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ORIGINAL

AI for All: Bridging Accessibility and Usability Through User-Centered AI Design

IA para Todos: Unir Accesibilidad y Usabilidad a Través del Diseño de IA Centrado en el Usuario

Khalil Omar[1], Izzeddin Matar[2], Jamal Zraqou[2], Hussam Fakhouri[3], Jorge Marx Gómez[4]

[1]University of Petra, Computer Science Department. Amman, Jordan.
[2]University of Petra, Software Engineering Department. Amman, Jordan.
[3]University of Petra, Data Science & Artificial Intelligence Department. Amman, Jordan.
[4]Carl von Ossietzky, University of Oldenburg, Computing Science Department. Oldenburg, Germany.

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Corresponding author: Khalil Omar

ABSTRACT

Artificial Intelligence (AI) technologies are promised to improve digital services and automate tasks. However, there are still significant barriers to ensuring that AI technologies are accessible and usable by a broad range of users. As AI solutions proliferate across mainstream systems and applications, design-based approaches that explicitly bring in inclusive and human-centric values have become critical. This paper provides a concerted look at user-centered design at the intersection of AI, accessibility, and usability, proposing a framework that cuts across technological, social, and regulatory challenges. Contributions include identifying existing work and current literature gaps, key research questions, and a methodology to explore how to optimize AI systems for the widest possible range of users. We anchor our recommendations with a use-inspired case of an AI-driven public transportation assistant for individuals with diverse physical and cognitive abilities to demonstrate how our framework could benefit real-world applications. On the basis of existing standards and theoretical insights, this paper argues that the design process should be proactive, iterative, and implemented with the participation of multiple stakeholders. In their design of AI systems, this is meant to make the systems adaptive to users, rather than users being adaptive to the AI systems, thus revealing that "AI for all" can indeed be a realistic and realizable paradigm.

Keywords: Artificial Intelligence; Accessibility; Usability; User-Centered Design; Inclusive Design.

RESUMEN

Se promete que las tecnologías de IA mejorarán los servicios digitales y automatizarán las tareas. Sin embargo, todavía existen barreras significativas para garantizar que las tecnologías de IA sean accesibles y utilizables por una amplia gama de usuarios. A medida que las soluciones de IA proliferan en los sistemas y aplicaciones convencionales, los enfoques basados en el diseño que incorporan explícitamente valores inclusivos y centrados en el ser humano se han vuelto críticos. Este documento proporciona una mirada concertada al diseño centrado en el usuario en la intersección de la IA, la accesibilidad y la usabilidad, proponiendo un marco que supera los desafíos tecnológicos, sociales y regulatorios. Las contribuciones incluyen la identificación de trabajos existentes y brechas bibliográficas actuales, preguntas clave de investigación y una metodología para explorar cómo optimizar los sistemas de IA para la gama más amplia posible de usuarios. Anclamos nuestras recomendaciones con un caso inspirado en el uso de un asistente de transporte público impulsado por IA para personas con diversas habilidades físicas y cognitivas para demostrar cómo nuestro marco podría beneficiar las aplicaciones del mundo real. Sobre la base de los estándares existentes y las ideas teóricas, este documento argumenta que el proceso de diseño debe ser proactivo, iterativo e implementado con la participación de múltiples partes interesadas. En su diseño de sistemas de IA, esto tiene la intención de hacer que los sistemas se adapten a los usuarios, en lugar de que los usuarios se adapten a los sistemas de IA, revelando así que la "IA para todos" puede ser un paradigma realista y realizable.

Palabras clave: Inteligencia Artificial; Accesibilidad; Usabilidad; Diseño Centrado en el Usuario; Diseño Inclusivo.

INTRODUCTION

Over the past 10 years, rapid advancements in machine learning and AI have completely changed the way users interact with digital services and physical products. From intelligent personal assistants to complex predictive analytics platforms for health, transportation, education, or finance — in all these domains and more — increasingly valuable user-facing applications depend on AI. This more-than-swift technological evolution has brought forth powerful new capabilities in a number of areas, such as natural language processing, computer vision, and automated decisions, that can make user interaction much easier by providing personalized support while promising to engage human-computer interaction (HCI). This, in turn, is also one of the remaining grand challenges: human factors, physical and cognitive impairments, and social intelligent systems in making accessibility and usability features integral components of applied research and development.

Most often, AI is built from data and engineering paradigms that do not naturally consider vastly different physical, cognitive, and social characteristics among users. It could result in systems that are difficult for the vision- or hearing-impaired to navigate, that rely heavily on reading or literacy skills, or that exhibit bias toward majority user groups.[1] Clearly, these drawbacks underscore a more fateful urgency for the principles of accessibility and usability to be embodied in all stages of AI design and deployment. The World Health Organization (WHO) estimates that more than 1 billion people globally live with some form of disability.[2] This underscores the size of the challenge.

Failure to consider the accessibility of AI systems means leaving out such a big part of the world's population and the potential social benefits that can be gained by empowering those very people with AI. Increasingly, there is a view that the usability of AI-driven systems is front and center for their adoption and usage. Unintelligible or badly executed interfaces generate "technophobia in technology", which further prevents users from adopting the solutions to their full capacity.[3] Usability challenges are not just for the category of disabled users; many "able-bodied" people also find themselves dealing with cognitive and emotional obstacles due to sophisticated features of AI.

