The Role of User Experience Design in Advancing Digital Sustainability

Ravi Palwe

Abstract: ***Digital systems, particularly in the Information and Communication Technology (ICT) sector, are responsible for growing energy consumption. This paper examines how user experience (UX) design choices contribute to digital carbon emissions through inefficient data processing, premature hardware obsolescence, and cognitive overload. Drawing from real-world applications and research-backed principles, the study proposes a sustainable UX design framework that prioritizes cognitive efficiency, longevity, and clarity. The findings emphasize that enhancing user-centric experiences can align closely with environmental goals, offering a dual advantage for businesses and the planet.***

Keywords: Sustainable UX design, digital carbon footprint, interface efficiency, user-centered systems, environmental sustainability, Solar Framework

1. Introduction: The Cost of Getting It Wrong

In 2021, I advised an energy provider in the United States that had invested heavily in developing a dashboard to monitor real-time energy usage in households. The dashboard included features like real-time visualizations, social benchmarking, historical data, and trend comparisons. Despite this significant investment, only 12% of their customer base actively engaged with the tool. User testing revealed that the dashboard's computational demands—due to complex data processing, animations, and constant polling—drained user patience and depleted device batteries. The most ironic part? offer the dashboard, intended to help users conserve energy, ended up consuming more energy than it saved.

This situation exemplifies the hidden environmental costs of poorly optimized digital experiences **[1]**. When interfaces and systems are built without accounting for computational efficiency, they become resource-hungry, consuming excessive energy to process, transmit, and display data **[2,3]**. Studies show that the IT sector in the U.S. is one of the largest consumers of electricity, with digital systems and data centers contributing significantly to this consumption **[4,5]**. Focusing solely on user interaction, while overlooking underlying energy costs, these systems are amplifying the problem **[1]**. The frustration users feel with complex, slow-loading interfaces is mirrored in the energy exhaustion of the digital infrastructure that supports them. Each unnecessary page load, excessive feature, or bloated system contributes to a waste of electricity, highlighting the failure to apply systems thinking in design **[3,6]**. In the U.S., where energy costs are rising, and sustainability is increasingly critical, this issue exacerbates the inefficiencies within both the tech industry and the broader environmental landscape **[7]**.This study holds significance as it bridges the gap between digital design and ecological responsibility, highlighting how thoughtful UX strategies can directly reduce environmental impact.

2. The Shift: How We Got Here

We can trace today's digital design complexities by reflecting on their evolution over the past two decades. It started at 2000 with the digital overload being restricted by the magnitude of the designs. We dialed modems and low-res screens creating experiences lagging in efficiency. I remember in 2006 I worked for a big retail bank and we custom designed the system with all images being limited to 15 KB and the HTTP requests being under a dozen for usability, for remote users. Such requirements these days might be called artificial measures, and back then we didn't.

The growth of internet speed and devices saw a rapid growth in design. 2010 to 2020 felt like the golden years, with high speed internet becoming abundant. People would boast about skeuomorphic designs of physical items, and people would mystified by the heavy 4 MB loaded pages. The decade saw every site digitally bursting with growth, and every during those years witnessed hefty pages. New animated stunners were the next obsession. Along with every page, users found discomfort with autoplay videos that streamed endlessly. One felt the presence of tracking scripts found barely at the edges, continuously running in the background, disguised as high quality features.

We are now facing the repercussions of the rapid development in technology that we have enjoyed in the past. It has been shown that the process of constructing a new smartphone is responsible for a significant share of the CO_2 the device will generate over its lifetime (Apple, 2024; Google, 2024; Sánchez, 2024; European Commission, 2023).

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Due to the demand of more powerful smartphones to accommodate the dense software, the ease of replacing the smartphones has resulted in manufactured waste, creating a vicious cycle which is further worsened by the ever-increasing IoT devices. What was once a genuine improvement in the experience of the user has now spiraled out of control with respect to the balance between humanity's sustenance and the well-being of the planet.

