

Reducing Cognitive Load in Micro-School Systems through Frugal Interaction Design

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ABSTRACT

The rapid digitalization of education marginalizes peri-urban micro-schools, forcing them to adopt complex digital administration tools to maintain institutional legitimacy. However, conventional Content Management Systems (CMS) impose excessive extraneous cognitive load on non-technical school stakeholders, leading to persistent digital enclaves. This study aims to reduce this cognitive load by designing and evaluating a serverless school administration portal based on frugal computing principles. Utilizing a Targeted Participatory Action Research (TPAR) approach, the study engaged the complete governance unit (N=4) of an Islamic micro-school. The system architecture leverages Next.js, Supabase, and WhatsApp Deep Linking to operationalize cognitive offloading, routing administrative data directly into stakeholders' habitual messaging environments without reliance on complex APIs. Usability was evaluated using moderated in-situ testing, employing time-on-task as a behavioral proxy for cognitive load. The intervention achieved a 100% complete independent success rate for core monitoring tasks. Furthermore, administrative task completion times for high-complexity workflows averaged 45 seconds, significantly reducing the navigational friction inherent in desktop-oriented platforms. End-to-end encryption ensures data privacy, while the free-tier infrastructure and Insider Action Research methodology guarantee long-term sustainability. These findings validate that frugal interaction design can effectively bridge the digital divide, providing a highly usable and zero-cost administrative model for resource-constrained educational institutions.



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I. INTRODUCTION

The progressive digitalisation of public administration in Indonesia has created a new axis of institutional stratification within the education sector. Under directives from the Ministry of Education, Culture, Research, and Technology, schools are increasingly required to maintain formal web presences bearing government-assigned domain names (sch.id) as a precondition for administrative recognition, funding eligibility, and competitive visibility during annual new student admission cycles [1]. For established urban institutions with dedicated IT departments, this mandate is operationally manageable. For small, privately-governed Islamic schools serving peri-urban communities, institutions that the present study terms "micro-schools", the same

requirement constitutes a profound structural challenge, one theorised here as a Digital Enclave condition: the school is surrounded by a digitising institutional environment to which it must signal belonging, yet lacks the internal technical resources to do so sustainably. KB-TK ISLAM Darul Ulum is precisely such an institution. Located in the sub-district of Jambe in Tangerang Regency, Banten Province, it occupies a liminal spatial position adjacent to the rapidly urbanising Tigaraksa district.

This proximity exposes Darul Ulum to a competitive dynamic in which parents increasingly evaluate schools partly through digital signals of institutional quality, a professional website being among the most salient of these proxies, even as the school's governance structure, managed by a small family foundation (yayasan), lacks the resources or technical

expertise to deploy and sustain conventional digital platforms that meet standard accessibility and usability requirements [2]. The theoretical framework most apposite to this predicament is Institutional Isomorphism [3]. Applied to the present context, the (.sch.id) domain requirement operates as a coercive isomorphic pressure: governmental and social expectations compel the school to acquire digital credentials that signal legitimate membership in the Indonesian educational field. As [4] demonstrate, the emotional and cognitive costs of externally mandated technology adoption are significant, particularly when the adopting population's technical readiness is misaligned with the complexity of required tools.

The governance stakeholders of Darul Ulum represent a user profile common to thousands of privately-managed Islamic micro-schools across Indonesia: educated adults with robust smartphone literacy and high daily WhatsApp usage, but no professional IT background. This structural lack of technical human resource readiness is a persistent barrier to digital transformation across regional and peri-urban Indonesian institutions [5]. Cognitive Load Theory provides the diagnostic framework [6]. When such users engage with conventional Content Management Systems (CMS) such as WordPress or standard cloud-based Learning Management Systems (LMS), they encounter high extraneous cognitive load due to deep navigation architectures, plugin management, and complex dashboard interfaces. This load generates a well-documented adoption failure pattern, as users without adequate digital competency experience elevated friction that suppresses meaningful engagement with the system [7].