Therefore, the main issue is the long-standing division between AI technology development and user-centered design principles. Most AI applications are created according to purely technical standards, such as correctness, speed, and efficiency in computing, with little regard for human factors like user autonomy, transparency, and error tolerance. Such systems lack compatibility and do not find general usage for a variety of users because they work well but function well.

In the context of still-emerging regulatory and ethical frameworks for AI, with remarkable initiatives such as the European Commission's guidelines for trustworthy AI that emphasize accessibility, inclusion, and human agency, more attention is being drawn to these factors. However, detailed technical and design best practices remain outstanding challenges for translation. This gap is exemplified by relatively few standardized frameworks that cover accessibility from the inception and prescriptive stages of the design of AI systems, prototyping and testing to scaling up.

This paper sets out to fill some of these knowledge gaps by discussing how AI-based systems can be made accessible and usable through user-centered design. In particular, the paper is intended to achieve the following objectives:

1. Review Related Work: The paper presents a concise survey on the existing accessible and usable AI, plus an indication of shortcomings, challenges, and promising research paths.
2. Asking the Right Research Questions: Define primary directions in which further research needs to progress to promote the course of an inclusive AI approach.
3. Research Methodology: An approach that should be followed systematically to study variant AI system adjustments according to varied user bases.
4. A Model for Accessible and Usable AI: Details on the interaction between user-centered design principles, technical details, and stakeholder participation.
5. Use Case Example: AI in Public Transportation as a practical application that serves to illustrate the feasibility and potential effect of strategies for inclusive design within this framework.

6. Recommendations and Future Work: Practical conclusions for design guidelines and a roadmap toward future research and development activities.

The significance of this study is the ability to trigger a shift in the paradigm whereby accessibility and usability are the building blocks of the process of developing AI, as opposed to after-the-fact or compliance checkboxes. Empowering AI solutions that are both universally accessible and highly usable accelerates digital equity, fosters innovation, and guarantees ethical AI practices. This paper attempts to be a touchstone in terms of best practices captured and articulated into a coherent theoretical framework for furthering the cause of “AI for All” in collaboration among researchers, developers, policymakers, and user advocacy groups. The major goal of this paper, therefore, is to develop AI solutions that will proactively infuse, at every stage of development, features of design accessible and usable, pro from the earliest stage of data collection and model training up to deployment of an interface, to ensure that individuals of different abilities can engage effortlessly and take advantage of the benefits of emerging technologies.

In the next sections, we furnish an in-depth review of theoretical frameworks underpinning accessibility and usability in AI, articulate research questions, expound research methodology, posit our framework, delineate a use case, debate implications, and recap with final remarks and directions for future work.

Theoretical frameworks underpinning accessibility and usability in ai

A strong theoretical basis contributes towards the design of AI systems that are accessible and usable. Several established theories and models, ranging from HCI theories to Universal Design (UD) and cognitive load theories, inform AI system development to meet the broad requirements of different users. In this section, we highlight some of the key theoretical frameworks and show their relevance to the usability and accessibility of AI:

1. HCI Theories
   - Norman’s Theory of Action: According to Donald Norman’s[4] Stages of Action model, users interact with technological systems in a circular process comprising goal formation, execution of intentions, and evaluation of outcomes. In this way, the theory applied to AI interfaces stresses sharply defined and intuitive user goals, transparent system behavior, and immediate feedback. Thus, providing support for each stage—forming an intention, carrying out actions, evaluating system responses—to all different kinds of users is essential to making AI-driven applications accessible and usable.
   - Distributed Cognition: Distributed Cognition holds that cognitive processes reside not in the human mind but spread across objects, people, artifacts, and the environment.[5] In AI settings, this view leads to a distribution of tasks and decisions between the system and the user in such a way that cognitive load is minimized. For example, AI systems might make repetitious work or give contextual hints; hence, they would reduce the mental effort required by users and thereby enhance general usability for people with varying cognitive or physical abilities.

2. Technology Acceptance Model (TAM)
   - The Technology Acceptance Model (TAM) was developed by Davis[6] in 1989 and is one of the most widely used models to explain users’ acceptance of new technologies. TAM asserts that two primarily perceived factors—Perceived Usefulness (PU) and Perceived Ease of Use (PEOU)—are related to an individual’s intention to use a technology. Over the years, several extensions of TAM (like TAM2 and UTAUT) have added more variables, such as social influence, facilitating conditions, and user experience, to predict technology acceptance.[7] Therefore, TAM application to AI systems underscores the following:
     - Perceived Usefulness: The user conceptualizes the automation by the AI system and enhancement of decision-making capabilities, and it seems to use the system to meet its needs.
     - Perceived Ease of Use: AI systems should be perceived to be easy to use, a perception wherein explicit instruction, rock-solid feedback, and minimal complexity contribute to fostering a favorable perception toward usage.

Therefore, considering these aspects will enable AI designers to preempt user concerns and provide useful and usable solutions, increasing system accessibility to a wide range of users.