3. The Core Challenge: Balancing Frictionless Experience with Environmental Responsibility

As now many companies continue to struggle with the trade off having to cut costs versus sustainable business practices. On one end there are companies that work towards user interaction on large masses and in addition to that help assist in data collection. There are also organizations committed to environmental protection, and those efforts include trying to limit data transfer and computational operations. Don Norman refers to this dilemma as a 'double bind'—a conflict between business goals and sustainability; in conflict with one another, trying to achieve two different goals that seem as they would contradict each other. It is often assumed that by taking away element of functionality and/or aesthetic value there would be less satisfying experience for the user. Results from over 20 years of user testing show that this is in fact not the case: when experiences are friendly in terms of complexity and cognitive demands, that is, simplicity benefits both business stakeholders and user satisfaction. This holds true for performance in the rest of the domain of the environment as well.What minimizes mental burden—organized information, rationalized steps, and limited irrelevant information—lowers energy usage. The Gulf of Execution and Gulf of Evaluation directly parallel energy used. Every second of user confusion, misclick, or redundant navigation adds to computational load.

The greatest of challenges is not technological, but rather, in changing the viewpoint. Engagement should be focused on task completion rather than the time spent on the site and the number of pages viewed. I've seen Fortune 500 companies decline more efficient designs that improved customer satisfaction and conversion rates because they improved "stickiness" metrics. Success should be reframed in outcomes and not the attention consumed which, as in this case, is focused on the user and the planet.

Sustainable Design for Interfaces and Interactions

Sustainable Design for Interfaces and Interactions is New Design's main goal for the 21st Century. From experience and research, I have built the framework to sustainable user interface design. It captures user attention while also addressing the imbalance in the ecology of the planet. The principles are: Efficiency, clarity and coherence of information, and systems that promote user processes and attention over time.

4. The principle

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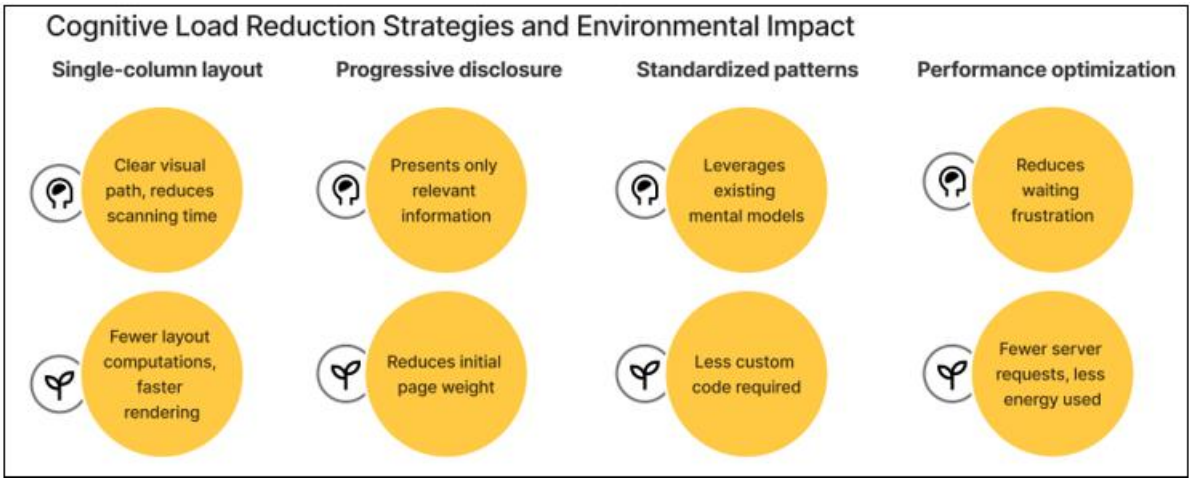
4.1. Principle 1: Efficiency (Cognitive and Computational)

Efficiency is a balance between reduced cognitive load and reduced demands on memory and other internal processes. The mental power used and the energy spent to visualize and operate on an interface is directly proportional.

- Data transfer: Set stringent performance budgets on page weight (try to achieve <1MB) and number of requests. Compress images without losing perceptual quality, lazy-load offscreen content, and remove extraneous tracking pixels.
- User flows: Reduce the steps to accomplish a key task by 40% compared to the industry average. Every click that is taken out helps the user and saves processing power on the servers.
- Information architecture: Construct shallow hierarchies to reduce page loads needed to retrieve content. Users seek to click no more than 3 times to access content, and this also saves requests to the server.