The research gap motivating the present study lies at the intersection of three bodies of literature. First, Human-Computer Interaction (HCI) scholarship on technology adoption among non-technical adult users has documented the cognitive mechanisms underlying adoption resistance [8], but rarely in the specific context of school governance in low-resource peri-urban settings. Second, educational technology research examines digital transformation in Indonesian schools [9] and comparable Global South contexts [10], but the granular design challenge of building sustainable digital portals for micro-schools remains understudied. Third, Frugal Innovation scholarship establishes a compelling normative framework for resource-efficient solution design in the Global South [11], [12]. However, while the concept of frugal design is established, concrete operational cases demonstrating how to architect such systems without creating ongoing server maintenance costs or reliance on complex API integrations are critically sparse.

To address this gap, the primary objective of this study is to reduce the cognitive load of non-technical stakeholders by designing, developing, and evaluating a serverless school administration portal based on frugal computing principles. The concept of cognitive offloading, redistributing cognitive demands from working memory onto environmental affordances or habitual interaction channels [13], provides the

central design principle. Rather than expecting non-technical users to learn new administrative workflows, the portal utilizes WhatsApp Deep Linking (URL Schemes) to route key information flows directly into a messaging application already used habitually by all stakeholders [14], [15]. Methodologically, this study operationalises Targeted Participatory Action Research (TPAR) to ensure sustainable, top-down technology adoption from the institutional leadership [16].

The benefits of this research are twofold. Practically, it provides a seamless, zero-maintenance administrative system for KB-TK ISLAM Darul Ulum that functions efficiently within their existing technical constraints. Theoretically, it offers a validated, replicable design model for resource-constrained educational institutions navigating digital transitions across Indonesia and comparable developing contexts, proving that institutional legitimacy can be achieved through targeted frugal interaction design rather than massive resource expenditure.

II. METHOD

KB-TK ISLAM Darul Ulum is a private early childhood and kindergarten education institution established by a family foundation and operated under the governance of four principal stakeholders. Developing technology for early childhood institutions requires specific administrative sensitivities, as stakeholders primarily focus on immediate community engagement rather than complex digital administration [17]. The school is situated in Jambé sub-district, an administrative zone at the eastern boundary of Tangerang Regency. Prior to the intervention documented in this study, Darul Ulum's administrative infrastructure consisted entirely of paper-based enrolment forms and an unstructured WhatsApp group for parent communications. No formal digital presence existed, which systematically excluded the institution from the digital legitimacy markers expected of formally-recognised schools.

A. Research Design This study employed a Targeted Participatory Action Research (TPAR) design, integrating iterative system co-design with embedded usability evaluation. Participatory Action Research (PAR) was selected because it creates conditions for sustainable technology adoption by positioning institutional stakeholders as co-investigators who share ownership of both the problem diagnosis and the solution architecture [16]. Furthermore, the researcher holds an internal position within the foundation, characterising this study as Insider Action Research. This positionality ensures continuous knowledge transfer and guarantees long-term systemic sustainability without reliance on external IT vendors. The "Targeted" qualifier applied in this study signals a deliberate delimitation of the participant scope to the individuals whose adoption was both necessary and sufficient for the portal to function without any external IT support. The TPAR was organised into four sequential but iterative phases: (1) a diagnostic phase to map stakeholders' existing digital workflows and mental models; (2) a co-design

phase; (3) a development and deployment phase; and (4) a usability evaluation phase.

B. Participant Profile our participants (N = 4) were recruited through purposive sampling to represent the complete institutional governance chain. This sample size

represents Total Population Sampling for the institutional governance unit, as these four individuals are the absolute end-users of the administrative dashboard. Detailed profiles are presented in Table 1.

TABLE 1.
PARTICIPANT PROFILES

Participant ID	Institutional Role	Age Category	Self-Reported IT Proficiency	Primary Digital Device
P-01	Foundation Mentor (Senior)	Senior Adult (50+)	Novice	Smartphone
P-02	Foundation Mentor	Adult (40-50)	Intermediate	Windows Desktop
P-03	Foundation Head	Adult (40-50)	Intermediate	Smartphone
P-04	Principal	Adult (30–40)	Intermediate	Smartphone

This sample size aligns with the purposive logic of TPAR and with established principles of qualitative usability evaluation, where five or fewer representative users are sufficient to identify the vast majority of critical interaction bottlenecks [18]. All four participants identified the smartphone as their primary computing device for both personal and professional tasks. None owned or routinely used a desktop computer for school administration, dictating the system's mobile-first design requirements.