3. Nielsen’s Usability Heuristics
   - Jakob Nielsen’s 10 Usability Heuristics for User Interface Design represent the most commonly used principles that guide interface evaluation.[8] Though not targeted at AI, these heuristics provide a solid foundation from which to guarantee that AI-driven interfaces will be understandable, efficient, and easy to use. Some of the major ones are:
     - Visibility of system status: Feedback should be timely to inform users regarding what the system is doing—particularly important for “black box” AI algorithms.

- Match between system and the real world: Use familiar language and concepts, reduce cognitive load, and improve accessibility for non-experts.
- User control and freedom: Provide a suitable exit point and undo capabilities, which are crucial with AI-generated suggestions or actions that do not meet expectations.
- Consistency and standards: Should design apply to common practice to reduce confusion, particularly in multi-modal AI systems?
- Error prevention: A proactive design choice could prevent an error (e.g., improper data entry) that would render usability and hurt accessibility.

However, if these heuristics are incorporated into the design process early enough, developers can use pushover before it impedes user adoption and satisfaction. In an AI context, following these heuristics also means offering a transparent rationale for AI outputs to empower users with trust and success in working with the system.

4. Universal Design Principles
   - The UD principles focus on the product and environment used by all people to the greatest possible extent.[9] These principles were originally formulated for physical environments but have been adapted to digital and AI systems as their application holds identical importance across all domains:
     - Equitable Use: All AI UIs should provide an environment that encourages all capabilities without segregation.
     - Flexibility in Use: All AI systems should accept different inputs and outputs and allow personal customization for diverse user needs.
     - Simple and Intuitive Use: Clear directions, low jargon use, and help to reduce user error and increase usability.
     - Perceptible Information: Provide information in many ways to support people with sensory impairments, such as text, audio, and video.
     - Error Tolerance: Safeguards against mistakes in actions by unintended actions, including steps of confirmation or undo actions.
     - Input Mechanism: Complexity Low: Reducer of unneeded complexities in input mechanisms.
     - Size and Space for Approach and Use: Ensure that screen elements and interactive controls are appropriate for all users.

The integration of these principles in AI systems supports inclusive design, aiming to enable effective use of technology by people with a broad range of physical, sensory, and cognitive abilities.

5. Cognitive Load Theory
   - Cognitive Load Theory argues that humans have a limited cognitive capacity, and higher demands on this capacity can degrade learning or task performance.[10] In AI systems—typically rich in features such as recommendation or predictive analytics created through machine learning—management of the cognitive load is essential for usability. High complexity impedes users' chances of forming correct mental models, increasing the likelihood of making errors and becoming frustrated. Consider the following to reduce cognitive load in AI contexts:
     - Segmented Interactions: Break down the steps or wizards of the tasks, thus supporting users who might find the complexities of the tasks when themselves involving complex activities.
     - Progressive Disclosure: Advance features revealed gradually reduce the overload for novice users and provide functionality for power users alike.
     - Adaptive Interfaces: Use AI to personalize the user interface based on users' prior experience, cognitive preferences, or accessibility requirements.

The application of these principles should help ensure that AI systems can remain engaging, efficient, and accessible to users, even as underlying technologies scale up.

6. Synthesis and Application to AI

The application of these theoretical frameworks creates a multi-faceted, accessible, and usable AI system. For example, the TAM relates user perception and intention to use, and Nielsen's Usability Heuristics present operational guidelines. HCI theories would illuminate better ways for users to relate to technology cognitively and behaviorally. It places a critical emphasis on diversity, inclusiveness, and equity in design. Finally, Cognitive Load Theory emphasizes designing for human cognitive limitations in the complex world of Artificial Intelligence. The design team would, therefore, be able to trace and detect vulnerabilities from issues of transparency and trust to complex requirements of accessibility. Thus, they would be able to institute AI-driven systems that would function at a high level of technical sophistication and in accordance with the basic goal of technology, which is to serve and empower all users.

Accessibility involves the use of all products, devices, services, or systems implemented in such a way that they assist or do not impede diverse human abilities. While this term was previously utilized to describe the compliance of standards, such as the Web Content Accessibility Guidelines (WCAG), modern explanations within the context of AI use it to refer to respecting differences and designing for diversity among users, including variations in literacy, language skills, cultural backgrounds, and socio-economic status. AI can provide pervasive access because it can learn from a wide variety of inputs, adapt to new contexts, and go further toward digital inclusion. However, truly accessible AI should involve a deliberately prepared development process that makes an effort to eliminate barriers from the onset.

Regulatory bodies at both national and international levels have made policies such as the World Wide Web Consortium (W3C) and their related accessible technology policies as wide-based as possible.[11] The W3C's Web Accessibility Initiative (WAI) has many guidelines for different forms of disabilities (visual, auditory, or cognitive) in static content over the web.[12] Dynamic AI-powered applications, which learn from changing datasets and user behaviors, were not part of the original scope of the guidelines created for web content. Furthermore, though established techniques such as creating alternative text for images or enabling keyboard navigation are generally well-documented, the new interfaces of AI systems, like chatbots, prediction systems, and gesture-based controls, have become too complex for traditional guidelines.