Table: Cognitive Load Reduction Strategies and Environmental Impact

Strategy	Cognitive Benefit	Environmental Benefit
Single-column layout	Clear visual path, reduces scanning time	Fewer layout computations, faster rendering
Progressive disclosure	Presents only relevant information	Reduces initial page weight
Standardized patterns	Leverages existing mental models	Less custom code required
Performance optimization	Reduces waiting frustration	Fewer server requests, less energy used



4.2 Principle 2: Clarity (Through Intelligent Reduction)

Understanding is improved by removing unnecessary items and complexifying what is left. This principle instantly interacts with Norman's concept of signifiers.

- Limit proactive disclosure by default: Keep the displayed information to what is absolutely critical and most relevant, with the option to elaborate. This approach is also within the bounds of cognitive caps and extra unnecessary costs.
- Simplified language: Speak to the public at 6-8 grade reading levels and eliminate all jargon and in-house language. People ought to be able to engage without having to spend extra time and energy battling convoluted sentences.
- Inventive application of visual hierarchy: Purposefully and strategically move eyes and increase focus with space, contrast, and grouping (the Gestalt principals). Minimal effort required. Strong visual hierarchy is required, so the user can get straight to what they want.
- Appropriately set smart defaults: Avoid unnecessary choice, while promoting more eco friendly decisions by setting the most popular or most beneficial to the environment as default selected options.

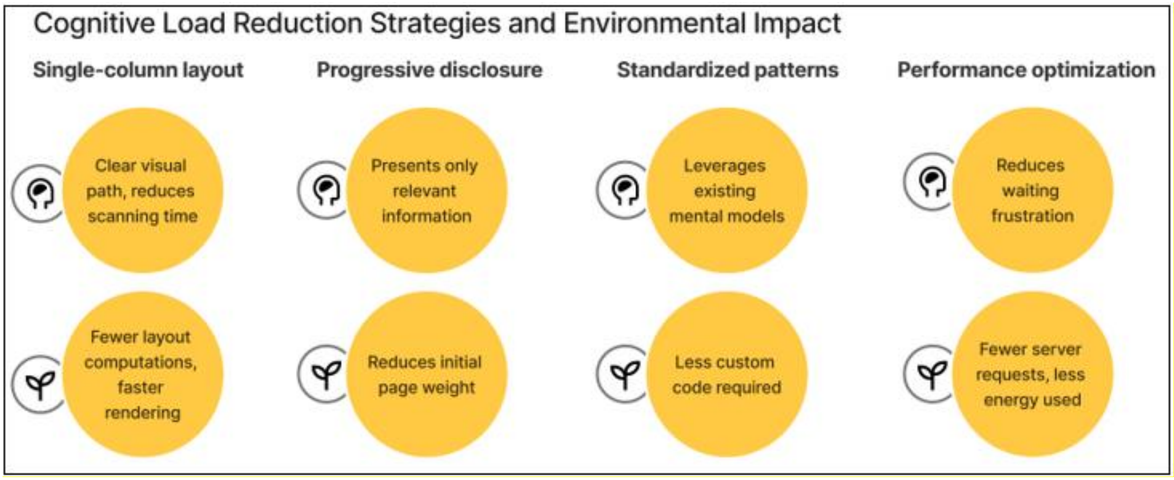
4.3 Principle 3: Longevity (Designing for Durability)

Sustainability design deals with the curious case of interfaces which, after serving their primary function, render one or more digitable disposables obsolete while the equipment itself is mindlessly cast aside. Certain design experiences retain their relevance and utility over time.

- Have clear convictions: Designs should remain functional for years, allow modular updates, and reduce the need for full redesigns.
- Prepare for disassembly: Incremental interface changes which, by design, do not necessitate a redesign of the entire system, contribute to the modular, circular interface ecosystem.
- Accessible old and used devices: Relieves the psychological stress of device saturation and the regrettable, regrettable e-waste.
- Assist self-archiving PLR systems: A service becomes more user centered when it allows easy export of user data and, after failing to "lock-in" the users and permitting easier service cancellation, makes is more user centered.

