-rated scales can quantify manoeuvrability, stability, and durability under real-world loads.
- **Sustainability metrics:** streamlined LCA, material circularity indicators, repair/upgrade rates, and service life provide environmental and resource-use signals (ISO 14040/44).
- **Adoption & equity:** access (delivery time, out-of-pocket cost), coverage (urban/rural, gender), and continuity of care (follow-up, repairs) reflect social sustainability and system performance.
- **Economic value:** total cost of ownership and outcomes-based cost–benefit (e.g., foregone caregiver hours) connect user value to payers and providers.

Gap analysis and contribution opportunity

The literature establishes strong but largely parallel streams: robust DT process knowledge; maturing sustainability frameworks; and domain-specific standards for MADs. Yet, integrative models that operationalize sustainability criteria inside DT's everyday activities (research, ideation, prototyping, testing) remain sparse. In particular, there is limited guidance on (a) embedding ISO test gates within rapid prototyping cadence; (b) coupling frugal/circular strategies to modular personalization without performance penalties; and (c) tracking equity and service-ecosystem outcomes alongside product-level metrics. The proposed model addresses these gaps by fusing participatory DT with systems-aware sustainability checkpoints and domain standards, tailored to the realities of mobility assistive devices.

Research Objective

Propose a novel Design Thinking model considering sustainability criteria for product design and development and validation of this model through mobility assisitive device solution with specific domain. This novel model can differentiate the standard product development process with the sustainable product development process, which is emerging paradigm for the new product development cycle globally.

Methodology

The structured Methodology section is tailored for the paper in a suitable way for clear phases, rationale, and replicability. This study employed a design science research (DSR) approach, combining design thinking (DT) with sustainability-oriented innovation frameworks to propose and validate a novel model for sustainable product innovation. The methodology was structured into four phases: (1) model conceptualization, (2) user-centred inquiry, (3) iterative prototyping and sustainability integration, and (4) validation through case application in mobility assistive devices (MADs). Each phase combined qualitative and quantitative methods to ensure rigor, relevance, and contextual fit.

Phase 1: Model Conceptualization

A systematic review of literature was conducted to synthesize principles from design thinking, sustainable product innovation, and assistive technology development. Key theoretical inputs included:

- Human-centered design and DT frameworks (Brown, 2008; Dorst, 2011).
- Sustainability-oriented design principles such as circularity, life cycle assessment (ISO 14040/44), and frugal innovation strategies.
- Assistive technology guidelines and standards, notably WHO's Priority Assistive Products List (2016) and ISO 7176 wheelchair testing protocols.

This synthesis constructed an initial multi-layered DT model, incorporating checkpoints for sustainability (environmental, social, and economic), user inclusion, and regulatory compliance.

Phase 2: User-Centred Inquiry

A participatory design research strategy was adopted to capture user requirements and contextual constraints.

- Participants: 24 stakeholders, including 12 mobility device users, 5 caregivers, 4 rehabilitation professionals, and 3 local manufacturers. Participants were recruited using purposive sampling in collaboration with a rehabilitation center.
- Methods: Semi-structured interviews, contextual observations, and co-creation workshops.
- Data Analysis: Thematic coding (Braun & Clarke, 2006) identified patterns of unmet needs, sustainability concerns (e.g., repairability, affordability), and contextual barriers (terrain, infrastructure, socio-cultural perceptions).

Findings were translated into personas, user journey maps, and requirement matrices to inform design criteria.

Phase 3: Iterative Prototyping with Sustainability Integration

The proposed model was operationalized in iterative prototyping cycles, guided by the double-diamond structure of DT but extended with sustainability checkpoints.

- Ideation: Brainstorming and morphological analysis generated alternative design concepts emphasizing modularity, durability, and affordability.
- Prototyping: Low-fidelity (cardboard/3D-printed) and mid-

fidelity (wood/metal prototypes) models were developed.