Usability is typically thought of in terms of efficiency, effectiveness, and satisfaction of the user.[13] In AI-driven systems, usability takes on entirely new characteristics with the factors of algorithmic transparency, trust, adaptability, and interpretability. In plainer language, an AI model could be highly accurate but still not be usable if the users cannot understand or control it. Usability should be treated not as an add-on but as a fundamental part of system design, as Nielsen famously pointed out.[14]

One major tenet of usable AI is the effective collaboration between humans and AI: the system should enhance human intelligence rather than replace or subvert it.[15] For instance, the decision support systems for healthcare need to extract information that the clinician can easily understand, verify, and act upon. The need for interpretability, often known as eXplainable AI (XAI), greatly contributes to the establishment of trust with users.[16] Most current solutions place the developers and data scientists of the model at the center of interpretability, producing explanations that are too technical or not comprehensive enough to be useful to a wide range of user groups.[17]

While accessibility and usability have a set of common design imperatives, they represent distinct but overlapping views regarding user experience evaluation. Accessibility is the removal of barriers of entry for users with different abilities or disabilities, while usability is defined as the degree to which any user can efficiently and effectively accomplish tasks. Prior research has argued that a system may well be accessible but not necessarily easy to use, and vice versa. The dual attainment of these objectives is through intersectional design, considering many user categories and usage contexts.

Several conceptual models have tried to converge accessibility and usability principles for AI within their scopes. However, such guidelines aren't universally affordable at this point, and most AI-based products do not integrate such principles methodically. Key design considerations from the literature that fuses the objectives of accessibility and usability are identified in table 1.

Table 1. Summary of key accessibility and usability design considerations in AI

Design Consideration	Description	References
Multi-modal Interfaces	Support various input/output modes (text, audio, haptics)	(18), (19), (20)
Adaptability	Dynamically adjust interface based on real-time user data	(21), (22)
Interpretability	Provide user-friendly explanations of AI-driven decisions	(23), (24), (25)
Consistency	Maintain consistent UI elements for navigation and feedback	(26), (27), (28)
Personalization	Allow customization according to user preferences or disabilities	(22), (29), (30)
Robust Error Handling	Offer error messages and fallback mechanisms for user mistakes	(31), (32)
Regulatory Compliance	Align with existing accessibility standards and ethical guidelines	(33), (34)

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However, the following is a set of challenges in designing inclusive AI:

1. Bias in Datasets and Algorithms

Algorithmic biases emanate from the fact that training data may not be fully representative of the population when inherent societal biases get built into the AI model. All this added challenge to accessibility is because the bulk of datasets typically do not have enough examples of interactions for people with disabilities or from minority groups, thus leading to suboptimal performance for these segments. Data augmentation, re-sampling methods, or collaborative labeling can be biased mitigation strategies that bring about inclusivity.

2. Technical Complexity and Resource Constraints

Implementing AI solutions may even be computationally expensive, calling for specific hardware and software requirements. Thus, such complexity might shy away small organizations or communities from advancing local or customized AI solutions that address specific accessibility needs. The scarcity of resources also acts as a barrier to iterative user testing and cross-functional collaboration, two things that are essential for continuous improvement in accessibility and usability features.

3. Limited Expertise and Training.

Accessibility and usability experts are often in separate groups that do not mix, and AI is driven by data scientists and engineers who might not have ever received any formal training on human-centric design principles or accessibility best practices. Educational initiatives and interdisciplinary collaboration frameworks are what bridged this gap.

Despite these challenges, it is worth noting that there are several emerging trends and opportunities for designing inclusive AI, such as:

- Assistive AI Applications: AI-fueled assistive technology, which could be an image recognition tool for the blind, speech-to-text software for the hearing impaired, or cognitive aid for memory or attention deficits, is going to witness a fast pace of development in this area. These developments strongly succeed in convincing the world about AI's ability to change and improve independence among disabled users.
- Ethical and Regulatory Momentum: The proliferation of AI-driven services has led to an increased interest from policymakers and advocates, resulting in the creation of emerging principles, norms, and even laws in the areas of fairness, transparency, and accessibility to be written into recommendations—momentum that may help propel inclusive AI design from being a "nice-to-have" feature to becoming what is expected from a legal and ethical system.
- Cross-Platform and Ubiquitous Computing: The fusion of AI with the ubiquitous computing paradigms can usher in a novel domain for accessibility. With ambient intelligence systems, it is possible to proactively predict the needs of the user and make related changes in lighting, size of text, or levels of sound measured by real-time monitoring.[34] However, with this opportunity comes a panoply of concerns related to user privacy, data governance, and system transparency.

Existing research has highlighted the need to integrate access and usability principles into AI systems, but there is a gap in the widely accepted holistic frameworks that bring these objectives together with the user at the center. In addition, existing studies are often too high level in abstract ethical or regulatory principles or too narrow in scope with application-specific usability best practice guidance that isn't easy to generalize. By bringing together and synthesizing existing knowledge in the field, this paper proposes a consolidated framework for "AI for All," mainstreaming accessibility and usability into the design of AI.

Research Questions

This paper builds on the literature and is driven by the following research questions (RQs):

1. RQ1: What user-centered design principles can be considered fundamental in ensuring an AI system is accessible and usable for diversified user groups, including users with disabilities?
2. RQ2: How can these principles be systematically injected into every phase of the AI development lifecycle, from data collection up to the deployment of the model, to ensure the eradication of bias and barriers to usability?
3. RQ3: What specific, measurable indicators of accessible, user-centered AI systems can be conceived, and how can they be properly validated in real-world use?