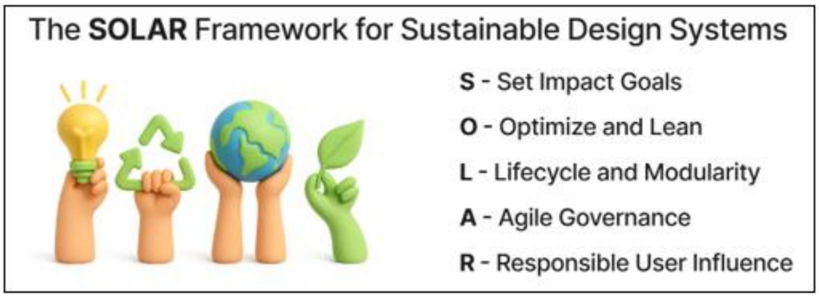
Table: Environmental Impact of Common Digital Elements

Element	Typical Impact	Sustainable Alternative
Unoptimized image	1MB+ transfer, high processing	Compressed WebP (<100KB), SVGs where possible
Autoplay video	Continuous data transfer, high CPU	User-activated video, optimized compression
Complex animations	High GPU utilization, battery drain	Purposeful animations, CSS rather than JS
Third-party trackers	Multiple external requests, data processing	First-party analytics, minimized track



5. The SOLAR Framework for Sustainable Design Systems

Over the course of my two decades working with design systems in various industries—financial services, consumer apps, and enterprise software—I've seen the same challenge arise time and time again: teams want to move quickly and maintain consistency, but without a guiding framework, these ambitions often lead to chaos. Systems grow unnecessarily complex, design patterns become fragmented, and what started as a unified system turns into an unmanageable collection of ad-hoc decisions. The SOLAR Framework emerged from this struggle, crafted from countless retrospectives and discussions where the teams asked, "How can we speed up delivery without accumulating both technical and environmental debt?"



S - Set Impact Goals

A lot of design systems begin with visual or functional goals, but they overlook the crucial step of setting specific impact metrics. In the same way that we can't improve what we don't measure, sustainability can't thrive without clear, measurable goals. For example, setting a target page weight under 500KB or ensuring that most of our design components (at least 80%) are reused rather than created from scratch helps align teams toward tangible outcomes. It's no different from accessibility: having measurable KPIs from the beginning of the process ensures everyone knows the stakes. When designers are considering large animations, they aren't simply weighing the aesthetics—they're also factoring in the environmental cost and performance trade-offs, all of which can be measured and managed from the start. By setting these goals early on, you can prevent the gradual drift toward unsustainable design practices.

O - Optimize and Lean

Some of the most sustainable systems I've worked with were the simplest ones. At one point, we reduced a cumbersome 20-color palette down to just four core colors, which immediately simplified decision-making, improved consistency, and reduced file sizes. Lean design prioritizes essential elements and removes unnecessary complexity. Instead of designing hundreds of variations for every element, use semantic tokens to standardize design choices. Focus on progressive enhancement rather than loading the system with unnecessary polyfills, and favor lightweight assets over heavy, superfluous imagery or animations. This principle of optimization extends to governance as well—simplifying the architecture of your design system helps scale it efficiently and prevents bloated, inefficient libraries. Though it might seem counterintuitive at first, stripping away the excess often leads to faster and more sustainable growth.

L - Lifecycle and Modularity

Every design system component has an expiration date. Without proper versioning, modular design, and deprecation policies in place, systems start to stagnate. I've seen this happen firsthand when teams are reluctant to touch outdated components because there's no clear migration path. A sustainable design system should be treated like a living organism—its components should be swappable, its tokens backward-compatible, and its evolution should be deliberate. This means thinking beyond the current project and considering how each component will be maintained, replaced, or retired in the future. This forward-thinking mindset helps reduce technical debt, avoid wasted effort, and prevent the environmental waste that comes from constantly building new, inefficient solutions.

A - Agile Governance

Design systems can't be treated as side projects or afterthoughts. They need structure and governance to thrive. Agile governance means empowering a diverse group of stakeholders—designers, engineers, product managers, and compliance officers—to oversee the system's growth and health. It also means automation—using continuous integration and delivery (CI/CD) to ensure every update is checked for performance, accessibility, and sustainability standards. This approach makes sure that decisions about energy consumption or technical debt are made early in the process rather than after the fact. Agile governance is the glue that holds a sustainable system together, ensuring it evolves without losing its integrity.

R - Responsible User Influence

One of the most overlooked aspects of sustainable design is how systems influence user behavior. Sustainable systems don't just optimize for kilobytes or server calls—they also promote responsible user interactions. For example, simplifying forms to minimize the number of clicks not only improves the user experience but reduces the number of server requests. Microcopy that guides users through tasks efficiently prevents unnecessary steps and reduces cognitive load. Sustainable design isn't just about making systems faster—it's about fostering mindful engagement. By eliminating manipulative growth tactics that encourage unnecessary interaction, designers can reduce both the environmental impact of digital services and the mental burden on users.