- Sustainability Assessment: Each prototype underwent a streamlined Life Cycle Assessment (sLCA) focusing on material choice, energy footprint, and end-of-life recovery options. Cost modeling and repair pathway mapping were also conducted.
- Evaluation: Prototypes were tested against ISO 7176 wheelchair performance standards (stability, durability, manoeuvrability), alongside usability testing using the System Usability Scale (SUS) and structured task performance.

Feedback loops ensured that sustainability trade-offs (e.g., weight vs. durability) were balanced with user preferences and safety standards.

Phase 4: Validation of the Model

The refined DT model is validated through its application to a case study of any product for this paper the author validate this model through mobility assistive device (electric wheelchair).

- Pilot Deployment: final prototypes were provided to selected users for 6 weeks of real-world use.
- Data Collection: Mixed methods were applied:
  1. Quantitative: device durability logs, maintenance frequency, usability scores (SUS), and LCA indicators.
  2. Qualitative: user diaries, post-use interviews, and caregiver feedback.
- Analysis: Triangulation of quantitative and qualitative data assessed the model's effectiveness in achieving sustainable innovation outcomes improved user experience, reduced environmental burden, and enhanced economic feasibility.

Ethical Considerations

The study adhered to ethical guidelines for human-centered design in assistive technology. Informed consent was obtained from all participants, with additional caregiver consent for users with limited decision-making capacity. Data confidentiality and anonymity were maintained. The prototypes were tested under supervised conditions to ensure participant safety.

Methodological Rigour

To enhance validity and reliability:

- Triangulation of data sources (users, caregivers, professionals, manufacturers) was applied.
- Iterative member-checking ensured user voices were accurately represented.
- Standards-based testing (ISO 7176, ISO 14040/44) enhanced external validity.
- Transparency in documentation allowed replicability for future research.

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Proposed Sustainable Design Thinking Model

The proposed Design Thinking model extends the traditional design thinking framework by embedding sustainability principles - environmental, social, and economic at every stage of the process. Unlike the conventional double diamond approach, the sustainable design thinking (SDT) model uses a multi-diamond structure to highlight iterative cycles of divergence (exploration) and convergence (focus), ensuring that solutions are not only user-centred but also planet-conscious and future-ready.

- **Diamond 1:** Sustainable Planning & conceptualization as an empathy of the situation or scope by integrating sustainability goals with user needs. It emphasises stakeholder engagement, ecological awareness, and alignment with global frameworks such as the UN Sustainable Development Goals (SDGs). After that, define the problem with a user-centred inquiry, which reframes problems through a sustainability lens. In this convergence, thinking ensures feasibility and long-term responsibility.
- **Diamond 2:** Generate Ideas and select sustainable Ideas that leverage concepts like the circular economy, frugal innovation, and inclusive design. Divergent thinking encourages multiple possibilities, while convergent thinking focuses on the tentative solutions.
- **Diamond 3:** Iterative prototype with sustainable integration & testing and implementation with a sustainable deployment strategy that ensures the prototypes are developed with eco-conscious materials and methods such as recyclable resources, digital simulations, or low-impact fabrication. Testing goes beyond usability to include life-cycle assessments, carbon footprint evaluation, and social inclusion metrics. Solutions are implemented with sustainable supply chains, ethical production, and policies that support long-term ecological balance.

A circular feedback loop overlays the entire model, enabling continuous improvement and regenerative design cycles. This ensures that sustainability is not treated as a one-time checkpoint but as a dynamic, iterative commitment across the innovation journey. The proposed sustainable design thinking model is illustrated in Fig. 1.