Here are the research questions that set the scope for the conceptual framework and methodology to be expatiated upon in the subsequent sections, thereby aspiring to inform both academic research and pragmatic, industry-oriented solutions.

METHOD

Research Methods

This section outlines the mixed-methods research methodology to be employed, which blends qualitative and quantitative approaches both to explore and validate the principles of user-centered AI design. As a matter of choice, we do not include large-scale surveys or prototype testing at this stage; instead, we focus on an in-depth review of the literature, expert interviews, and scenario-based evaluation because these can deliver fairly rich insights without necessarily having to retrieve much data on users:

1. Methodological Rationale
   - This is particularly well suited for a multidisciplinary area of study, such as inclusive AI. Each phase allows for different aspects of the research questions to be considered, from the theory (RQ1) to issues of implementation in practice (RQ2) and methods of evaluating outcomes (RQ3).

2. Phase 1: Thematic Literature Review
   - Objective: Identify recurrent themes, best practices, and gaps regarding AI that are accessible and usable.
   - Scope: All journal articles, conference proceedings, and white papers that have been published within the last 10 years.
   - Data Analysis: The literature was coded based on the accessibility features it reported, usability metrics, and user-centered design processes it followed. Any emergent themes were recorded.

3. Phase 2: Expert Interviews
   - Objective: Garner expert perceptions on the feasibility and impediments of user-centered design in AI.
   - Participants: AI developers, accessibility consultants, HCI researchers, and industry practitioners.
   - Procedure: Semi-structured remote interviews, zeroing in on the possibility of including accessibility features in AI, resource constraints, and how design choices interact with mandates on regulation.
   - Analysis: The responses were recorded and qualitatively analyzed. The findings were compared with the review of the existing body of knowledge, enabling us to refine our conceptual framework.

4. Phase 3: Scenario-Based Evaluation
   - Objectives: To determine how an abstract AI system may be made inclusive and usable, considering an actual context to which it would be applied—a public transport aid.
   - Approach: A scenario-based assessment approach was taken, in which experts worked together to visualize possible user interactions, limitations, and conditions of satisfaction.
   - Outcome: The design trade-offs were identified, the components of the framework were validated, and there was reflective feedback on the actual reality of the real world.

5. Phase 4: Synthesis and Framework Validation
   - Objective: Consolidate findings across Phases 1–3 into a coherent model and ascertain its theoretical validity.
   - Activities: Describe patterns found for each theme, propose design recommendations, and develop a validation checklist that will be used to compare and contrast with existing standards and guidelines.
   - Criteria for Validation: The principles advocated to guide the validation process (e.g., WCAG, ISO 9241 usability standards) and advice that can be implemented from the review process.

The research approach facilitates a multi-perspective analysis building from real-world feedback from experts in different fields to arrive at a comprehensive, sturdy framework for AI design that is usable and accessible.

Proposed Framework for Accessible and Usable AI

Incorporating our findings from the literature review conducted, expert interviews held, and scenario-based evaluation that took place, we offer the Accessible and Usable AI Framework (AU-AI). The framework rests on four interlinked pillars—User-Centered Design, Inclusive Data Practices, Adaptive Interaction, and Regulatory and Ethical Alignment—all carefully orchestrated within an Iterative Development Cycle. The conceptual layout of the framework is depicted in figure 1.

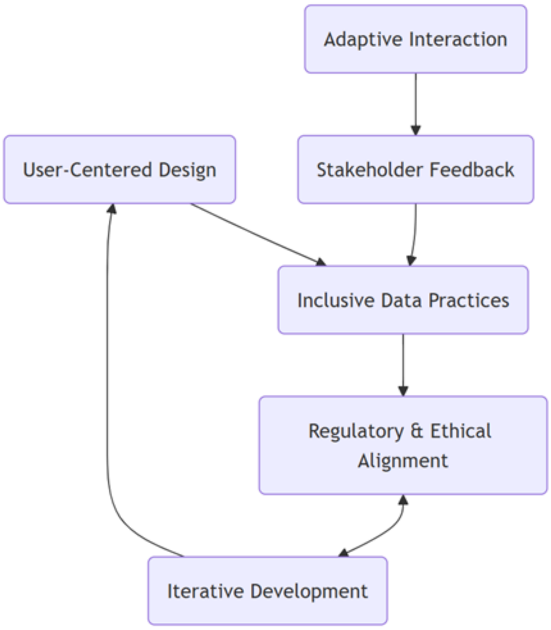

Figure 1. Accessible and Usable AI (AU-AI) Framework

1. Pillar 1: User-Centered Design: This pillar emphasizes that user requirements, preferences, and constraints must be explicitly stated at the outset. It extends the traditional UCD methodologies to highlight inclusive user research activities, persona development, and iterative prototyping. More importantly, it calls for continuous user participation during the entire process of the AI system's development, even in activities like training data selection and model validation. As such, table 2 lays out the specific activities and expected outcomes for this pillar.