The SOLAR Framework reframes sustainability from being an optional add-on to a fundamental part of a healthy design system. By incorporating measurable impact, lean architecture, lifecycle thinking, agile governance, and user responsibility into every stage of a system's lifecycle, companies can build products that are not only faster and more efficient but also more environmentally responsible. In today's landscape—where energy consumption is a growing concern and the business world increasingly values sustainability—design systems that ignore these considerations are destined to be short-lived. Sustainable systems are more than just good for the planet; they're also better for the long-term health of a business.

6. Case Study: Applying the SOLAR Framework to Revamp a Retail Banking Platform

With over 20 years of experience in the financial services sector, I led a cross-functional transformation of a mid-sized U.S. retail bank's digital platform using the SOLAR Framework for Sustainable Design Systems. Over twelve months, we consolidated a fragmented design system into a streamlined, well-governed structure that reduced customer friction, improved accessibility, and measurably lowered the environmental and operational footprint of the bank's digital channels. This transformation resulted in faster experiences, a simpler user interface, and a durable governance model that continues to scale.

Context and Challenges

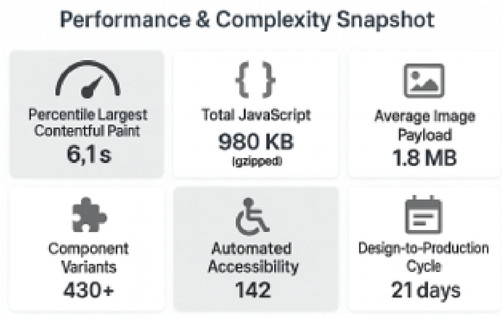
The bank operated a responsive web app along with two native apps for iOS/Android, serving about 4.5 million active monthly users. Over the years, incremental growth had created a "thicket" of inconsistent styles and components across marketing, onboarding, and service-related flows. This led to large file sizes, accessibility inconsistencies, redundant design patterns, and rising maintenance costs. Internally, teams struggled to address environmental impact in a measurable way, as discussions were generally limited to high-level performance metrics.

The regulatory and organizational constraints added complexity:

- **Compliance**: WCAG 2.2 AA, PCI DSS, SOC 2, and privacy regulations (e.g., opt-in tracking, data minimization).
- **Risk**: Change management scrutiny, audit requirements, and disaster recovery policies.
- **Scale**: Multiple teams releasing updates weekly, causing frequent divergence from shared design patterns.

Baseline (Quarter 0)

At the start of the project, the platform's performance metrics were underwhelming:



- **Percentile Largest Contentful Paint (LCP)** on mid-tier 4G: 6.1 seconds
- **Total JavaScript (gzipped)**: 980 KB
- **Average Image Payload**: 1.8 MB
- **Component Variants**: 430+
- **Automated Accessibility Violations**: 142
- **Design-to-Production Cycle**:21 days

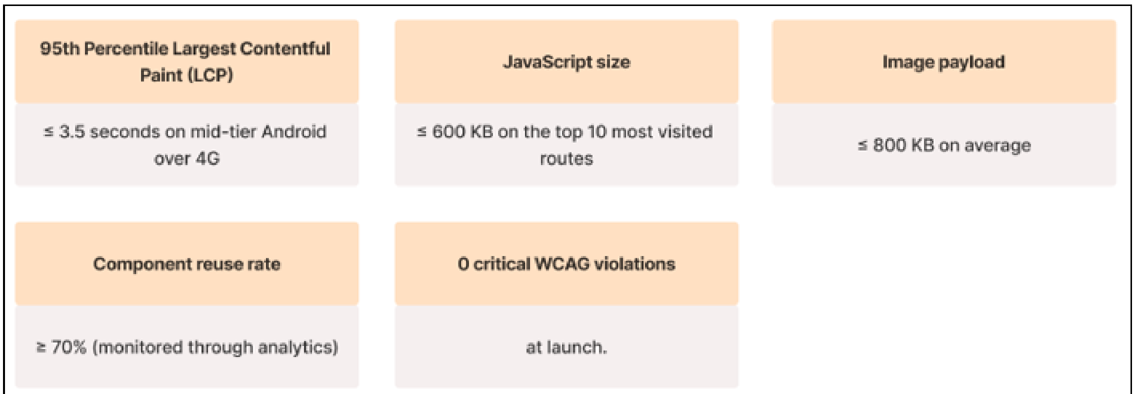
Applying the **SOLAR** Framework

S — Set Impact Goals

We began by drafting a System Charter that outlined clear, testable targets, along with Service Level Objectives (SLOs) for performance, accessibility, and sustainability. Initially, the scope covered the responsive web app and shared mobile views, with plans to extend this approach to the native apps.