C. System Architecture and Design Rationale The portal was engineered using a serverless architecture, selecting Next.js as the full-stack framework deployed on the Vercel continuous integration/continuous deployment (CI/CD) platform [19], [20]. The system is integrated with Supabase (PostgreSQL) as a Backend-as-a-Service (BaaS) to manage relational entities (e.g., Post, Registration, and Admin tables). This architecture eliminates the need for the institution to maintain server infrastructure or pay hosting costs.

The architecturally critical design decision was the PPDB module's notification workflow. Rather than relying on complex and costly API integrations, the system employs WhatsApp Deep Linking (URL Schemes). When a user submits a validated registration form, the system generates a unique registration code in the database and immediately routes a summary of the submitted data directly to the administrators' designated WhatsApp numbers as pre-filled text. This mechanism operationalises cognitive offloading: it redirects the cognitive cost of information monitoring from the working memory burden of checking a secondary platform to the automatic, habitually-executed action of receiving a message in WhatsApp [14], [15]. Role-Based Access Control (RBAC) was implemented within the Next.js frontend, and while Row Level Security (RLS) in Supabase was temporarily configured to facilitate initial testing, strict RLS policies are outlined for full production deployment to ensure data privacy [21].

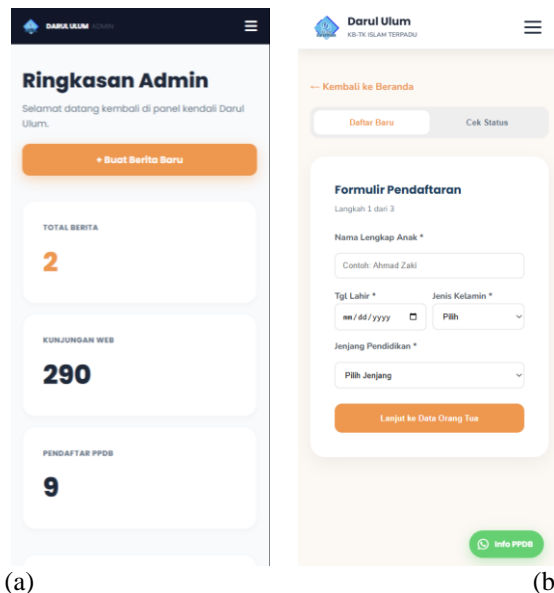


Figure 1. Application of Frugal HCI design principles in the Darul Ulum portal: (a) the minimalist mobile admin dashboard featuring low navigation depth and clear informational scent, (b) the streamlined mobile registration form optimized for touch

D. Usability Evaluation Protocol Following the deployment phase, a moderated in-situ usability testing protocol was conducted. Participants were evaluated individually using their own smartphones in their natural working environment to preserve ecological validity. Completion time (time-on-task) was measured precisely using a stopwatch, calculated from the moment the participant confirmed understanding of the task scenario until successful completion.

To ensure rigorous operational definitions, success modality was coded across three levels: (1) *Complete Independent Success*, defined as the participant's ability to navigate the interface and complete the entire workflow without any verbal instruction or physical scaffolding from the researcher; (2) *Assisted Success*, where the task was completed but required researcher intervention; and (3) *Failure* [18]. The three task scenarios are presented in Table 2.

TABLE 2.
USABILITY EVALUATION TASK SCENARIOS

Task ID	Task Description	Complexity Level	Design Rationale
Task 1	Navigate to the PPDB module and view registered applicant data	Low	Core monitoring workflow; read-only; single navigation path
Task 2	Navigate to the News section and read a published article	Low	Most-used public page; read-only; tests information architecture
Task 3	Log in to admin panel and publish a new news article	High	Requires authentication, form interaction, and content submission