Table 2. User-centered design activities and outcomes

Activity	Description	Desired Outcome
Persona Generation	Develop representative user profiles, including those with disabilities	Inclusive design considerations
Task Analysis	Identify critical tasks and user workflows	Clear feature requirements
Low-Fidelity Prototyping	Create wireframes/mockups to test interface concepts	Early detection of design issues
Heuristic Evaluation	Expert reviews focusing on accessibility guidelines	High-level validation
User Testing (Iterative)	Repeated testing with diverse user groups at each development cycle	Continuous refinement

2. Pillar 2: Inclusive Data Practices: Diverse, representative, and ethically sourced data sets are of the utmost importance to guaranteeing that AI systems do not accidentally leave out or distort user groups. This principle deals with approaches to bias mitigation, such as balancing the composition of the training data regarding abilities, socio-economic statuses, and cultural contexts of HCI. It also argues for open data labeling to ensure that those who label data are sufficiently trained in capturing the diversity of user interactions accurately.

3. Pillar 3: Adaptive Interaction: Adaptive interaction leverages AI's capacity for learning and responding to individual contexts, preferences, and abilities. Examples include dynamically resizing text for visually impaired users, providing real-time sign language interpretation, or offering a simplified interface for users with cognitive challenges. Importantly, these features must be transparent and user-controlled to allow users to make opt-in/opt-out choices and avoid any perceived invasion of privacy or autonomy.

4. Pillar 4: Regulatory & Ethical Alignment: This should also form a basic component of the framework, that is, compliance with diverse and ever-evolving AI ethics and accessibility mandates. WCAG 2.1, ISO 9241, and other policies, along with the emerging AI ethics frameworks as proposed in the European Commission Ethics Guidelines for Trustworthy AI steer the practice. This pillar balances the "design for dignity" on a moral imperative, making AI solutions respect user privacy with no paternalistic processing and providing proper safeguarding for vulnerable populations.

5. Iterative Development Cycle: An iterative development cycle that fuses all four pillars is to be followed. Developers, designers, domain experts, and users come together to define requirements, create prototypes, test solutions, and make modifications informed by continuous feedback loops. As a

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result, this cycle ensures that the features for accessibility or usability are never treated as mere post-hoc add-ons.

In addition, the following comparative analysis in table 3 brings out the differences between the AU-AI Framework and other proven frameworks on accessibility and usability, such as WCAG, Universal Design Principles, Nielsen's Usability Heuristics, and ISO 924. The traditional frameworks dealt with static accessibility compliance, general usability principles, and human-centered interaction design; AU-AI encompasses all these elements plus AI-driven adaptability, bias mitigation, and multi-modal interaction in real-time. Unlike WCAG or Nielsen's heuristics, which mainly focus on web accessibility and interface usability respectively, the AU-AI Framework explicitly incorporates ethical AI design, transparency, and iterative development into its processes to continuously improve AI-driven systems. Thus, it is a framework that goes beyond compliance because that would ensure AI systems dynamically adapt to diverse user needs, fostering inclusivity aside from usability in intelligent applications.

Table 3. Comparative analysis of AU-AI framework against other accessibility and usability frameworks in AI

Feature/Aspect	AU-AI Framework	WCAG	UD Principles	Nielsen's Usability Heuristics	ISO 9241 (Ergonomic Requirements for HCI)
Primary Focus	Accessibility and usability of AI-driven systems	Web accessibility for disabled users	Designing for all users, not just those with disabilities	Usability of user interfaces	Human-centered interaction design
Scope	AI systems, inclusive design, data practices, user-centered methodology	Websites and digital content	Any product or environment	User interfaces (software and hardware)	General ergonomics of HCI
User-Centered Design	Explicit focus with iterative feedback loops	Considered, but primarily in testing phase	Embedded in design principles	Strong emphasis on user control and error prevention	Strong focus on user needs and task efficiency
AI Adaptability	Dynamic adaptation to user preferences and abilities	Not explicitly covered	Encourages flexible design, but not AI-driven	No direct mention of AI adaptivity	Mentions adaptability, but not AI-specific
Regulatory Compliance	Integrates AI ethics guidelines (EU, ISO, WCAG)	Defines compliance for web accessibility	No specific legal mandate but influential in policy	Not compliance-oriented	Strong emphasis on regulatory compliance
Bias Mitigation	Focuses on inclusive data sourcing, bias reduction	Not explicitly covered	Acknowledges fairness but does not provide solutions	No direct mention of bias	Limited discussion of bias in system design
Multi-Modal Interaction	Encourages voice, text, gesture, and haptic input options	Mostly text-based recommendations	Supports multimodal accessibility	Primarily text and graphical interaction	Discusses multimodal usability but not AI-driven
Personalization	Allows real-time user-based customization	Limited to static content adjustments	Encourages flexible design but lacks real-time adaptability	Not emphasized	Addresses some aspects but lacks AI-driven adaptation
Explainability & Trust	AI decision transparency and interpretability embedded	No explicit guidance on AI explainability	No direct mention of AI explainability	Supports visibility of system status but not AI-specific	Promotes transparency but not AI-focused
Error Handling	Emphasizes proactive AI-driven error prevention	Provides alternative navigation strategies	Designs should be forgiving but lacks AI-specific details	Highlights importance of error prevention	Includes error tolerance, but general to HCI
Iterative Development Approach	Strong emphasis on continuous improvement with AI-driven user feedback	Lacks iteration beyond compliance checks	Encourages iterative design but not AI-specific	Not explicitly iterative	Includes usability testing but not as iterative as AU-AI

Consequently, the key contributions of the proposed AU-AI Framework be summarized as follows:

1. AI Adaptability: AU-AI allows for adaptivity to happen in real-time depending on the needs of users, making AI systems significantly more inclusive compared to static accessibility standards (WCAG, ISO 9241).
2. Bias Mitigation & Data Practices for Inclusion: The bias of datasets is something that usability and

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accessibility frameworks do not address comprehensively.