Key targets for the first 6 months:

- **95th Percentile LCP** ≤ 3.5 seconds on mid-tier Android over 4G.
- **JavaScript size** ≤ 600 KB on the top 10 most visited routes.
- **Image payload** ≤ 800 KB on average.
- **Component reuse rate** ≥ 70% (monitored through analytics).
- **0 critical WCAG violations** at launch.



We implemented telemetry to track performance, with pull requests requiring performance budget differences and comprehensive automated checks for accessibility and sustainability.

O — Optimize and Lean

Rather than adding more components, we focused on reducing complexity:

- **Token System**: We simplified the design to a core palette of 4 colors and a single type scale, allowing the brand to evolve without unnecessary disruptions.
- **Component Consolidation**: We reduced over 430 component variants to just 92 reusable, tested components.
- **Asset Optimization**: We moved to AVIF/WEBP for images, replaced scattered SVGs with an icon sprite, and removed heavy legacy elements like autoplay media and carousels.
- **Script Optimization**: We removed third-party trackers and A/B testing SDKs, transitioning to server-side flagging and lazy-loaded analytics for non-critical pages.

L — Lifecycle & Modularity

We treated the design system as a product with a clear versioning process:

- **Versioning**: We published tokens, themes, components, and content guidelines as separate packages, ensuring easy updates and compatibility.
- **Deprecation Playbooks**: Each replacement included migration guides and codemods to simplify transitions.
- **Shadow Tokens**: These allowed marketing to refresh the brand look without disrupting the core design system.

A — Agile Governance

We implemented distributed governance to ensure that sustainability was consistently prioritized:

- **Cross-functional Council**: The council included design, engineering, product, accessibility, security, and compliance teams, meeting bi-weekly to review updates.
- **CI/CD Integration**: Performance checks, accessibility validation, and bundle size monitoring were integrated directly into our CI/CD pipeline to catch issues early.
- **Contribution Model**: All updates went through an RFC process in Git, with visual regression tests and performance checks at each stage.

R — Responsible User Influence

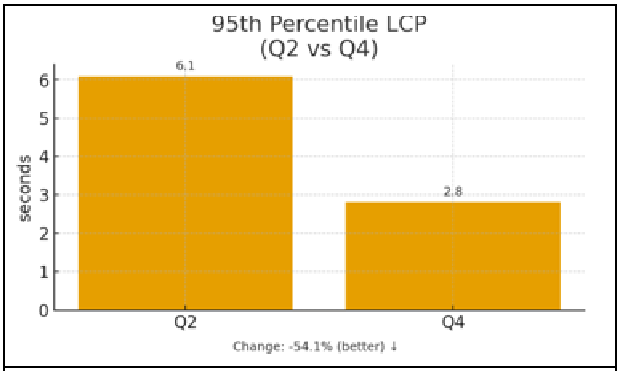
We redesigned user flows to minimize unnecessary interactions and reduce the environmental impact:

- **Payments & Transfers**: We simplified four screens into two, using clearer microcopy and inline validation to reduce errors.
- **e-Statements & Notifications**: We transparently communicated the benefits of opting into fewer emails, encouraging in-app notifications instead.
- **Efficiency Through Accessibility**: By improving focus management and labeling, we reduced the need for users to revisit tasks, lowered cognitive load, and increased completion rates.