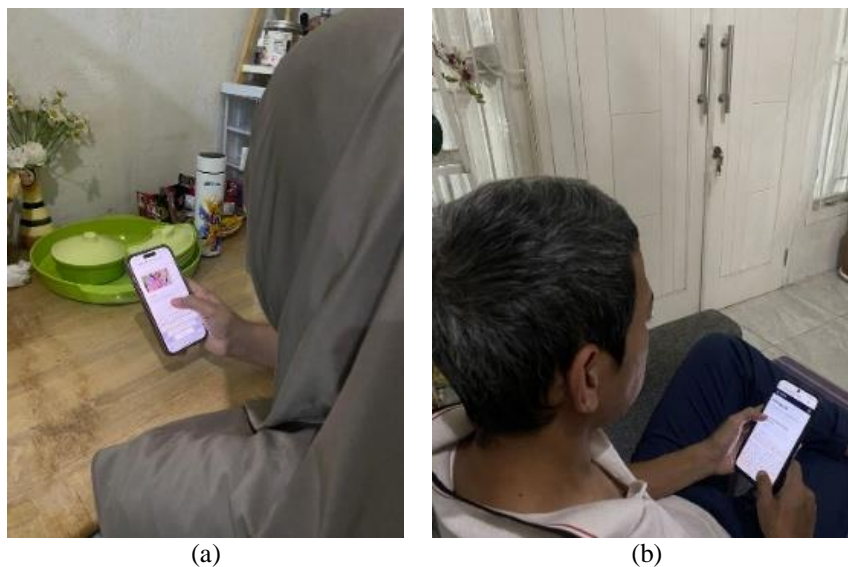


Figure 2. Targeted Participatory Action Research (TPAR) evaluation in action at KB-TK ISLAM Darul Ulum: (a) a female stakeholder interacting with school content, (b) a male foundation stakeholder utilizing the simplified mobile admin dashboard for task scenario 3

E. Data Analysis Quantitative usability data, including task completion times and success modality distributions, were analysed descriptively, consistent with the conventions of small-sample HCI usability evaluation [22]. Qualitative data from post-task participant reflections were analysed using Reflexive Thematic Analysis (RTA) [23]. Themes were generated inductively from participant discourse and subsequently mapped against the study's theoretical lenses.

III. RESULT AND DISCUSSION

The usability evaluation and post-task reflexive thematic analysis produced consistent, interpretable results across all four participants. This section presents the quantitative performance metrics followed by an analytical discussion of the underlying human-computer interaction themes, contextualised against the study's theoretical frameworks.

A. Usability Performance Overview The quantitative usability evaluation measured task completion times and success modality distributions across three administrative

scenarios. The aggregate performance metrics are presented in Table 3

TABLE 3.
USABILITY EVALUATION TASK SCENARIOS

Task	Complexity	Mean Completion Time	Independent Success	Assisted Success	Failure
Task 1	View PPDB Data	Low	~10 seconds	4/4 (100%)	0/4 (0%)
Task 2	View News Article	Low	~15 seconds	4/4 (100%)	0/4 (0%)
Task 3	Admin Login & Publish News	High	~45 seconds	3/4 (75%)	0/4 (0%)

All four participants completed Task 1 (locating PPDB registrant data) and Task 2 (reading a published news article) independently. Task 1 required approximately 10 seconds, while Task 2 required approximately 15 seconds. The uniformity of this result across participants of varying IT proficiency indicates that the module's navigation architecture successfully aligns with users' mental models. The sub-15-second completion times suggest that the information architecture does not require iterative searching or backtracking. Regarding the reviewer inquiries on cognitive load measurement, this study operationalised *time-on-task* and observational heuristics as immediate behavioural proxies for cognitive load. While formal instruments like the System Usability Scale (SUS) or NASA-TLX are valuable, introducing lengthy questionnaires during an in-situ mobile evaluation risks disrupting the natural interaction flow of non-technical users.

Task 3 generated the most analytically substantive results. Three of the four participants (75%) completed the full administrative workflow, login, article creation navigation, content entry, and publication, independently in approximately 45 seconds. One participant (P-01, self-rated novice) required initial scaffolding to locate the administrative login entry point, after which the remainder of the task was completed independently. Crucially, there were zero complete task failures.

B. Mobile-First Accessibility vs. Conventional CMS Friction. A recurring and theoretically significant finding in the qualitative data was participants' expressed surprise at the completeness of the portal's administrative functionality on a smartphone. Participant P-03 stated, "It turns out everything

can essentially be done via mobile phone." This assumption reflects their cumulative experience with conventional systems. When compared to conventional School Management Systems or standard Content Management Systems (e.g., WordPress), our frugal approach demonstrates a clear advantage. Conventional CMS platforms introduce excessively high extraneous cognitive load for non-technical staff due to deep navigation architectures, plugin management, and complex desktop-oriented dashboard interfaces [7]. By stripping away these complexities and ensuring full administrative capability on a simplified mobile interface, the portal collapses the total cognitive cost of administrative engagement to task-level load alone [8].