3. Explainability & Trust: Unlike Nielsen's heuristics and universal design, AU-AI will explicitly integrate AI transparency principles to make sure that interpretability is present.

4. Multi-modal Interaction & Personalization: User-centered AI interfaces with multi-modal interaction (text, speech, gesture, etc.) are part of AU-AI.

5. Iterative Development & Regulatory Alignment: This framework integrates HCI principles with legal and ethical AI guidelines such as the EU AI Act, ISO 9241, and WCAG.

This comparison underlines the novel contributions of AU-AI; it ensures that the framework does not become just another accessibility framework but a usability model for AI ready for the future, adapting to inclusive digital experiences.

Use Case: AI-Driven Public Transportation Assistant

1. Contextual Overview: To demonstrate the practical application of the AU-AI Framework, we sketch a use case of an AI-driven public transport assistant, purposing help to a wide range of users, including people with physical, cognitive, or sensory impairments. "TransitPal4U" is a notional system that presents up-to-the-minute bus and train schedules, route planning, step-by-step navigation, and on-demand notifications of disruptions or delays. Importantly, we do not provide an implemented system or give results of a formal user study; instead, we show it by way of a scenario.

2. Rationale for the Use Case: Public transportation systems can be very daunting, especially for the differently-abled, in dense urban environments. High frequency of route changes mixed with noise, large crowds, and many ticketing options can compound stress and confusion. It gets even harder for travelers using mobility aids or being visually impaired. An intelligent assistant could offer personalized context-aware support and remove these barriers.

3. Applying the Framework to TransitPal4U

- User-Centered Design: User Research and Persona Generation: We conducted interviews with disability advocacy groups to develop personas:
    - A visually impaired user is dependent on text-to-speech features.
    - A user with a cognitive problem needs simplified step-by-step instructions.
    - An aged person is facing problems related to mobility and demanding information concerning the availability of seats.
    - Low-Fidelity Prototyping: As a first step to realizing complex AI features, basic wireframes are drawn up to propose likely user navigation paths—for example, in providing input relating to the trip. Input is solicited from the pool of users about how best to modify the design to ensure large font size, legibility, and color contrast for easy visibility.

- Inclusive Data Practices
    - Data Sourcing: The route-planning algorithm of TransitPal4U is diversified to include city transit APIs, historical traffic data, and user feedback. The system learns better when diversity in user feedback is ensured (e.g., people with mobility devices) to discover real impediments in the world, like broken elevators or a block of sidewalks.
    - Bias Mitigation: The dataset is under constant surveillance for the presence of any possible bias. An instance of this is the underrepresentation of wheelchair-accessible routes; synthetic data or targeted user submissions may be used to supplement the training dataset.

- Adaptive Interaction
    - Multi-modal Output: In the visual mode, TransitPal4U provides audio alerts for ease of access by the visually impaired, sign language video pop-ups for the hearing impaired, and simplified text options for users with cognitive impairments.
    - Dynamic Content Adjustment: The assistant can monitor the user's stress level (inferred by the settings they choose on the app or wearable data) and switch to "guided mode", in which a lot more simple instructions are offered. As soon as the user is comfortable again, TransitPal4U reverts to expert mode with more condensed information.

- Regulatory and Ethical Alignment
    - Compliance and Privacy: The UI design implemented on TransitPal4U is able to meet the WCAG 2,1 standards in color contrast, navigability, and keyboard interactions.[12] Data privacy is also taken care of since the location data is dealt with in a way that preserves privacy details, and no user data needs to be kept.

- Ethical Assurance: The system's intelligence is transparent; users can view how route recommendations are made. Potential conflicts, such as changing a suggested route due to crowding, are communicated upfront, avoiding any sense of the system overriding personal choices.

- Scenario Walkthrough
  - Initiating the Trip: A visually impaired individual accesses TransitPal4U via voice command. The assistant greets them verbally, mentioning the present local time and whether buses are available.
  - Planning the Route: TransitPal4U requests information on the intended destination, providing a beep or vibration for feedback to confirm. As the individual speaks about their destination, an NLP subsystem decodes the intention and makes a query into bus schedules that include wheelchair accessibility.
  - Navigating the Station: Arriving at the station, the user receives real-time audio prompts to inform them about where the bus stop is, how many people are likely waiting there, and other ways to reach the bus stop if, for example, the elevator is not working.
  - Adaptive Guidance: Should the user manifest signs of disorientation (such as asking repeated questions or spending an extended period in one location), TransitPal4U will switch to a guided mode to give turn-by-turn auditory prompts and confirmations.
  - Arriving at Destination: As the user nears the destination, TransitPal4U will announce the next stop and some landmarks that are upcoming. Post-trip feedback is requested, based on improving system learning, with consent from the user.