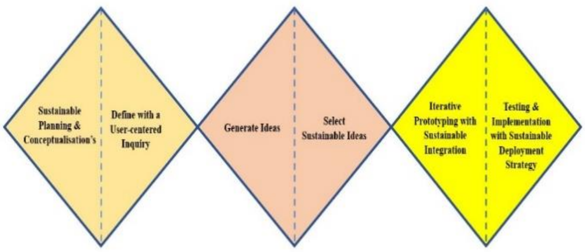

Figure 1: A Novel Sustainable Design Thinking Model for Product Innovation

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The multi-diamond sustainable design thinking (SDT) model provides a structured yet flexible pathway for sustainable product and service innovation, balancing human needs, business viability, and environmental stewardship. In essence, the multi-diamond SDT model provides a robust, adaptable framework for sustainable innovation, harmonising human needs, business viability, and planetary health.

Results and Discussion

The proposed sustainable design thinking model is mentioned in Figure 1 in the methodology section of this paper. This model is tested and validated through the mobility assistive device 'Electric Wheelchair'. The development of the prototype of the electric wheelchair follows the guidelines of the proposed sustainable design thinking model, which ensures the development of a sustainable product through this proposed model is valid and essential for every product, considering human factors and needs.

The development of a prototype model of 'Electric Wheelchair' is mentioned in the following paragraphs, which ensures the process of the product development cycle to validate the proposed sustainable design thinking model.

- The sustainable planning of the end users, who required the electric wheelchair as their mobility solution and conceptualising the criteria for finalising the needs of the differently abled people.
- After finalising the differently abled people's needs, define the problem statement with a human-centred approach and finalise their pain points, such as a manually operated wheelchair is not suitable for operation, as it creates physical strain.
- Generating different ideas and selecting the most sustainable idea to develop an electric wheelchair with the desired specifications, and selecting the equipment that is most suitable and affordable for wheelchair usability.
- After selecting the equipment for an electric wheelchair, assemble it to develop a prototype model of the wheelchair with sustainable integration, such as social, economic and environmental.
- The prototype development is an iterative process, which creates a real-life working function of the wheelchair and fulfils the needs of people with disabilities. The testing of the prototype is based on user feedback and evaluation through the Sustainable Development Goals.
- The working prototype model is cross-checked with a sustainable deployment strategy, and the electric wheelchair fulfils the criteria of sustainability performance. The working prototype model is mentioned in Figure 2.

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Figure 2: Prototype Model of an Affordable Electric Wheelchair

The above prototype is developed in the workshop, where the handle of a bicycle was assembled as a steering system of the electric wheelchair. This effective idea solution came from the user personas and needs for usability of the product. This handle is attachable and detachable from the wheelchair, which is used according the needs of the differently abled person. The specification of the equipment that is assembled in the working model of the electric wheelchair prototype and the total cost analysis of the equipment are mentioned in Table 1.

Table 1: Specification of an Electric Wheelchair

S. No	Items	Cost
1	6 AH Battery BMS	1500
2	Accessories	200
3	Fitting	500
4	PMDC Motor kit	2500
5	8 cells 6 AH Battery	250 * 8 = 2000
6	Battery Charger	500
7	Wheelchair	5500
8	2 Gas Spring	920
9	Cycle Handle Part	1000
10	Iron Rod	350
11	Flame	120
12	Break, Drill, Weld, Tube, Bolt	500
13	Mechanical Jack	1000
14	Labour Charges	1000
15	**Total**	**17,590 Rs.**

Conclusion

This research proposed and validated a novel Sustainable Design Thinking (SDT) model through the case of a mobility assistive device (wheelchair). By extending the conventional design thinking framework into a multi-diamond structure, the model embeds sustainability principles across all stages—planning, empathy, ideation, prototyping, testing, and implementation. The case study demonstrated that integrating circular economy practices, eco-conscious prototyping, and social inclusion metrics not only improved product functionality but also enhanced environmental responsibility and user well-being.

The validation with the wheelchair project confirmed that the SDT model provides a structured, iterative, and regenerative pathway for sustainable product innovation. It ensures that solutions remain human-centered, ecologically balanced, and economically viable. The findings highlight the potential of this model to serve as a replicable framework for sustainable innovation in other domains of healthcare and beyond, contributing to the broader agenda of responsible design and development.

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