C. Cognitive Offloading Through Habitual Application. The most theoretically fertile finding concerns the WhatsApp integration in the PPDB module. Participant P-04 articulated the mechanism's functional value with precision: "It is easier to click directly to WhatsApp, as we open WA far more frequently than the web portal." This statement encapsulates the cognitive offloading principle. Rather than utilizing complex webhooks, the system employs WhatsApp Deep Linking (URL Schemes) to generate pre-filled registration messages. This redirects the cognitive cost of information monitoring from the working memory burden of checking a secondary platform to the automatic, habitually-executed action of receiving a message in WhatsApp [14]. Furthermore, regarding data privacy and security concerns, transmitting applicant data via WhatsApp Deep Linking inherently benefits from the platform's native end-to-end encryption (E2EE), securing sensitive communications without requiring local server storage.

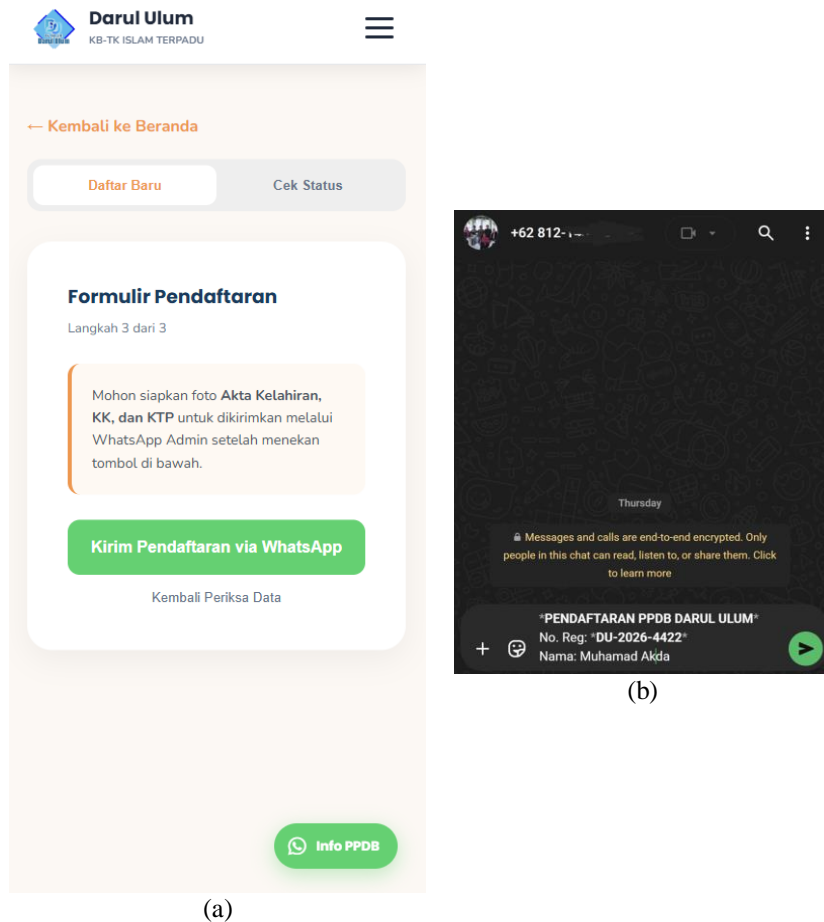


Figure 3. The seamless contextual workflow operationalizing cognitive offloading: (a) the Next.js frontend form redirecting the applicant to (b) the pre-filled WhatsApp application. This mechanism bypasses manual data entry and bridges the institutional web portal directly into the users' habitual messaging environment.

D. Iterative Satisfaction and Architectural Sustainability. Participant P-02 noted, "Excellent, the application can be continuously updated and adapted as new needs arise." The participant perceived the system as a living infrastructure capable of evolution. The architectural enabler of this perceived iterability is the Vercel CI/CD pipeline. Addressing concerns of long-term sustainability, the Insider Action Research methodology ensures that continuous knowledge transfer, such as training modules for educational staff (*tendik*), occurs organically without external IT dependency [16]. Additionally, the utilization of free-tier cloud infrastructure guarantees zero ongoing hosting costs,

resolving the primary financial barrier to IT maintenance in frugal contexts [11].