- Hypothetical Evaluation Outcomes
  - To measure the efficiency of TransitPal4U within the AU-AI Framework by considering metrics like task success rate (e.g., reaching the desired destination successfully), error rate (e.g., missed bus stops), and user satisfaction. Hypothetical performance indicators are presented in table 4.

Table 4. User-centered design activities and outcomes

Indicator	Metric	Target Value
Task Success Rate	% of users arriving without errors	≥ 90 %
Interaction Efficiency	Average number of steps per task	≤ 5 steps
User Satisfaction	Self-reported score (1–5 scale)	≥ 4,0
Accessibility Compliance	WCAG 2,1 compliance level	AA or above
Trust & Transparency	% of users who understand the system's decisions	≥ 80 %

This scenario shows how each pillar contributes to achieving an AI-driven assistant that is accessible and easy for all users, thereby providing a concrete example of how "AI for All" can take shape in real-life situations.

DISCUSSION

Addressing Research Questions

RQ1: Critical User-Centered Design Principles

The use case of TransitPal4U reconfirms the necessity of early-stage engagement with a variety of user groups, alongside iterative testing and a modular design approach. Principles like having multilingual interfaces, allowing user autonomy, and ensuring interpretability proved very important.

RQ2: Systematic Integration in the AI Lifecycle

Through bakeoffs for inclusive data sourcing and bias mitigation strategies, the developers have an opportunity to harden accessibility within their applications. The iterative development cycle, of course, also acts on feedback to keep improving usability and accuracy. The use case shows how scenario-based design can take effect as a reference for implementation in reality.

RQ3: Measurable Outcomes and Real-World Validation

Tangible benchmarks include performance metrics such as task success rates, user satisfaction, and attainment of accessibility standards. Though full empirical validation calls for extensive user testing, the metrics under hypothesis testing in the scenario of TransitPal4U paint a picture of how the evaluations can be built.

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Theoretical and Practical Implications

The proposed AU-AI Framework provides contributions at the theoretical and practical levels. At a theoretical level, it consolidates several streams of research: accessibility, usability, HCI, AI bias and locates them within the context of a user-centered methodology. At a practical level, it guides those practitioners who would like to develop inclusive AI solutions from data collection to interface deployment.

Limitations

Though the scope is all-encompassing, our methodology draws greatly from expert interviews and literature-based analysis. It does not include large-scale empirical data or evidence from real-world prototype deployment. Even when the TransitPal4U scenario is richly illustrated, it is still hypothetical. Longitudinal studies or pilot programs are required to validate and further improve the research framework in actual deployments.

Opportunities for Future Research

- Longitudinal Field Studies: The Research of Inclusive AI Solution Performance over Extended Periods in Light of Evolving User Needs and Changes in the Environment.
- Cross-Cultural Validation Study: An Adequacy Test of Model Adaptability in Different Regions and Cultures, Especially in Cases Where Accessibility Norms and Infrastructures Differ.
- Integration of Explainable AI: Deepening the Exploration of the Explanability Approaches for End-Users to Assure Al Algorithmic Decisions Integer Transparent and Comprehensible.
- Applicatory Expansion: Testing It in Healthcare Triage Systems or Educational Platforms and Finance Apps Where Accessibility and Usability Are Important Too.

CONCLUSIONS

A user-centered design approach was used as the foundation of the proposed holistic strategy for closing the gap between the accessibility and usability of AI systems. The paper introduces the Accessible and Usable AI Framework that combines User-Centered Design, Inclusive Data Practices, Adaptive Interaction, and Regulatory and Ethical Alignment as four pillars of equal strength and arranged in a circle within an iterative development cycle. It does so through a review of the literature, expert elicitation, and a demonstration involving a use case inspired by the real world (TransitPal4U) to focus attention on how AI can be consciously sculpted for wide application in human ability and preference ranges. Beyond regulation and ethics, designing AI systems for all is a fundamental cornerstone toward sturdy, adaptable, and high-performance systems. Inclusive AI is going to make better user adoption, more user engagement, and more significant societal effects. With the increasing integration of AI technologies into your life, it becomes essential for researchers, developers, and policymakers to adopt an inclusive approach in which every development takes active steps toward fostering access and usability. Through this, we achieve AI not as a luxury for the few but as an enabling force for the many.

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AUTHORSHIP CONTRIBUTION

*Conceptualiza*tion: Jamal Zraqou, Hussam Fakhouri, Khalil Omar, Jorge Marx Gómez.
Data curation: Hussam Fakhouri.
Research: Jamal Zraqou.
Methodology: Jamal Zraqou.
Project management: Izzeddin Matar.
Resources: Izzeddin Matar.
Software: Khalil Omar.
Supervision: Jorge Marx Gómez.
Validation: Hussam Fakhouri.
Display: Jamal Zraqou.
Drafting - original draft: Khalil Omar.
Writing - proofreading and editing: Jamal Zraqou.