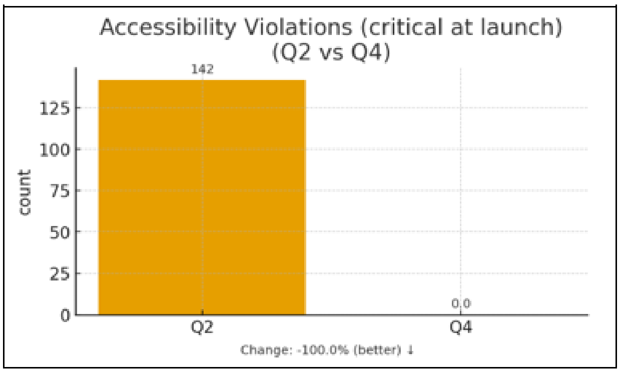
Outcomes (Quarter 2 and Quarter 4)

By Quarter 2 and Quarter 4, the improvements were evident:

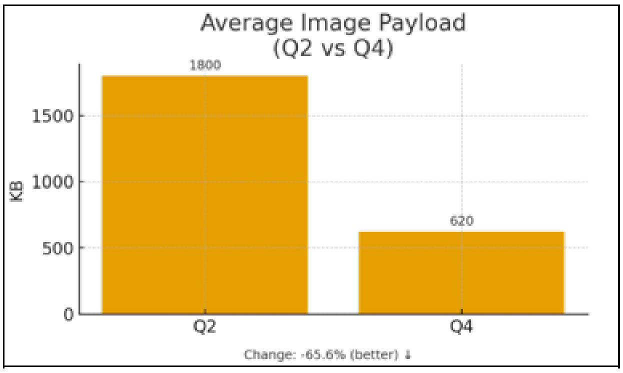
- **95th Percentile LCP**: Improved from 6.1s to 2.8s.



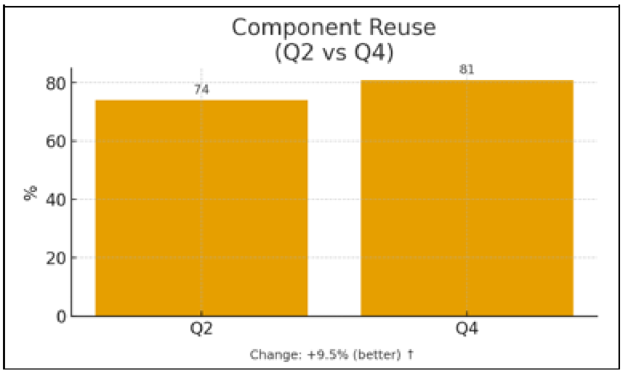
- **Accessibility Violations**: Dropped from 142 to 0 critical violations at launch.



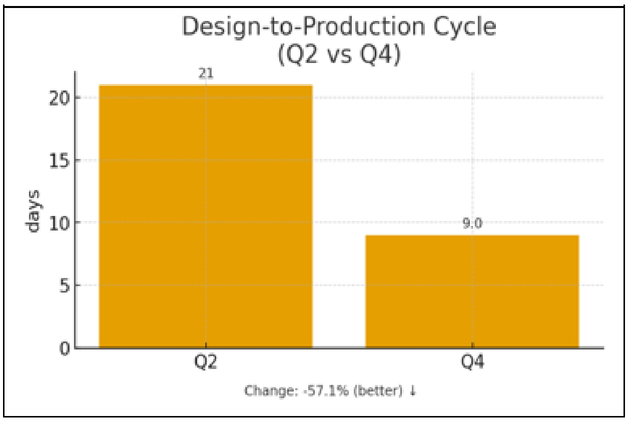
- **Image payload**: Decreased from 1.8 MB to 620 KB.



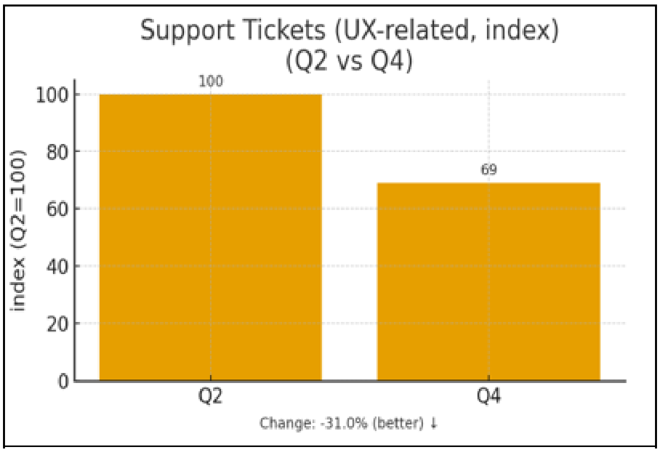
- **Component Reuse**: Increased from 74% to 81%.