E. The Discoverability Gap in High-Complexity Tasks. The 25% assisted success rate in Task 3, attributable to difficulty locating the admin login entry point, warrants targeted analytical engagement. This finding aligns with the discoverability dimension of usability, where login accessibility is a common source of first-session friction for non-expert users [22]. Relocating the admin login pathway to a more visually prominent position would likely eliminate this discoverability gap without disrupting the public-facing interface's aesthetic.

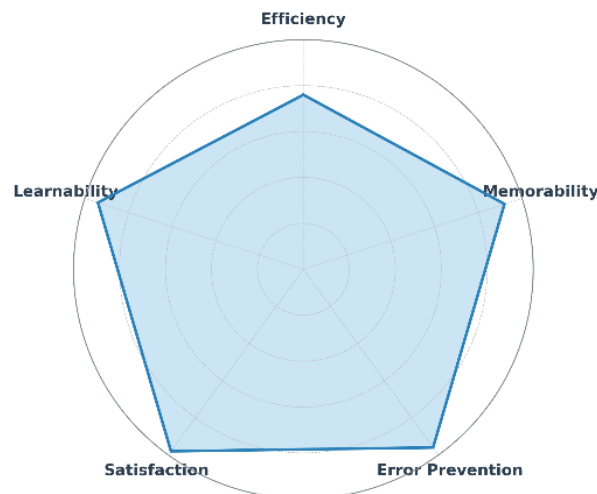


Figure 4. Heuristic evaluation mapping demonstrating strong performance in error prevention and user control, with an identified discoverability gap.

F. Theoretical Implications and Limitations

Peri-urban micro-schools like Darul Ulum are organisations whose governance structures and stakeholder cognitive profiles generate qualitatively distinct technology adoption requirements. Applying Institutional Isomorphism theory [3] reveals that the formal domain and professional portal are legitimacy signals. Achieving this legitimacy requires adequate signal quality achieved through a design architecture that non-technical stakeholders can sustain without external IT dependency [4].

This study acknowledges several limitations. First, regarding the sample size ($N = 4$), it is crucial to note that this represents Total Population Sampling for the institutional governance unit; these four individuals constitute 100% of the executive end-users for the administrative dashboard, validating the qualitative HCI metrics. Second, while data transmission is encrypted via WhatsApp, the underlying relational database currently utilizes a temporarily disabled Row Level Security (RLS) state in Supabase to facilitate frictionless prototype testing. Strict RLS policies limiting public API access will be deployed prior to the full production release [21]. Future research should incorporate longitudinal follow-ups, formal quantitative instruments like SUS, and cross-site comparative studies to assess the transferability of this Frugal HCI model across other peri-urban micro-schools.

IV. CONCLUSION

This study has documented the design, development, and usability evaluation of a custom serverless web portal for KB-TK ISLAM Darul Ulum, a peri-urban Islamic micro-school in Jambe, Tangerang. The findings support the core argument that Frugal Interaction Design, implemented through a serverless Next.js architecture and cognitive offloading via WhatsApp Deep Linking, effectively addresses the Digital Enclave condition. The portal achieved a 100% independent task success rate for core informational workflows with completion times under 15 seconds. By testing the entire target population of the institutional governance unit ($N=4$),

this study proves that institutional-grade usability is achievable for non-technical stakeholders without external IT dependency or the extraneous cognitive load associated with conventional Content Management Systems.

The integration of habitual messaging applications as an offloading mechanism was empirically validated as a primary driver for reducing extraneous cognitive load, allowing stakeholders to manage school administration securely within their existing behavioral routines. Furthermore, the combination of zero-cost cloud infrastructure (Vercel and Supabase CI/CD pipelines) and an Insider Action Research approach ensures profound architectural and operational sustainability. This methodology allows the system to evolve responsively alongside the institution's needs through continuous internal capacity building.

In conclusion, this research provides a validated, replicable model for resource-constrained educational institutions in the Global South. It demonstrates that bridging the digital divide does not necessarily require massive financial investments, complex enterprise systems, or professional IT departments, but rather design intelligence that prioritises the operational constraints, cognitive realities, and habitual technologies of the end-users.

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