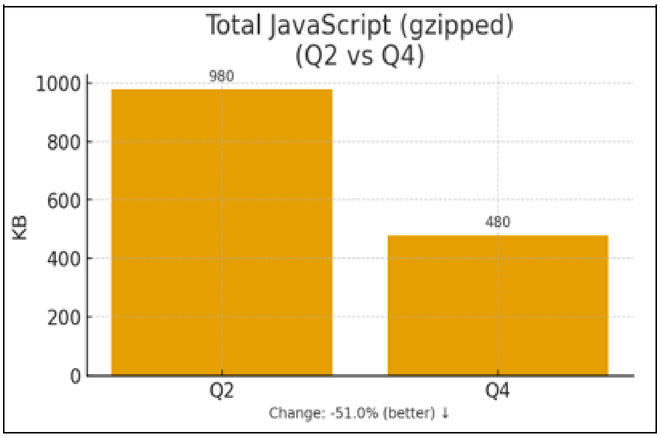
- **Design-to-Production Cycle**: Shortened from 21 days to 9 days.



- **Support Tickets**: UX-related tickets decreased by 31%.



- **JavaScript size**: Reduced from 980 KB to 480 KB.



Environmental Proxy Impact

- **Checking Balance (Web, Auth)**: Reduced data transfer per task by 41%.
- **Paying a Bill (Web)**: Reduced data transfer per task by 37%.
- **Opening a Savings Account (Web + Doc Upload)**: Reduced data transfer per task by 29%.

What Changed on the Ground

- **For Customers**: Pages loaded faster, especially on budget Android devices. Core tasks required fewer steps, and clearer error messages improved accessibility, making the overall experience more user-friendly and consistent.
- **For Teams**: Designers used a more concise token set, and engineers accessed well-documented components. Compliance teams could easily audit releases, speeding up the development process without delays.
- **For the Business**: Infrastructure costs decreased due to lower bandwidth consumption and fewer retries. Support tickets dropped, and the business saw higher customer satisfaction (NPS) in service-related interactions.

Risks, Trade-offs, and How We Managed Them

- **Brand Flexibility vs. Token Discipline**: Marketing required flexibility for seasonal campaigns, but we used shadow tokens to maintain brand expression without disrupting the core system.
- **Third-Party SDK Deletions**: We replaced third-party SDKs with server-side solutions, ensuring compliance with input from product and legal teams.
- **Blocking Gates Anxiety**: We held "budget clinics" early in the process and set grace windows, allowing teams to receive feedback before hitting blockers in development.

Operating Model & Artifacts Delivered

- **Design System Packages**: Tokens, components, and content guidelines were published as independent packages for easy updates.
- **Storybook**: A tool for visual regression snapshots and performance tracking.
- **Contribution Guidelines**: An RFC process for updates, with deprecation playbooks and code mods for easy migration.
- **Release Evidence**: Every deployment came with performance and accessibility reports for compliance auditing.
- **System Charter**: This document set clear performance, accessibility, and sustainability goals for the design system.

Lessons Learned

1) **Subtraction scales better than addition**: Simplifying the token set improved both flexibility and maintainability.
2) **Automate the non-negotiables**: Ensuring performance and accessibility checks were automated in CI/CD was crucial for maintaining standards.
3) **Governance is a product**: A well-organized governance council built trust and kept the system aligned with business goals.
4) **Responsible UX reduces waste**: Streamlined steps and improved microcopy reduced redundant server requests and data usage.
5) **Evidence wins hearts**: Showing side-by-side comparisons of budget changes effectively convinced stakeholders more than theoretical arguments.

7. Conclusion: The Strategic Advantage

For the most part, sustainable design 'is not altruism, it is the bottom line' (M. Smith & A. Sweeney 2022). Principal form and cognitive load reduction, streamlining of tasks and energy work also capture higher support cost reduction and improve customer retention. We live in an era of ballooning energy prices coupled with heightened concern about our planet. In this situation, digital sustainability is a business advantage.

Smart organizations of the future will appreciate that user experience and environmental impact are two sides of the same coin. The principles applied in energy and memory conservation that have been mentioned also align with taking care of the area and the planet. Saving energy is also saving the planet.

In the next ten years, the digital sustainability movement promises to drive the e-waste industry's energy disclosure labels, positive or negative e waste. For the User Experience (UX) folks whose designs utilize the Internet principle of sustainable construction, they'll thrive. Those who provide digital surpluses old-style will suffer redesign costs and financial losses due to loss of reputation.

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